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Determining the saturated vertical hydraulic conductivity of retention basins in the Oum Zessar watershed, Southern Tunisia

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Alterra, Wageningen, the Netherlands.

Institut des Régions Arides, Médenine, Tunisia.

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Abstract/Résume

Pour la version française, voir dessous.

This report aims to measure and estimate the saturated vertical hydraulic conductivity of retention basins in the Oum Zessar watershed, South Tunisia. To do so, field measurements have been done on 42 sites using double ring infiltrometers. If the diameter of such an infiltrometer is small, conductivity values are overestimated because of lateral flow. In the study area, measurements were done with small and large pairs of rings. On three reference sites outside the study area, measurements with small and large double ring infiltrometer sets, and measurements with a disk infiltrometer were conducted. For this study, we found that multiplication of the values measured with a small set of double ring infiltrometers (18/30cm inner ring diameter/outer ring diameter) by a factor of 0.65 (-) gives the best results. Using measurements and SWAP analysis, we found that the infiltration rate depends on water level in a generally linear fashion in a simple system with stable or deep wetting front. Water level and wetting front depth are important for the infiltration rate, therefore it is recommended to use a combination of SWAP and PCRaster or MODFLOW and PCRaster for runoff modeling. No runoff modeling is performed for this research.
The average measured hydraulic conductivity of retention basins is estimated at 65 mm/hr. The hydraulic conductivity is highest in the center of the water shed (105 mm/hr), intermediate in the downstream area (56mm/hr), and lowest in the upstream area (29 mm/hr). The Saxton et al. (1986) and Schaap et al. (2001) pedotransfers were used to estimate conductivity from texture measurements. However, the estimated and measured conductivity values showed a negative correlation. It was not possible to predict hydraulic conductivity based on the characteristics of the retention basin. Spatial interpolation worked better to estimate hydraulic conductivity than using pedotransfer functions. Therefore, a spatial interpolation was used to predict conductivity at non-measured sites.
The results of this research do not lead to the conclusion that a significant amount of water is lost to evaporation due to the stagnation of water. However, lower layers might cause a stagnation but these are not assessed in this research.

Le but de cette recherche est de mesurer et d'estimer la conductivité hydraulique verticale des bassins de rétention dans le bassin versant d'Oum Zessar, situé près de Médenine, en Tunisie du sud. Sur 42 de ces bassins, des mesures avec un infiltromètre double anneau ont été faites. Si une paire de ces anneaux est de petite taille, on surestime la conductivité à cause de l'écoulement latéral. Sur le terrain d'étude, des mesures avec de petites et de grandes paires d'anneaux ont été faites. Sur un site de référence en dehors du bassin versant, des mesures avec de petites et de grandes paires d'anneaux et avec un infiltromètre à disque ont été faites. Pour cette étude, la multiplication des valeurs mesurées avec une paire d'anneaux de diamètre 18/30 cm (anneau intérieur/anneau extérieur) avec un facteur de 0.65 (-) a donné les meilleurs résultats. En utilisant le modèle SWAP et les mesures, il a été montré que le taux d'infiltration dépend linéairement du niveau d'eau pour des systèmes simples. Comme le niveau d'eau et la profondeur de l'eau infiltrée sont importants pour le taux d'infiltration, il est conseillé d'utiliser une combinaison de SWAP et de PCRaster ou bien une combinaison de MODFLOW et de PCRaster pour évaluer un modèle d'écoulement du bassin versant d'Oum Zessar. Un tel modèle n'a pas été évalué lors de cette recherche.
La conductivité mesurée moyenne des bassins de rétention dans le bassin versant est de 65 mm/h. La conductivité est la plus élevée dans le centre du bassin versant (105 mm/h), intermédiaire à l'aval (56 mm/h) et la moins élevée à l'amont (29 mm/h). Les fonctions de pédotransfert de Saxton et al. (1986) et de Schaap et al. (2001) ont été utilisées pour estimer la conductivité à partir de la granulométrie. Cependant, les valeurs ainsi estimées et les valeurs mesurées montraient une corrélation négative. Ce n'est pas possible d'estimer la conductivité en se basant sur les caractéristiques des bassins de rétention. Une interpolation spatiale donnait de meilleurs résultats. De ce fait, l'interpolation spatiale a été utilisée pour l'estimation de la conductivité sur

les sites où l'on ne dispose pas de mesures directes.
Les résultats de cette recherche ne permettent pas de supposer qu'il y a une importante perte d'eau par évaporation causée par la stagnation de l'eau dans les bassins de rétention. Pourtant, il est possible que des couches moins perméables se situent sous les couches mesurées. Ces couches pourraient causer une stagnation de l'eau ce qui entraine une perte importante de l'eau par évaporation.

Acknowledgements

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Context

This report is written by Stan van den Bosch, for Alterra (Wageningen, the Netherlands) and the Arid Regions Institute IRA (Medenine, Tunisia). Supervisors from Alterra are Coen Ritsema and Rudi Hessel. Supervisor from the IRA is Mohamed Ouessar. The report was written in the context of an extra-curriculur internship, after graduation from the University of Utrecht in hydrogeology. Ammar Zerrim, Mongi Ben Zaied, Messaoud Guied, Nawab Halifa and Amor Jelali played a major role in the fieldwork of which the results are used in this research.

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Chapter 1. Introduction

The area under consideration is the Oum Zessar watershed in south Tunisia. The watershed receives an average of 150mm of precipitation per year. There is great variability in the yearly amount of precipitation. Groundwater is used for drinking water, industry and irrigation. The groundwater resources are dwindling because the natural recharge rate is lower than the extraction rate. This leads to a lowering of the water table and a salinization of the groundwater.

In order to increase the recharge and diminish flash floods, 258 recharge check dams have been installed in the wadis. The check dams are barriers constructed in the wadi beds perpendicular to the flow direction and have a height of approximately 0.6 m and up to 2.6 m. They are designed to diminish flow velocity and to retain water in their associated retention basins in case of runoff, thereby allowing water to infiltrate and preventing water to be 'lost' to sea. 25 spread dams were also installed. They are similar to recharge check dams but equipped with a deviation canal to allow spreading of the floodwater into neighboring fields. The stagnation of water in the retention basins of check dams allows finer particles to settle. This effect is called clogging and leads to a diminution of the retained water volume and can lead to a decreased hydraulic conductivity compared to the natural situation. It is therefore uncertain whether or not the check dams lead to an actual increase of recharge.

Figure 1.1: Two pictures of the same check dam in a dry river bed in the Oum Zessar watershed. Since flow is from right to left, the retention basin is directly to the right of the dam. Pictures taken by author.

The infiltration rate in a retention basin depends mainly on hydraulic conductivity, suction, water level and depth of wetting front and is an important parameter for estimation of recharge. Another factor which may influence the infiltration rate is that when the retention basin is filled, the top layer of the soil is broken. This will increase the infiltration rate. After a while, the particles settle, thereby reducing the hydraulic conductivity again.

The main focus of this report is ***determining the hydraulic conductivity of retention basins in the Oum Zessar watershed and the effect of water level on the infiltration rate.*** Suction and the dynamic effect of breaking of the surface layer and settling of particles are not taken into account in this research. The dynamic effect of the influence of the depth of the wetting front on the infiltration rate is not taken into account. For a deep wetting front, the infiltration rate equals the saturated vertical hydraulic conductivity.

A second effect of check dams is that they decrease the flow velocity. This leads to a higher recharge since the water is available for infiltration for a longer time, both in the retention basins and in the 'natural' river bed between the retention basins. This effect is not assessed in this paper. The aim of this paper is not to estimate the effect of retention basins on recharge. It can merely provide one of the steps to undertake for such an estimation. Even though no surface water model is evaluated for this report, some advice for modeling is provided.

The saturated vertical hydraulic conductivity is measured in the watershed using double ring infiltrometer tests. The infiltration rate in a retention basin is not necessarily equal to the hydraulic conductivity. When the water level in a retention basin is high and/or the wetting front is shallow, the infiltration rate exceeds the hydraulic conductivity. This effect is assessed in this report. The water level also influences the infiltration during a double ring infiltrometer test. Therefore, the water level is taken into account when determining the hydraulic conductivity from such a test. The flow underneath a double ring infiltrometer is not purely vertical. To correct for this lateral flow, the results measured with small rings are compared to measurements with bigger rings. The results are also compared to disk infiltrometer measurements on reference sites, and to pedotransfer functions on both the reference sites and several retention basins in the watershed using data collected by Said (2014). These comparisons are done in order to assess whether or not the measurements are in the right order of magnitude and whether or not pedotransfer functions are accurate predictors of hydraulic conductivity in the watershed. We present spatial information of clogging, texture and conductivity in order to increase understanding of the watershed. The effect of clogging on the hydraulic conductivity is assessed by comparing the hydraulic conductivity of sites with a different degree of clogging. Lastly, we provide estimations of the hydraulic conductivity at basins where no conductivity measurements were done by spatial analysis.

Chapter 2. Study area

The following description of the study area is taken from Ouessar (2007).

Introduction

The watershed of wadi Oum Zessar was chosen as a site for this study. Based on previous research works undertaken in the region (Chahbani, 1984; Mzabi, 1988; Talbi, 1993; Khatteli, 1996; Derouiche, 1997; De Graaff and Ouessar, 2002) this watershed can be considered, from the ecological, hydrological as well as socio-economical point of view, as representative of the arid southeastern Tunisia. In addition, it is has a long history with regard to water harvesting dating from the pre Roman era (Carton, 1888) until today (Ben Kehia et al., 2002; Ouessar et al., 2002).

Location

The study site belongs to the region of south eastern Tunisia (province (gouvernorat) of Médenine). It is situated at the northwest of the city of Médenine. It covers administratively the counties (délégations) of Béni Khédache, Médenine Nord, and Sidi Makhlouf (*Figure 2.1*).

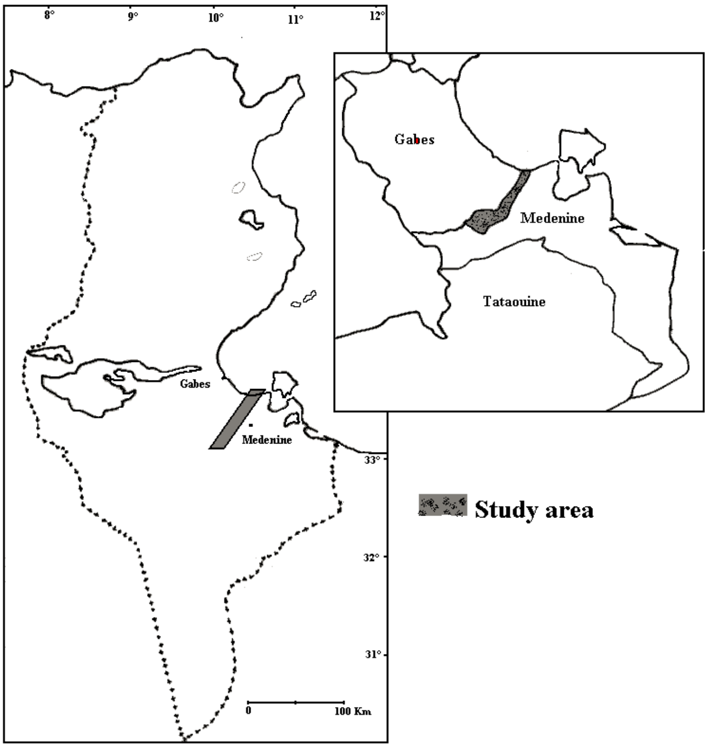

Figure 2.1: Location map of the watershed of wadi Oum Zessar (Ouessar 2007)

It stretches from the mountains of Matmata (Béni Khédache) in the south-west, crosses the Jeffara plain (via Koutine) and the saline depression (Sebkha) of Oum Zessar before ending in the Mediterranean (Gulf of Gabès). It is bordered in the north by the watershed of wadi Zeuss.

Climate

Located at the north of the 30th parallel, the climate of Tunisia is largely influenced by variability of the Mediterranean and the caprices of the Sahara. Depending on the season and the meteorological situation, air masses, originating from the tropics or the poles, can affect the country and can generate sometimes contrasting weather conditions. The climate of the pre Saharan Tunisia, as defined by Le Houérou (1959), is subject to two completely opposite climatic action centers: the first, located in the south west, is the area of dry and hot subtropical climate; and the second, located at the east on the Gulf of Gabès, is under the influence of a relatively moderate Mediterranean climate. The study watershed is thus affected by the Gulf of Gabès in the north and the North-East and the presence of the Matmata mountain chain, and the great oriental Erg in the south and south-west: the hot and dry summer lasts four to five months, the winter is a mild and irregular rainy season, the autumn and spring are very variable. In fact, except the summer, which is a stable and calm season, the climate of the area is characterized by an extreme irregularity whose essential features are as follows (Floret and Pontanier, 1982; Ouessar et al., 2006b):

- rare but very variable rains falling during the cold period and a quasi-absolute drought period between May and September,
- a contrasting temperature pattern with mild to cold winters and warm to very hot summers,
- a strong evaporation,
- dominant winds of sectors W, NW and SW from November to April, very dry and cold violent ones; from May to October, winds of the sea sector (E, SE); and during the summer period, are the dry and hot winds of the sector SW (sirocco) which prevail.

Temperature

The coldest months are those of December, January and February with occasional freezing (up to -3 °C). June-August is the warmest period of the year during which the temperature could reach as high as 48°C. The temperature is affected by the proximity to the sea and the altitude (Table 2.1).

Rainfall

It is the North-East Mediterranean winds which provide to the area the main part of precipitations that it receives because of the broad opening of the golf of Gabès. The latter exposes the littoral band and part of the continental zone to the great disturbances generated by the shallow vast water body of the gulf of Gabès. However, the Saharan disturbances of south-west and the west are also responsible for some rains in the area (Mzabi, 1988).

Table 2.1: ***Monthly mean maximum and minimum temperature in Médenine (1979-2003), Beni Khédache (1990-1996) and IRA (1992-2003). Taken from: Ouessar (2007)***

Month		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Médenine	Tmax	17.2	19.2	21.6	24.8	29.1	33.1	35.7	36.5	33.2	29.2	23.0	18.2	26.7
	Tmin	7.9	8.4	10.5	12.9	16.8	20.2	22.3	23.5	21.7	18.0	12.7	8.7	15.3
Béni	Tmax	14.7	17.0	19.6	22.7	28.3	32.3	34.7	35.9	33.3	27.9	21.3	16.0	25.3
Khédache	Tmin	6.6	7.6	9.2	11.2	15.6	19.0	20.9	22.8	20.8	17.0	11.8	7.6	14.2
IRA	Tmax	18.3	19.7	22.7	26.0	30.0	33.1	36.0	36.7	34.0	29.5	24.1	19.3	27.5
	Tmin	5.5	6.6	9.1	11.8	16.3	19.2	21.2	22.2	21.1	16.9	11.4	7.1	14.0

Sources: INM (1979-2003), IRA (1992-2003).

Annual rainfall

The study watershed receives between 150 and 240 mm a year (Derouiche, 1997). The isohyets of the average interannual precipitation are presented in the Figure 2.2.

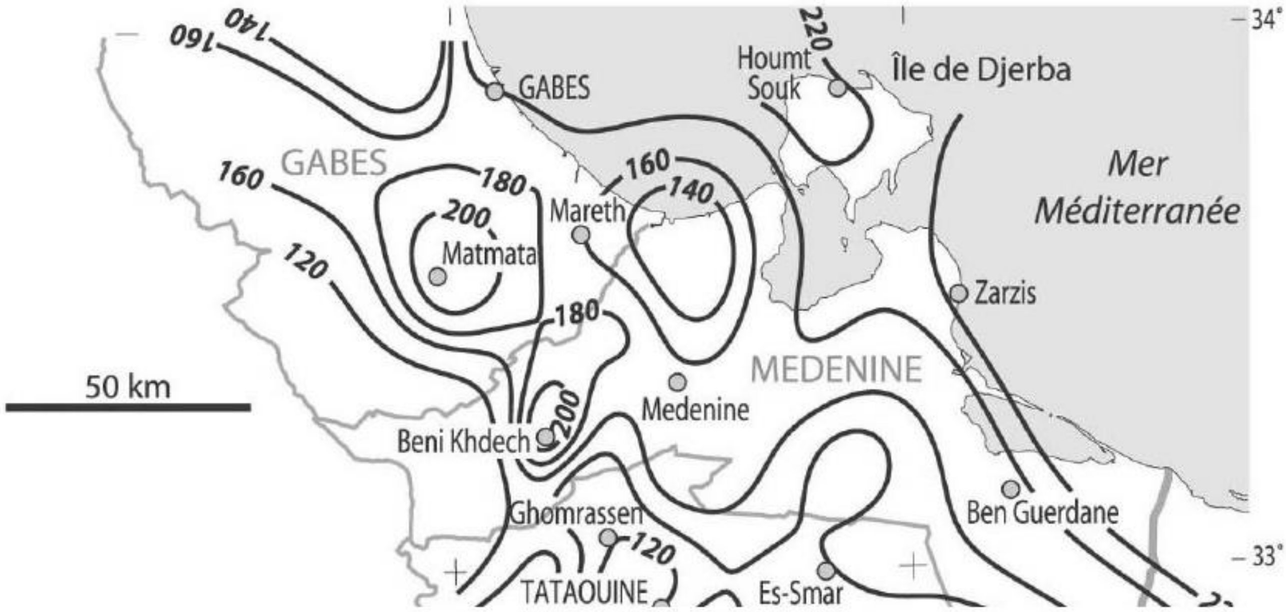

Figure 2.2: Isohyet map of the average interannual rainfall (mm) in the Jeffara region (after Ouessar et al., 2006b)

It shows that:

- rainfall decreases from north to south and from coast towards the continent,
- the Matmata mountains induce an increase in rainfall due to the effect of altitude known by the Foehn effect,
- the maximum of rainfall is observed along the littoral and on the mountain zones.

All the studies undertaken on the rainfall regime and its variability in the southern areas of Tunisia (Kallel, 2001; Fersi, 1985) agreed on the extreme variability of annual rainfall as illustrated in *Table 2.2*.

Table 2.2: Characteristics of the annual rainfall in the study area (1969-2003). Taken from Ouessar (2007)

.	Allamat	Koutine	Ksar Jedid	Ksar Hallouf	Sidi Makhlouf	Toujane Eddikhila	Béni Khédache
Average	171.6	169.1	176.2	193.7	179.0	184.0	222.8
Median	146.7	127.8	157.6	164.9	148.3	155.7	196.6
Min	30.0	14.2	20.2	55.6	28.7	39.7	39.7
Max	550.1	590.2	532.8	678.9	550.1	517.4	720.0

When examining the rainfall regime in the Jeffara region for the period 1969-2001, Kallel (2001) reported that the year 1975-76 was the wettest year whereas 2000-01 was the driest year. He found also that, on average, more than 30% range within the normal years and around 20% are classified as wet or dry years. The exceptional wet and dry years represent 8 and 20% respectively. He concluded that the evolution of the rainfall deviation from average confirms the high interannual variation of the rainfall regime in this region:

- a phase with overall rainfall surplus tendency during the seventies. The high rainfall records of 1976 have been yet passed,
- the 80s and the 90s and the beginning of 2000 were marked by the dry and in some cases very severe and even lasting drought periods (1980-1984; 2000-2003),
- The last twenty years were marked also by the occurrence of exceptional wet years (1976, 1990, 1996, 1999).

Monthly and seasonal rainfall

The average interannual rainfall of each month in some stations of the study area is given in Table 2.3. The wettest months are December and March. January, October and November come in second position. On the other hand, May, June, July and August are almost dry. Rainfall falls mainly in winter (40%), then autumn (32%) and spring (26%) whereas summer is almost rainless.

Table 2.3 Average monthly rainfall (mm) in the gauging stations in the watershed of wadi Oum Zessar. Taken from Ouessar (2007)

	Allamat	Koutine	Ksar Jedid	Ksar Hallouf	Sidi Makhlouf	Toujane Edkhila	Béni Khédache
Sept	16.2	17.5	16.5	16.1	16.4	20.2	17.6
Oct	26.8	25.3	22.0	22.5	26.3	23.0	20.4
Nov	18.7	14.1	17.8	16.0	17.7	15.7	20.0
Dec	25.7	28.5	25.3	31.1	23.8	27.0	33.2
Jan	21.9	21.6	24.3	28.7	29.3	26.3	32.9
Feb	18.1	16.9	20.5	25.4	17.6	21.4	29.3
Mar	24.3	21.9	28.0	29.8	23.1	24.2	38.7
Apr	12.3	12.1	12.9	13.5	12.7	16.3	17.7
May	6.2	6.5	6.3	8.6	9.4	8.6	10.2
Jun	0.8	0.4	0.3	0.3	1.2	1.0	1.0
Jul	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Aug	0.8	4.3	2.4	1.8	1.4	0.4	1.9

Daily rainfall

At this level, the variability is more important. Around 20 rainy days (rainfall more than 0 mm) are recorded every year (Table 4). However, most of the rainfall does not exceed 10 mm but relatively high intense rainfall showers (more than 80 mm and 100 mm) could be expected once per decade and within 35 years, respectively.

Table 2.4: Daily rainfall (R) at some gauging stations. R: daily rainfall (mm); Avg: average annual rainy days (days), T: return period (years). Data: based on daily rainfall for the period 1969-2003. Taken from Ouessar (2007)

	Koutine		Ksar Jedid		Ksar Hallouf		Sidi Makhlouf	
	Avg	T	Avg	T	Avg	T	Avg	T
R >0	17.61	0.06	17.28	0.06	16.53	0.06	25.44	0.04
R>10	5.39	0.20	5.33	0.19	5.86	0.17	5.08	0.20
R>20	2.31	0.46	2.42	0.41	2.67	0.37	1.86	0.54
R>30	0.97	0.88	1.08	0.92	1.44	0.69	0.86	1.16
R>40	0.47	1.33	0.61	1.63	0.78	1.28	0.53	1.89
R>50	0.25	2.11	0.31	3.26	0.50	1.99	0.31	3.26
R>60	0.22	3.26	0.17	5.98	0.25	3.99	0.19	5.13
R>80	0.08	5.98	0.08	11.97	0.17	5.98	0.08	11.97
R>100	0.06	35.90	0.06	17.95	0.11	8.98	0.08	11.97
R>120	0.06	35.90	0.06	17.95	0.11	8.98	0.06	17.95

Wind

Generally, the winds blowing from N, NE, SE are more frequent than those from S, W, and SW. The active winds (>3m/s) are relatively important. They represent 44% in Sidi Maklouf, and 40.7% in Médenine (Chahbani, 1992; Khatteli, 1996). Spring is considered the windiest season followed by winter and, then, autumn (Khatteli, 1996) (Table 5). In summer, the hot winds blowing from the Sahara (sirocco), locally known as chili, are dominating. On average, 54 days of sirocco have been recorded in Médenine.

Table 2.5: Direction and frequency (%) of active winds in Médenine and Sidi Makhlouf. Taken from Ouessar (2007)

Direction	S	SE	W	SW	N	NW	E	NE
Sidi Maklouf	4.5	17.5	4.7	15	14	13.8	8	22.5
	S & SE		W & SW		N & NW		E & NE	
Médenine	4.6		13.5		11.9		107	

Sources: Chahbani (1992), Khatteli (1996).

ET0

With high temperature and low rainfall, the reference crop evapotranspiration (ET0) is very high. It reaches, for example, in Médenine, 1450 mm. The climatic water balance is almost negative around the year (Table 6).

Table 6. Average monthly ET0 (mm) (Hargreaves method) and rainfall P (mm) in Médenine (1979-2002).
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Year

Table 2.6: Average monthly ET0 (mm) (Hargreaves method) and rainfall P (mm) in Médenine (1979-2002). Taken from Ouessar (2007)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
ET0	52.7	67.8	99.2	129	167.4	186	201.5	189.1	138	102.3	66	49.6	1448.6
P	21.2	18.6	26.3	12.1	7.8	1.0	0.1	1.2	17.0	27.7	19.7	25.6	178.1

Hydrology

The study watershed represents the most important watershed in the region of Zeuss- Koutine. The hydrologic characteristics of the wadi Oum Zessar watershed and the neighboring watersheds (Zeuss, Zigzaou) are presented in *Table 2.7*. It has the largest area (350 km2) and perimeter (118 km). It is made of very dense hydrographic network. With a compacity index of 1.72, it has an elongated shape. The relief is classed as fairly high. The drainage network starts in the Matmata mountains (Kef Nsoura, 715 m asl; Moggar, 651 m asl; Mzenzen, 690 m asl) and, then, drains the western parts of Tajera and Rouis, and the eastern parts of Zemlet Leben. The main streams are: wadi Nagab, wadi Hallouf, wadi Moggar, wadi Nkim, wadi Koutine. They become wadi oum Zessar which flows into Sebeka Oum Zessar before reaching the gulf of Gabès (Figure 10; *Table 2.7*). Using his empirical formula developed for the dry regions of Tunisia, Fersi (1985) estimated the average annual runoff volume of the study watershed to 4.7 millions m^3.

Table 2.7: Physiographical characteristics of the watersheds of Zeuss-Koutine region. Taken from Ouessar (2007)

Parameters	Oum Zessar	Zeuss*	Zigzaou*
Area (km^2)	350	219	195
Perimeter (km)	118	61	95
Maxi. Altitude (m asl)	715	302	632
Mini. Altitude (m asl)	0	0	0
Global slope index (m/km)	11.1	13.94	8.2
Equivalent length (km)	51.7	18.64	42.82
Equivalent width (km)	7.1	11.74	4.5
Avg. runoff vol. (Fersi) (Mm^3/year)	4.70	1.26	2.8

* Given for comparison; Source: Derouiche (1997)

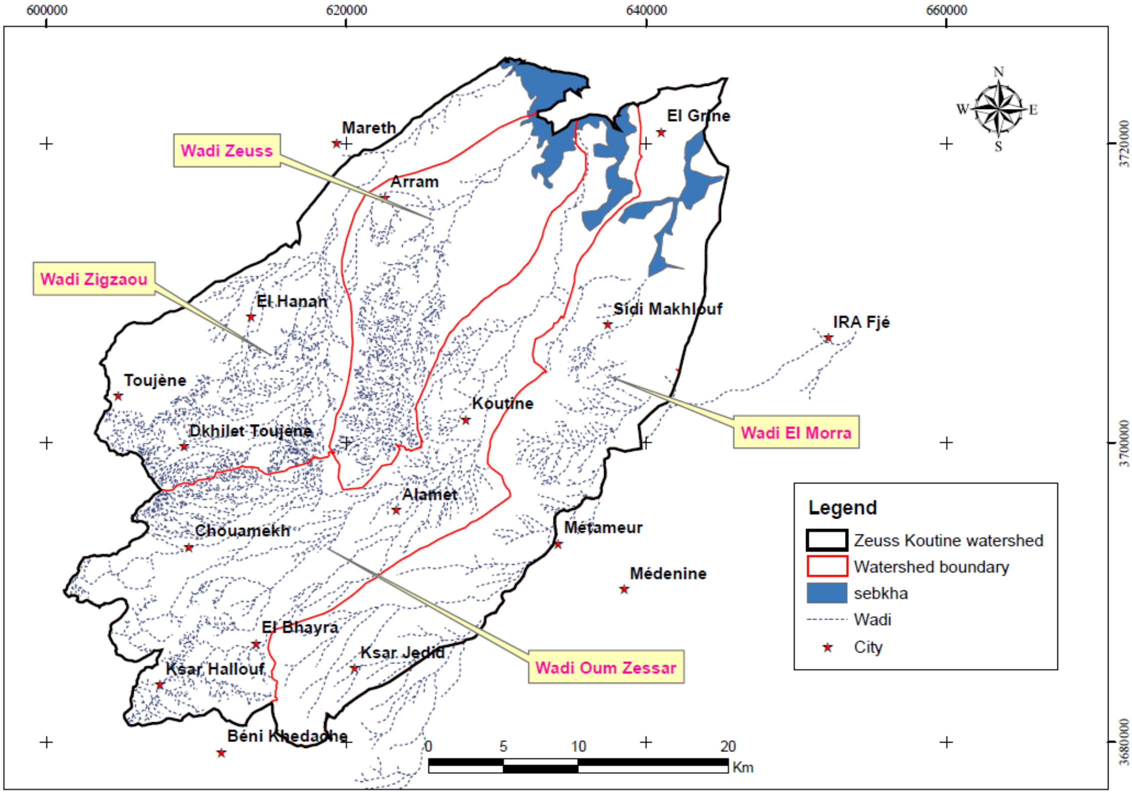

Figure 2.3: Hydrographic network of Zeuss-Koutine region. Taken from Ouessar 2007

Geology

Introduction

The study area is distinguished by the sedimentary sequences following temporary emergences with two major discordances (Mzabi, 1988). The geology of the study region has been described by Yahyaoui (2001a) and Gaubi (1988) as follows (*Figure 2.4*).

Stratigraphy

Permian

The unique Permian outcroppings in Tunisia and Africa are encountered in Jebel Tébaga.
They form a monoclinal with southern dip.

Triassic
It outcrops only in the southern part of Jebel Tébaga and it is present under three stratigraphic and lithological formations: Lower and medium Triassic, dolomitic Triassic made of dolomite formation, evaporite Triassic made of evaporite formation.

Jurassic
It exposes in the area of Tajera in the form of outcroppings around Jebel Tébaga and especially south of Jebel El Afia and Mejouj. The Jurassic is discordant with Paleozoic (Jebels Remtzia and Grouz). It is generally formed by two calcareous flagstones separated by the alternation of dolomite limestones and clays (often marly).

Cretaceous
The lower Cretaceous is represented by two different formations: a formation of fluviocontinental origin at the base (Asfer formation of Purbecko-Wealdian) and a formation of marine origin with sandy limestones of Barremo-Bedoulian.

Miopliocene
The Miopliocene forms a complex of fluvio-continental origin (erosion of the relief). It is made of pebbles of various natures: clays and multi-colored sands. This unit, known also as Zarzis formation, outcrops rarely. In the upstream of the fault of Médenine, it is either intensively eroded or is deposited in some sites. Downstream from the fault, it is discordant with the Senonian substratum.

Quaternary
The old Quaternary is made exclusively of calcareous (or sometimes gypseous) crust containing limestone concretions. The thickness does not exceed 10 m. The recent Quaternary is represented by the deposits: terraces found on the banks of the wadis (Hallouf, Lahimer, etc), the silts or 'loess of Matmatas' which are very fine detrital particles transported by the wind and accumulated in the deep valleys (Hallouf, etc), and wadi alluviums.

Tectonics
The study area is limited by three principal structures characterizing southern Tunisia: Matmata (Dhahar), the monoclinal of Tebaga and the Jeffara plain. These structures are generally affected by various faults.

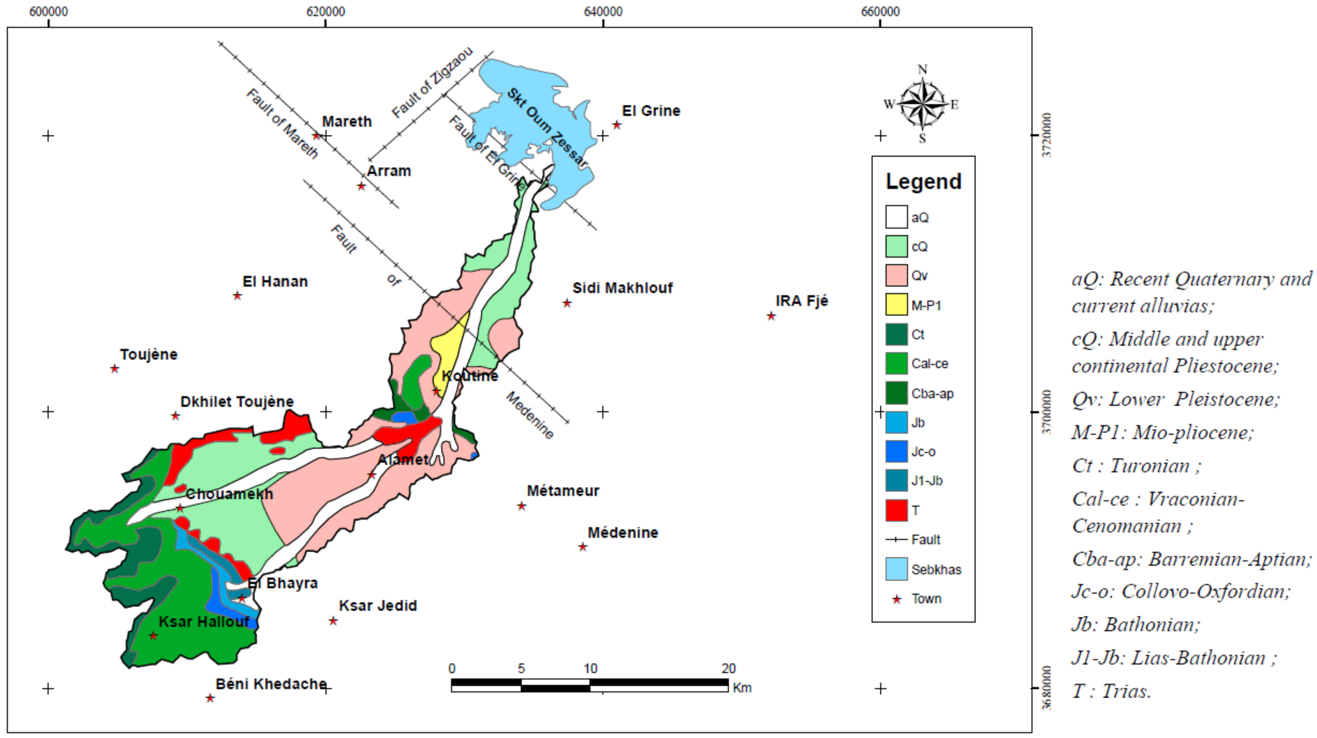

Figure 2.4: Geology map of the study watershed (adapted from ONM, 1980). Taken from Ouessar (2007)

Hydrogeology

According to Yahyaoui (1998) and Ouessar and Yahyaoui (2006), the groundwater system of the region can be subdivided into shallow (according to the Ministry of Agriculture regulation, the shallow refers to watertable depth less than 50 m bgl) and deep aquifers (***Error! Reference source not found.**, *Figure 2.5**). The main characteristics of the various aquifers in the study zone are summarized in **Error! Reference source not found.**. **Error! Reference source not found.**

Figure 2.5 Aquifers of the study region (adapted from Yahyaoui, 1997; Ouessar and Yahyaoui, 2006). Taken from Ouessar (2007)

Shallow aquifers

These aquifers are found within a production depth less than 50 m bgl. They are mostly generated by the subsurface underflow of the main wadis (Yahyaoui, 1998). The aquifer of wadi Oum Zessar is situated, in the upstream area, in alluviums on aJurassic substratum. Downstream and east of the road Gabès-Médenine, the substratum is formed by the Mio-Plio-Quaternary (MPQ) of the Jeffara. Increasing in downstream direction, salt content ranges between 2 and 5 g/l. Chapter 2: Physical and socio-economic characteristics of the study watershed The aquifer of Sidi Makhlouf is exploited by 112 wells (37 equipped with pumps). Salt content increases also downstream and varies between 2 and 5 g/l, but it exceeds in most of the cases 5 g/l when approaching the salt depression.

Deep aquifers

Aquifer of the Triassic sandstone (Grès de Trias)

This aquifer stretches over a large area between the two provinces of Médenine (coarse series, formation of Sidi Stout, lower Triassic) and Tataouine (higher fine series, formation of Kirchaou, Upper Triassic) (Khalili, 1986; Yahyaoui, 2001b). In our study area, it is limited to the north by the outcroppings of the upper Permian (Jebel Tébaga), to the west by the outcroppings of Dhahar, and to the east by the Jurassic aquifer (Gaubi, 1995). Thus, the reservoir is either covered by the MPQ layers or the Triassic outcrops and receive directly the runoff water. Therefore, the piedmont area and the wadis are considered the preferential recharge areas (Gaubi, 1995). The renewable resources are estimated to 150 l/s and the salinity varies between less than 1 g/l and 3 g/l. It is used mainly for drinking water and irrigation.

Aquifer of Zeuss-Koutine

The aquifer of Zeuss-Koutine (ZK) extends below the watersheds of Zigzaou, Zeuss, Sidi Makhlouf, Oum Zessar and partly Métameur and Smar and it covers 785 km^2. The renewable resources are estimated at 350 l/s and mainly used for drinking, irrigation and industry (Yahyaoui, 1997). The aquifer is made of two main entities separated by the fault of Medenine: ZK Jurassic and ZK Senonian (*Figure 2.5*). The ZK Jurassic aquifer is a series of dolomite black marls of basal Jurassic. In some sites, this aquifer is covered by very low permeable marl and marly limestones roof (Gaubi, 1988). In the western part, water of the aquifer is of good quality (1.5 g/l) because it is well replenished. Towards the South and North, the aquifer becomes deeper and the salinity can reach 5 g/l. In the ZK Lower Senonian aquifer, the unconfined horizon of the lower Senonian and Turonian can be replenished by the runoff but also and by lateral flow from the ZK Jurassic through the fault. However, the confined is covered by an impermeable roof of marls and clay of MPQ and it is replenished only laterally through the fault. The area upstream the fault of Medenine is made mainly of karstified limestones which can receive runoff water while the other compartment (downstream) is covered by a tick impermeable and semi impermeable layers (marls and gypsum) which can obstruct the direct infiltration of floodwater (Derouiche, 1997).

Aquifer of Béni Khédache (BK) Jurassic

The BK Jurassic is made of two carbonated aquifers: an aquifer placed in the condensed series of the upper Triassic to the lower Bahonian, and a calcareous aquifer of the upper Jurassic. These two adjacent aquifers are separated by the formation of clay and sandstones of Techout formation (Yahyaoui, 2001a). This aquifer can be reached at 200-300 m bgl. It is directly replenished by the infiltration of runoff water in the Dhahar or the percolation from the eastern cliff.

The Miocene aquifer of Jeffara

This aquifer extends on a very vast area from wadi Akarit at the north of Gabès to Zarzis passing through the extreme downstream area of the study watershed. It is an artesian quifer circulating in the Vindobonian sands. The resources are estimated at 700 l/s and the salinity ranges from 5 to 7 g/l.

Soils

The soil map of the study watershed was extracted from the soil map of Zeuss-Koutine region produced by Taamallah (2003) according to the French soil classification (CPCS, 1967) (***Figure 2.6***).

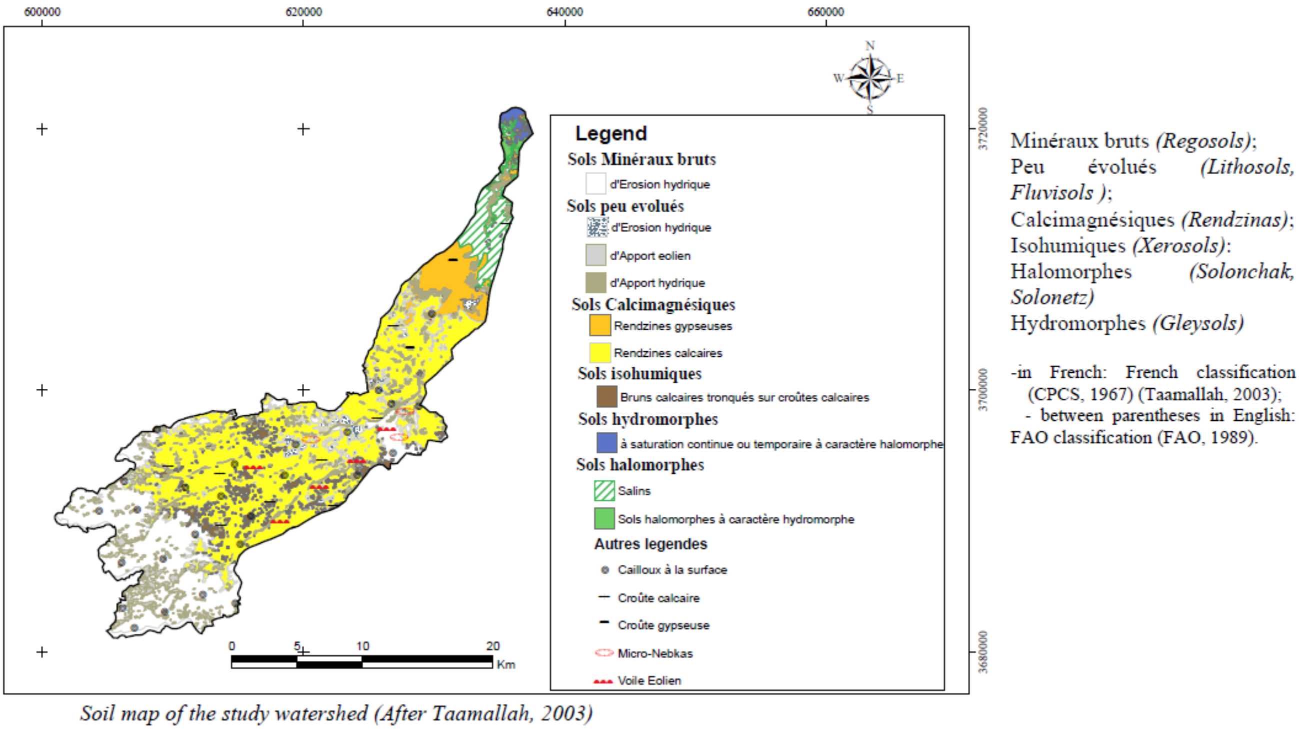

Figure 2.6: Soil map of the study watershed. From Ouessar (2007).

The soils are developed on a calcareous substratum in the upstream area and gypsum or gypsum to calcareous in the downstream area. The soil horizons are generally shallow, stony, unstructured with sandy to fine sandy texture. Five main classes have been identified (in French: French classification (CPCS, 1967) (Taamallah, 2003); between parentheses in English: FAO classification (FAO, 1989)):

- Les sols minéraux bruts d'érosion)(Regosols) made mainly of dolomites, limestone outcroppings and stony regs. They are located in the upstream area (mountains and hills);
- Les sols peu évolués (Lithosols, Fluvisols) occupy a relatively reduced area and are found in the plain and the downstream parts;
- Les sols calcimagnésiques (Rebdzinas) represented by rendzinas on calcareous or gypsum crusting or on the miopliocene. They cover an important area in the upstream and piedmont parts;
- Les sols isohumiques bruns calcaires tronqués (Xerosols): They are not very deep and covered sometimes by a shallow (few centimeters tick) wind deposits;
- Les sols halomorphes et hydromorphes (Solonchak, Solonetz, Gleysols) are encountered at the level of the depressions (sebkhas and garaas) on the coastal areas. They are characterized by a very high salinity.

Vegetation

Rangelands are the dominant land use in the study area. The vegetation is mostly steppe but the species composition is highly variable depending on relief and soil type. The characteristics of the main four ecological systems found in the study area were summarized from the studies of Attia (2003) and Hanafi and Ouled Belgacem (2006):

Mountain zone

The vegetation cover is mostly made of Stipa tenacissima, Artemisia herba alba, Reaumuria vermiculata and Gymnocarpos decander. Such vegetation type results from the degradation of forest of Pinus halepensis, Juniperus phoenica and Pistacia atlantica which completely disappeared from the area due to long history of cuttings. When moving downward from the hills, Hammada scoparia and Heliantheman kahiricum appear and take the place of Stipa tenacissima.

Wadi beds and water courses

These areas are characterized by their high biodiversity and vegetal species richness which may be due to the different biogeographical origin of seeds. The most dominant species are: Retama retaem, Nerium oleander, Pennissetum elatum, Marrubium deserti, Juncus maritimus, Cenchrus ciliaris, Rhanterium suaveolens, Thymus adriensis.

Plains

The vegetation of the remaining of the study area differs from one site to another depending on soil type. On sandy soils (with eolian deposits), the dominant plant species are those belonging to the Rhanterium suaveolens steppe with different levels of degradation. We can find Stipa lagascae, Stipagrostis plumosa, Argyrolobium uniflorm, Echiochilon fruticosum, Stipa grostis pengens. In overgrazed sites, the dominant species is Astragalus armatus whereas in the abandoned cultivated sites, the dominant species is Artemisia campestris. In gypsic soil, the dominant flora is anarrhinum brevifolium, Helianthemum kahiricum and Lygeum spartum.

Saline depression

It concerns the sebkha of Oum Zessar which is located close to the sea. The natural vegetation is composed of several halophytic species, such as: Limoniastrum guyomianum, Zygophyllum album, Nitrania retusa, Suaeda mollis and at lesser degree Atriplex halimus, Arthrocnemun indicum.

Water harvesting techniques

A wide variety of water harvesting techniques is found in the study watershed. In fact, the hydraulic history of this watershed is very ancient (Carton, 1888), witnessed by the remnants of a small retention dam, supposed to be built in the Roman era, near the village of Koutine and the abandoned terraces on the mountains of *wadi* Nagab in addition to numerous flood spreading structures (Ouessar *et al.*, 2002; Ben Khehia *et al.*, 2002). The main encountered systems are: *Jessour* on the mountain ranges, *tabias* on the foothills and piedmont areas, cisterns, and gabion check dams and recharge wells in the *wadis* (*Figure 2.7*). For further information on these techniques, please refer to Ouessar (2007).

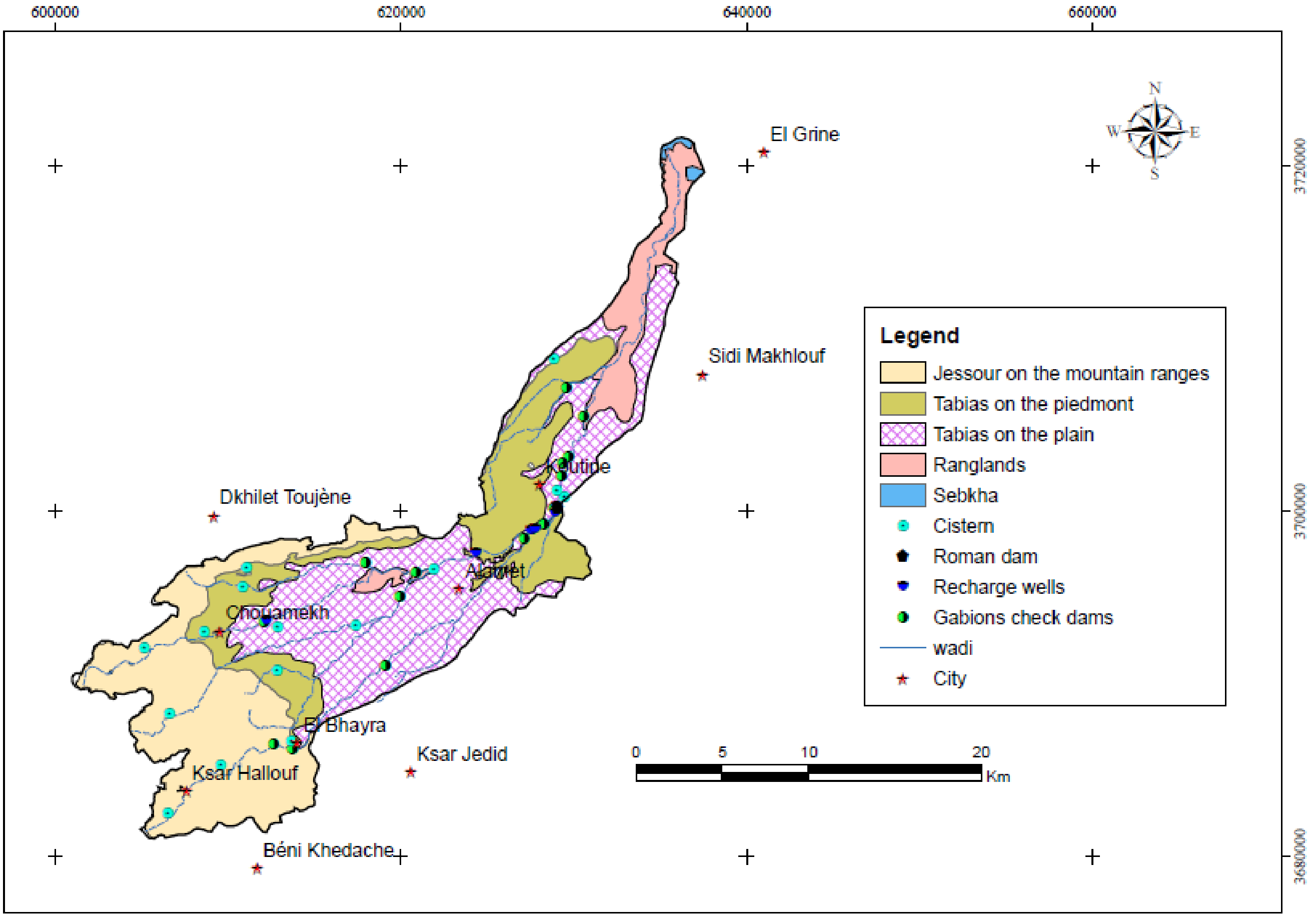

Figure 2.7: Water harvesting systems in the study watershed.

Socio-economic characteristics

Demography

The study watershed covers a territory of 10 *imadas* (the lowest administrative unit in Tunisia) belonging to three counties: Béni Khédache (3 *imadas*), Médenine North (3 *imadas*) and Sidi Makhlouf (*4 imadas*). As summarized in *Table 2.8*, the total population of the study watershed is estimated, according to the population census of 1994, to 24188 inhabitants whose 12159 (50.3 %) are male. The household number is 5758 with an average family size of 5.5.

Farming systems

The farming systems are marked by their diversity from the upstream to downstream areas of the watershed. These systems are essentially distinguished by the following characteristics (Labras, 1996; Rahmoune, 1998; Mahdhi *et al.*, 2000):

- non regular agricultural production that varies from one year to another depending on the rainfall regime,
- development of fruit tree orchards and the extension of newly cultivated fields at the expense of rangelands,
- gradual transformation of the livestock husbandry systems from the extensive mode, highly dependent on the natural grazing lands, to the intensive mode,
- development of irrigated agriculture exploiting the shallow and deep groundwater aquifers of the region,
- predominance of olive trees (almost 90 %) and the development of episodic cereals.

Table 2.8 Socio-demographic data of the watershed of wadi Oum Zessar (census 1994). Taken from Ouessar (2007)

County	Household	Population			Housing	GR	Density	Av. size	HG/HH	MR
Imada	(HH)	Male	Female	Total	(HG)	%	h/km^2	of HH		%
Béni Khédache	1182	3374	3465	6812	1637	2.3	22.6	5.8	1.3	50.0
El Bhayra	465	1268	1350	2618	656					
El Hmaïma	519	1546	1575	3121	666					
Zammour	198	533	540	1073	315					
Médenine North	1220	2876	2783	5659	1629	3.5	81.4	5.5	1.1	50.9
Oum Tameur Ouest	469	1076	1075	2151	668					
Oum Tameur Est	345	886	841	1727	490					
Koutine	406	914	867	1781	471					
Sidi Makhlouf	2326	5936	5781	11717	2492	2.9	36.0	5.3	1.1	50.8
Ragouba Ouest	718	1795	1753	3548	809					
Ragouba Est	748	1993	1956	3949	819					
Gosba	596	1494	1435	2929	615					
El Grine	264	654	637	1291	249					
Total	4728	12159	12029	24188	5758	2.9	46.7	5.5	1.16	50.5

T: Totally included in the study watershed; P: Partially included in the study watershed; GR.: Annual growth rate of the population; MR.: Male ratio; H: inhabitants
Source: Mahdhi *et al.* (2000).

The main encountered farming systems were described by Sghaier *et al.* (2002). They are summarized in the sections below.

System of '*Jessour*'
It is developed mainly in the upstream areas of the study watershed (mountainous zone of Béni Khédache). This system is based on runoff water harvesting (old technique of *Jessour*) for fruit trees cropping *(*mainly olives). Annual crops such as cereals, vegetables (beans, small pea, etc.) are also occasionally cultivated. The cropping areas are extremely small and rarely exceed 0.25 ha. Tree densities are relatively high and can exceed 60 trees/ha. The average parcel number by farmer is 6. Labras (1996) and Sghaier *et al.* (2002) found that the annual agricultural income by farmer is estimated to 1,195 TD (1 TD (Tunisian Dinar) ≈ 0.76 US$ (year 2007)) with 69% of the vegetable production source. The gross margin per hectare is relatively low, around 110 TD (Labras, 1996). The yearly non agricultural income is estimated at 200 TD with 69% due to migration.

System of irrigated perimeters
Two subsystems could be distinguished:

The subsystem of private irrigated perimeters: It is based on shallow wells. It is localized in the upstream area of the study watershed (at Ksar Hallouf) and in the downstream areas as well. The agricultural production is based on cash crops, greenhouses, vegetables and fruit tress. The cropping area varies between 0.2 and 10 ha per farmer (Rahmoune, 1998).

The subsystem of public irrigated perimeters: It is based on collective drilling created normally by the government. The water management is insured by collective interest associations, known by the '*AIC*'. These perimeters are situated in the downstream zone of the watershed, such as the irrigated perimeter of Kosba.

System of olive trees
This system is marked by the rainfed cropping of olive trees. It is mainly encountered in the plain and in the piedmonts. The area varies from 5 to 46 ha per farmer. Others tree species are also present such as, almond, apple, etc.

System of multi-cropping and animal husbandry

This system is heavily dependent on the rainfall irregularities. The agriculture is rainfed associated with an important livestock husbandry component. Two subsystems could be identified:

- The subsystem of marginal agriculture: It is marked by the cultivation of annual crops (cereals mainly) on small area and the most part of income is of non-agricultural sources.
- *The subsystem of the agro-breeders:* They are former breeders who are transforming their system by introducing an agricultural component which becomes increasingly important at the expense of livestock husbandry. It is mainly found in the downstream area of the watershed on scattered small pieces of land (average total area of 25 to 85 ha per farmer). The average livestock of one family is 20 to 150 goats and sheep, and 100 dromedaries grazing in the saline rangelands of the *sebkhas* (saline depressions).

Water harvesting realizations

The massive water harvesting projects in the province of Médenine, and particularly in the watershed of *wadi* Oum Zessar, started in the 1980s. However, the large intervention was undertaken during 1990-2000 for the implementation of the national strategies for soil and water conservation and water resources mobilization (Mahdhi *et al.*, 2000). The achieved works of the soil and water conservation strategy in the study watershed implemented during the period 1990-2000 are described below.

The action of watershed treatments concerned the construction of *jessour* (657 ha), *tabias* (5725 ha) and contour stone ridges (1014 ha) totaling 7406 ha. There has been the installation of 177 groundwater recharge gabion check dams and 21 flood spreading gabion check dams and 8 recharge wells.

The maintenance of the undertaken works (*jessour*, *tabias*, and contour stone ridges), pastoral and fruit trees plantations was carried out on an area of 3688 ha. It represents 50% of the total treated area but only 11% of the total watershed. In fact, fruit tree plantations and the structure maintenance represent the two main actions undertaken in the study area (1729 ha and 2815 ha, respectively).

The analysis of investments of the soil and water conservation strategy in the watershed showed that the global investment envelope was 9.86 MTD**.** It concerned the actions related to watershed treatment (4.9 MTD), maintenance, safeguard and consolidation of works (2.14 MTD) and the surface water mobilization (2.81 MTD). The global amount of investment by component shows that watershed treatment ranked first (49%) followed by surface water mobilization (29%) and then maintenance and safeguarding (22%). The average unit investment costs per technology are estimated at 2933 TD/ha, 539 TD/ha and 315 TD/ha for the techniques of *jessour*, *tabias* and contour stone ridges, respectively. These costs varied during the realization of the strategy (1990 to 2000) from one year to another due mainly to the type of the work and the physical characteristics of the sites (slope, soil, etc.) (Sghaier *et al.*, 2002).

Chapter 3. Methods

Measurement of hydraulic conductivity in the Oum Zessar watershed

Selection of sites

The systematic inventory work conducted by Said (2014) showed that there are 283 retention basins in the watershed of Oum Zessar. Measuring hydraulic conductivity in all these basins would have been too time-consuming. It was deemed important to measure sites with a good spread over several characteristics. These characteristics were: condition, occupation and type (check dam or spread dam). Condition of the check dams refers to whether or not the dam itself is damaged or not. Possible occupations are none, arboriculture and other agriculture. Random selections were made by assigning a 20 % chance for each site to be selected, until a selection was found which had a sufficient spread over the characteristics (Appendix A). An additional 8 sites were selected because they include a recharge well. Another site was added for detailed measurement.

Double ring infiltrometers

Of the 62 selected sites, 20 sites were too rocky or vegetated to measure with the double ring infiltrometers. In fact, driving the double ring infiltrometer into a rocky ground may cause damage to the rings. Appendix A shows which sites were selected, added to the selection and measured. Generally, 2 measurements were done per site. In 5 cases, more measurements were done per site to get a more detailed idea about the variation of hydraulic conductivity in the retention basin. The double ring infiltrometers used were similar to those of Eijkelkamp (1983). In June 2013, 99 measurements were done with “small”, 18/30cm (inner ring diameter/outer ring diameter) rings. An additional 3 measurements were done with “large”, 32/51cm rings. The rings were driven 5-10 cm into the ground. According to Bouwer (1986) and Eijkelkamp (2012), 5 cm is sufficient. Driving the rings in deeper may increase soil disturbance. The temperature of the water depended on the ambient temperature and is estimated to vary between 20 and 35 °C. The water is taken from the tap at the IRA, Route de Djorf, 22.5 km, Médenine. Its electrical conductivity as of October 16 2013 was 3.89 mS/cm, corresponding to a salinity of approximately 2.8 g/l. In some cases, water was taken from a tap in the study area itself. Initially, the rings were filled to a depth of about 14 cm. When the water level dropped below 5 cm, the water was replenished and the next repetition started. When the infiltration rate was constant, the experiment was stopped. In general, 1 to 4 repetitions were done. When pouring the water, a plastic bottle or bag was placed inside the rings to avoid soil disturbance.

Influence of water level on measured infiltration rate

A high water level causes a high hydraulic head at the infiltration surface. Therefore, the higher the water level, the higher the infiltration rate. It is important to have an idea about the influence of water level on infiltration rate for two reasons. Firstly, during a runoff event, the water level in the retention basin varies. Secondly, during an infiltrometer experiment the water level also varies, and the experiments were usually stopped before the water level decreased to zero. Therefore, we are not exactly measuring the hydraulic conductivity but a slightly higher value.

The influence of the water level on infiltration rate was assessed in three ways:

1) SWAP (Van Dam, 2000)
2) Analytical analysis based on the Green and Ampt (1911) formula.
3) Measurements

Usually, when the water in the double rings is replenished, we observe an increase in the infiltration rate. Often however, when comparing the infiltration rates for two repetitions, they show the same water level-infiltration rate relation. In this case, we consider that the variation in infiltration rate is only due to a change in water level.

SWAP (Soil, Water, Atmosphere and Plant)

SWAP is a 1D model for the simulation of water, solutes and heat in the vadose zone in interaction with vegetation development (Van Dam, 2000). It employs the Richards equation to simulate soil moisture movement in variably saturated soils. Its main inputs are the soil geophysical parameters (saturated hydraulic conductivity, saturated and dry water content, shape parameters) and meteorological data. We want to determine the relation between water level and infiltration rate. The basic principle of the simulations is to vary the water level and then read the infiltration rate. SWAP does not allow a straightforward implementation of a fixed water level. Therefore, it is necessary to change three parameters. Firstly, the precipitation rate is set to 990mm/day. This virtual precipitation rate exceeds the infiltration rate so a ponded layer is built up. Secondly, runoff is set to occur once the water level reaches a certain value. Otherwise, the ponded layer would continue to build up into infinity. This value corresponds to the height of the ponded layer we want to implement and is similar to or lower than the height of a check dam. SWAP uses a parameter called drainage resistance to surface flow (d). It assures that water does not run off instantly and allows the water level to exceed the value at which runoff starts to occur. However, we want the water level to never exceed the set value, so we set the drainage resistance for runoff to the lowest possible value (0.001 d).

Two conceptual models are used: a one layer model with a prescribed pressure head bottom boundary set to 0 (atmospheric pressure), and a two layer model where the bottom layer also has a prescribed pressure head bottom boundary set to 0.

A. Using one layer

For these simulations, the parameters which were used are shown in Table 3.1. The soil hydraulic parameters are derived from texture measurements on site 16 using the Schaap et al. (2001) (S2001) pedotransfer function. The bottom boundary condition corresponds with the water table.

Table 3.1: Parameters used for one layer modeling

Parameter	**Value**
Bottom boundary condition	Prescribed soil water pressure head
Soil layer thickness	0.8 m (scenario 1) or 1.6 m (scenario 2)
Water level (=ponding depth)	0, 0.2, 0.4, 0.6 or 0.8 m
Precipitation rate	990 mm/day
Residual water content θ_{res}	0.01
Saturated water content θ_{sat}	0.43
Shape parameter of main drying curve α	0.0227
Shape parameter n	1.548
Saturated hydraulic conductivity k_{sat}	18.3 mm/hr
Exponent in the hydraulic conductivity function L	-0.983
Shape parameter of main wetting curve in case of hysteresis α_w	0.0454
Air entry pressure head h_{enpr}	0.0

B. Using two layers

In this simulation, a bottom layer with a higher conductivity is added under the sediment layer (Table 3.2). The case where the bottom layer has a lower conductivity is not considered due to a lack of time.

Table 3.2: Parameters used for modeling two layers

Parameter	Value
All parameters	As in *Table 3.1*, unless otherwise mentioned
Thickness top layer	0.8 m
Thickness bottom layer	2 m, unless otherwise mentioned
Conductivity bottom layer	27.5 mm/hr, unless otherwise mentioned

Measurements

Since the water level varies during an infiltration experiment, we are actually measuring the water level-infiltration rate relation for low water levels (5-14 cm). This can be used to assess the influence of the water level on infiltration rate.

Influence of lateral flow on measured infiltration rate

In this study, we strived to measure the *vertical* saturated hydraulic conductivity. When conducting a double ring infiltrometer experiment however, water does not only infiltrate vertically but also laterally. This is why an infiltrometer contains two rings (Eijkelkamp, 2012). The theory is that lateral infiltration is mostly important at the edges of the infiltration area. By measuring only in the inner ring, lateral infiltration is supposedly taken care of. According to Bouwer (1986), this is a misconception. The only reliable way to decrease the influence of lateral flow is to increase the double ring infiltrometer size. As the size of a ring is increased, the ratio of perimeter over area decreases. Since lateral flow takes place especially at the perimeter of the infiltration area, this means that lateral flow is relatively less important when using large rings. In our small (18/30 cm) sets, the difference in diameter of the two rings is 12 cm. In our big (32/51) set, this difference is 19 cm. For this reason also, boundary effects are less important for the big set.

Al-Qinna and Abu-Awwad (1998) measured soil moisture below the infiltrometer in order to compare actual vertical infiltration to measured infiltration. For a 20/30 cm diameter set, they found that if they multiplied the measured infiltration rate by 0.91, they obtained the actual vertical infiltration rate. Their rings were driven in 15 cm as opposed to 5-10cm in this study. Also, they possibly applied a fixed amount of water for each experiment. Because of these differences, the different study area and because our measurements in the watershed indicated that this factor is too high, additional measurements were conducted at reference sites (chapter below).

Using the measurements from large and small sets, another factor is determined:

$$F_{lat} = \frac{K_{meas,small}}{K_{meas,large}}, \quad \textbf{(3.1)}$$

where F_{lat} is the correction factor for lateral flow [-], $K_{meas,small}$ is the hydraulic conductivity measured by a small set [L/T], and $K_{meas,large}$ is the hydraulic conductivity measured by the adjacent large set [L/T]. This factor was determined for 3 pairs in the watershed and for 12 pairs on the reference sites. The correction factor for lateral flow of a site was determined by dividing the average value of the measurements made with the small set by the average value of the measurements made with the large set. These site-values were in turn averaged, weighted by the number of measurements per site. The average of this factor F_{lat} was used to correct the measurements made with small sets to the value which would be measured with a large set. Possibly, these corrected values still overestimate the hydraulic conductivity, since lateral flow also influences the measured rate for large sets. However, since no information on this is at hand, we are forced to accept this factor as the final correction. Another assumption is that F_{lat} is similar for the reference sites and the sites in the watershed.

Measurements of texture and hydraulic conductivity on reference sites

In order to evaluate the values which were found with the 18/30 cm diameter rings in the Oum Zessar watershed, additional measurements were done on 3 sites. This allows us to compare measurement of 18/30cm diameter rings with other methods. These sites are at the IRA, Route de Djorf 22.5 km, Médenine, Tunisia. Note that none of the sites is located on a retention basin due to practical constraints. Site 1 is a site containing arboriculture, where the surface is mostly covered by loose material. Site 2 is just outside the IRA which is sparsely covered by vegetation (<5% surface area), and site 3 is again inside the IRA where the soil is more compacted. On each site, three types of measurements were done:

1) Double ring infiltrometer: both with 18/30 cm and with 30/50 cm diameter rings
2) Disk infiltrometer measurements
3) Texture measurements

The methodology for the double ring infiltrometer was outlined earlier. 2 to 4 pairs of measurements were done per site. A pair of measurements consists of a measurement with a small set and a measurement with a big set of rings. These two measurements were 1.5-3 m apart, and the pairs themselves were spread out over the site.
The disk infiltrometer is the Decagon Devices Minidisk Infiltrometer (Decagon Devices User's Manual, 2011). The tube has a length of 32.7 cm, an outer diameter of 3.1cm, and an interior diameter of 2.5 cm. A sintered stainless steel disk connects the water in the tube to the soil, and has a diameter of 4.5 cm and a thickness of 3mm. If the soil surface was too irregular for good contact, a thin layer of coarse sand was added underneath the disk. For an experiment, the infiltration rate was noted approximately every 30 seconds. This was then entered into the Decagon Devices Excel spreadsheet. Based on a correction for texture, a function was fitted which yielded the hydraulic conductivity. On each of the three sites, a rectangular perimeter of approximately $3m^2$ was drawn. In this perimeter, 3 measurements with a tension of -2 cm and 3 measurements with a tension of -5 cm were performed. The two advantages of using a tension infiltrometer have to do with the reproducibility of the results. Firstly, the pressure head applied to the soil surface is constant. In a double ring infiltrometer this is not the case, since the water level in the inner ring varies. Secondly, it is less affected by macropores, since they are not filled when applying a tension. The macropores act as a barrier to flow in this type of measurement, and therefore slightly lower the measured hydraulic conductivity as opposed to increasing it by a large amount. A tension of -2 cm is advised by the user manual. A tension of -5 cm is only advised for advanced users. In this research, we compare the results with the two tension values. For a tension of -5 cm, the water can only invade pores with a smaller diameter than for a tension of -2 cm and we therefore expect to measure a lower hydraulic conductivity. Note that the effect of applying a lower pressure head on the hydraulic gradient is corrected for in the calculations provided in the user manual so this does not influence the measured hydraulic conductivity. For these calculations, the texture of the site is needed.
At every site, three shallow soil samples were taken for texture analysis in the laboratory. The samples were spread out over the site and were taken close to where the infiltrometer measurements were performed. At least one was in or right next to the perimeter where the disk infiltrometer measurements were conducted.

Spatial variation of retention basin characteristics and their influence on hydraulic conductivity

During a large campaign in 2012 and 2013, Said (2014) collected various data (Appendix B). These characteristics include location of the dam (GPS coordinates), dimensions of the dam, surface area of the retention basin, current depth of the retention basin, initial depth of the retention basin, type of dam (check dam, spread dam), occupation (arboriculture, other culture, no occupation) and condition of the dam. The surface area of the retention basin was determined by investigating the presence of material deposited by the retreating water edge. Clogging is defined as the ratio of actual and initial depth of the retention basin and is a number between 0 and 1. For some sites, samples were taken for organic matter and texture measurements. For every retention basin, several characteristics were assessed using the data from Halifa (2014) and the data collected in the present research. We use the data for two goals.

1) Assess the spatial distribution of basins with certain characteristics (texture, clogging, hydraulic conductivity)
2) Assess the influence of certain characteristics on the hydraulic conductivity (type, clogging, occupation, location)

The spatial distribution of texture, clogging and hydraulic conductivity are most interesting to us. These were plotted in a graph where the x-axis represents distance downstream. The distance downstream was determined in the following way. Point 1, which is the most upstream point, has a distance of 0km. Since the orientation of the watershed is roughly south-west to north-east, a line was drawn from point 1 in the northeast direction. For every point, a line was drawn perpendicular to this line. The distance from the intersection of the two lines to point 1 equals the distance downstream.

By summarizing the hydraulic conductivity data per characteristic, the influence of each characteristic was assessed.

Determination of the suitability of pedotransfer functions

The suitability of two pedotransfer functions (PTFs) was assessed. The first is the built-in pedotransfer function of HYDRUS (Simunek et al. 2012), based on Schaap et al. (2001) (S2001). For this PTF, retention curves for 2134 samples were used. Most of the samples were taken in temperate to subtropical regions in North America and Europe. Saturated hydraulic conductivity was available for a subset of 1304 samples. The second is the Saxton et al. (1986) (S1986) pedotransfer function. They provided equations for the texture-hydraulic conductivity relation based on previous works.

Texture measurements have been performed on sites in the watershed (Said, 2014), and on the reference sites (this research). By comparing the results from the double ring infiltrometer tests and the PTFs, we determine the suitability of pedotransfer functions.

Estimation of conductivity at non-measured sites

Since only 42 of the 283 sites were measured, we do not have hydraulic conductivity values for the remaining 241 sites. We therefore have to somehow interpolate the measured values to the other sites. This was done in three ways.

1) Assigning an average value to all non-measured sites
2) Assigning the average value of the upstream area, the center or the downstream area to non-measured sites in those areas.
3) Assigning a value to non-measured sites based on inverse distance weighted interpolation

For the interpolation, inverse distance weighting is performed using FORTRAN. The conductivity value of a non-measured point is determined as follows (Shepard, 1968):

$$u(x) = \sum_{i=0}^{n} \frac{w^i(x)u^i}{\sum_{j=0}^{n} w^j(x)}, \tag{3.2}$$

where w_i is the weighting factor and is determined as follows:

$$w^i(x) = \frac{1}{d(x, x^i)^p}, \tag{3.3}$$

Where u is the value of a point (mm/hr), $d(x,x_i)$ is the distance between two points (m) and p is a power parameter (-). The power parameter is determined during validation.

To compare these three methods, a validation is performed. We choose 3 points in each area (upstream, center, downstream) for a total of 9 points. These points are not used when determining the hydraulic conductivity at non-measured sites as described above. For the interpolation, multiple estimations are performed with different p values in order to determine the optimal value for p. The deviation of the estimated values is determined as follows:

$$D_{av} = \sum_{i=1}^{n} \frac{\left|K_{est}^{i} - K_{meas}^{i}\right|}{n}, \quad (3.4)$$

where D_{av} is the average deviation of estimated values, K_{est}^{i} is the estimated value of a site and K_{meas}^{i} is the measured value of a site. It is assumed that the method which yields the lowest D_{av} is the best method.

Chapter 4. Results and discussion

Influence of water level on measured infiltration rate

SWAP

A. One layer

Figure 4.1 shows the results of two simulations. Note that due to the boundary conditions (ponding at top and 0 soil water pressure head at bottom), the entire layer is saturated. This means the thickness of the soil layer is also the thickness of the wetting front. The infiltration rate increases linearly with increased water level, and depends on the layer thickness. At 0 water level, the infiltration rate equals the saturated hydraulic conductivity. In the case where the layer thickness is 0.8 m, the

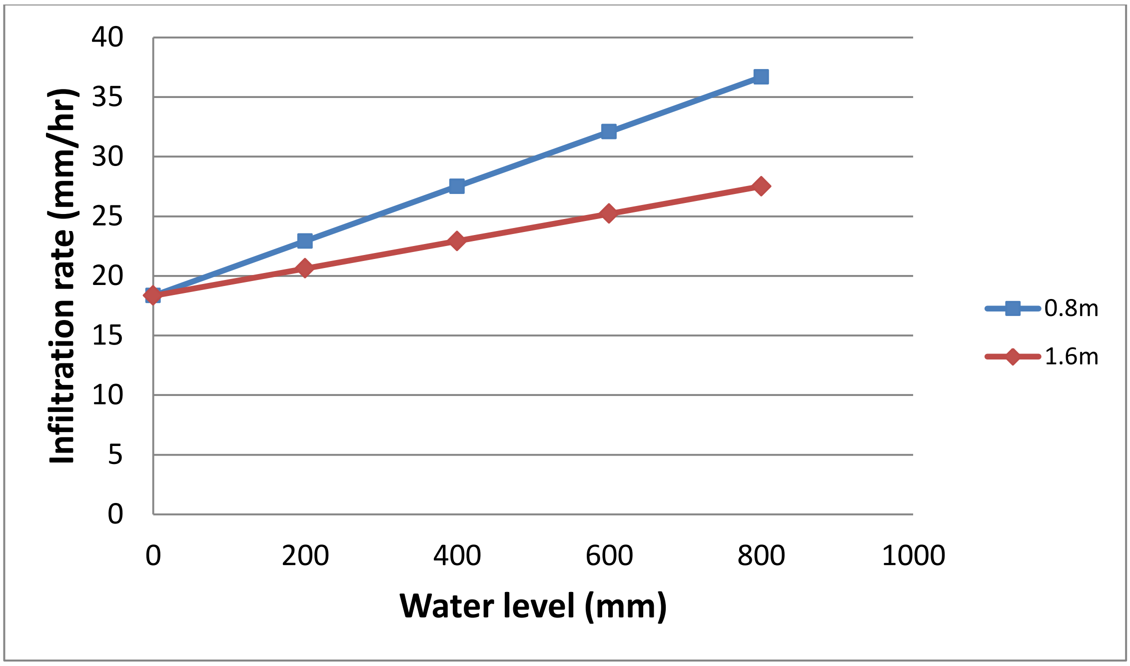

Figure 4.1: the water level-infiltration rate relation for a one-layer model for two layer thicknesses and a hydraulic conductivity of 18 mm/hr

infiltration rate is doubled when going from a water level of 0 to 0.8 m. This is attributed to the fact that the gradient is twice as high since a charge of water is added which is equal to the initial water charge. When the soil layer thickness is doubled to 1.6 m (red line in *Figure 4.1*), the water column which is needed to double the gradient is twice as high as that for a bottom layer of 0.8 m. This is reflected in the slope of the line being twice as low. Using this information, we obtain the water level-infiltration rate relation:

$$q = K_{sat} + \frac{K_{sat} H_w}{T} \tag{4.1}$$

where q is the infiltration rate [L/T], K_{sat} is saturated hydraulic conductivity [L/T], H_w is water level [L] and T is layer thickness [L]. For a large layer thickness (or a deep wetting front), the infiltration rate goes to the saturated hydraulic conductvitity.

B. Two layers

The results for different bottom layer hydraulic conductivity values for the bottom layer are shown in *Figure 4.2*.

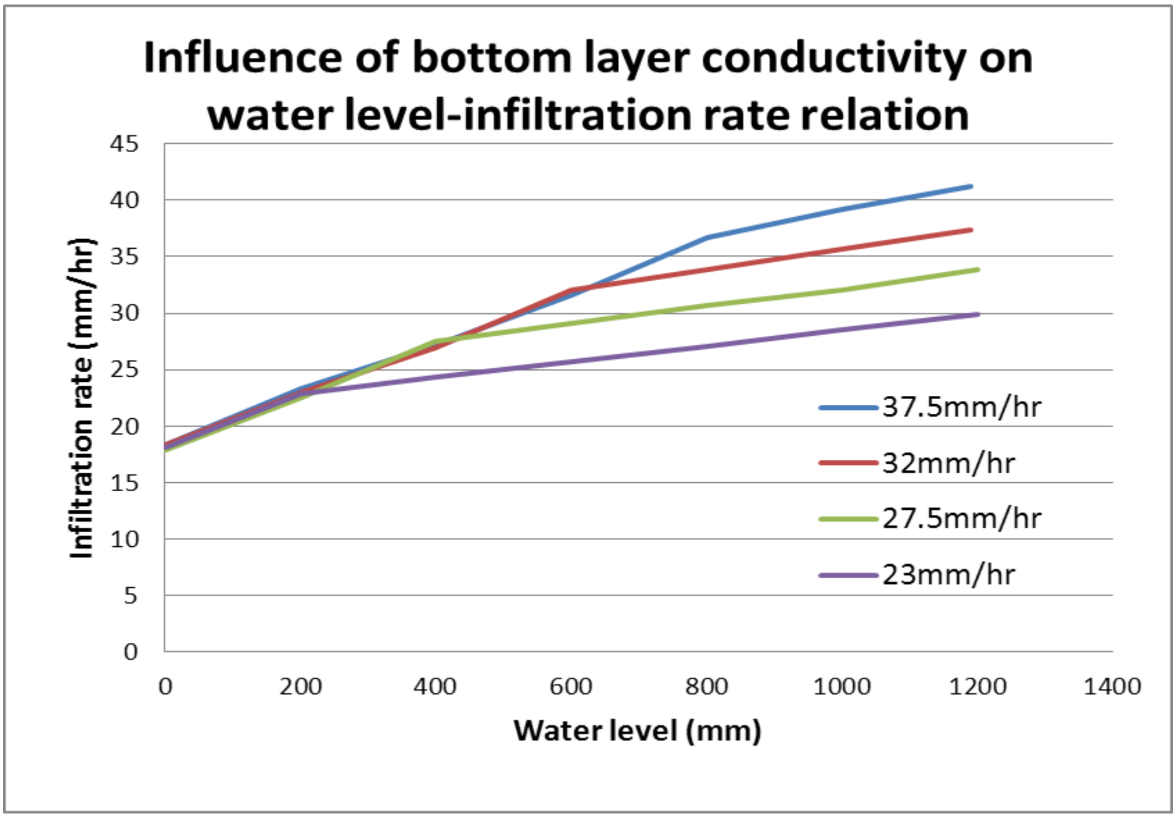

Figure 4.2: Infiltration rate versus water level for a SWAP simulation with 2 layers, where the conductivity of the bottom layer is varied.

The first parts of the graphs are identical to the case without a bottom layer. However, the slope decreases when the infiltration rate equals the saturated conductivity of the bottom layer. As can be observed in Figure 4.3, the thickness of the bottom layer influences the slope of this second part.

So when 0 < H_w < $(K_{sat,bot} - K_{sat,top})(K_{sat,top}/T_{top})^{-1}$, equation (4.1) holds. When H_w > $(K_{sat,bot} - K_{sat,top})(K_{sat,top}/T_{top})^{-1}$, the relation depends on the properties of the bottom layer. This relation is derived in the analytical analysis below.

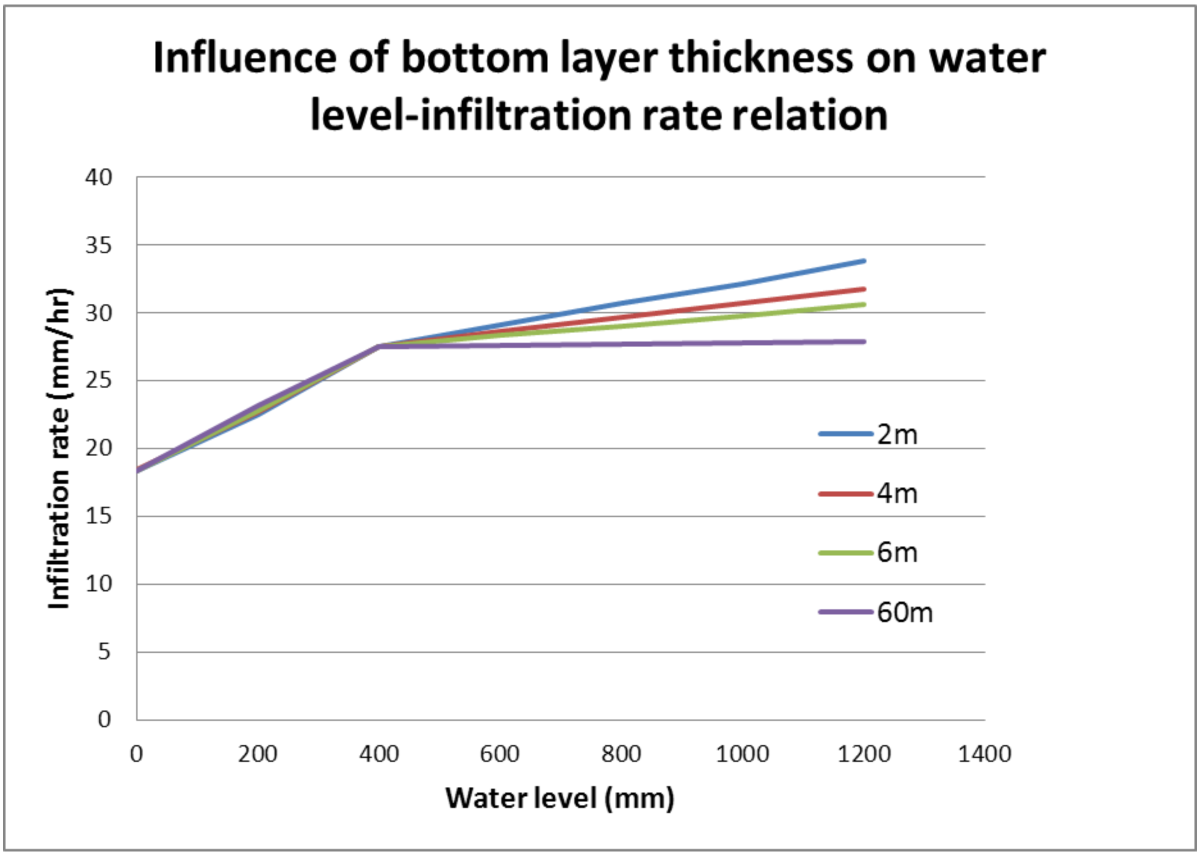

Figure 4.3: the water level-infiltration rate relation for four different bottom layer thicknesses. The conductivity of the bottom layer is 27.5mm/hr, and the thickness of the top layer is 0.8m.

Analytical analysis

One layer

The infiltration rate during ponding conditions may be described as follows (Green & Ampt, 1911):

$$q = K_{sat}\frac{H_w + L_f - h_f}{L_f}, \tag{4.2}$$

where L_f is the depth of the wetting front [L], and h_f is the water pressure head at the wetting front. In the case of a single layer with a zero pressure head boundary condition at the bottom of the layer, equation (4.2) becomes:

$$q_1 = K_{sat}\frac{H_w + T}{T} = K_{sat} + \frac{K_{sat}H_w}{T}, \tag{4.3}$$

where q_1 is the infiltration rate in the one-layer case. This agrees with equation (4.1). By derivation, we obtain the slope of the water level-infiltration rate relation:

$$\frac{dq_1}{dH_w} = \frac{K_{sat}}{T}. \tag{4.4}$$

Two layers

When two layers are present and saturated, the first part of the water level-infiltration rate relation is equal to equation (4.3). Thus, when $0 < H_w < (K_{sat,bot} - K_{sat,top})(K_{sat,top}/T_{top})^{-1}$:

$$q_{2,1} = q_1 = K_{sat,top} + \frac{K_{sat,top}H_w}{T_{top}}, \tag{4.5}$$

where $q_{2,1}$ is the infiltration rate for two layers for low H_w. For two saturated layers and when and the bottom boundary condition is a water pressure head of 0, a representative conductivity can be used:

$$K_{sat,rep} = \frac{T_{top} + T_{bot}}{\frac{T_{top}}{K_{sat,top}} + \frac{T_{bot}}{K_{sat,bot}}} = \frac{T_{tot}}{\frac{T_{top}}{K_{sat,top}} + \frac{T_{bot}}{K_{sat,bot}}}, \tag{4.6}$$

Where T_{top} and T_{bot} are the top and bottom layer thicknesses [L], T_{tot} is the total thickness [L] and $K_{sat,top}$ and $K_{sat,bot}$ are the saturated conductivities of the top and bottom layer [L/T]. When $H_w > (K_{sat,bot} - K_{sat,top})(K_{sat,top}/T_{top})^{-1}$, similarly to equation (4.4), the slope equals:

$$\frac{dq_{2,2}}{dH_w} = \frac{K_{sat,rep}}{T_{tot}} = \left(\frac{T_{top}}{K_{sat,top}} + \frac{T_{bot}}{K_{sat,bot}}\right)^{-1}, \tag{4.7}$$

Where $q_{2,2}$ equals the infiltration rate for two layers when $H_w > (K_{sat,bot} - K_{sat,top})(K_{sat,top}/T_{top})^{-1}$. In order to solve for $q_{2,2}$ itself, the following condition is put into the primitive of equation (4.7):

$$q_{2,1}\left(H_w = \frac{K_{sat,bot}T_{top}}{K_{sat,top}} - T_{top}\right) = q_{2,2}\left(H_w = \frac{K_{sat,bot}T_{top}}{K_{sat,top}} - T_{top}\right). \tag{4.8}$$

This results in the following relation:

$$q_{2,2} = K_{sat,bot} + K_{sat,rep}\frac{H_w - \frac{T_{top}K_{sat,bot}}{K_{sat,top}} + T_{top}}{T_{tot}}. \tag{4.9}$$

The results from this formula are lower than the results from SWAP. The deviation is always less than 0.06% and is attributed to numerical deviation in the SWAP model.

Measurements

From the SWAP and analytical analyses we expect to measure a linear relation between water level and infiltration rate. If the water level is high enough, the slope of the relation may decrease in case the infiltration rate exceeds the hydraulic conductivity of a possible bottom layer with lower hydraulic conductivity (Figure 4.2). Note that another requirement is that the wetting front has progressed into this bottom layer. Figure 4.4 shows four repetitions of a measurement in the Oum Zessar watershed. Initially, the infiltration rate is very high. This is due to a relatively high gradient: the wetting front is shallow, but the suction force is constant. After a certain amount of water has infiltrated, the suction force is less important. The second to fourth repetition show the same infiltration rate at a certain water level. This tells us the change in water level is only due to the water level. As expected, the infiltration rate increases linearly with increasing water level. This is confirmed in other measurements. Using excel, a linear function is fitted. The intercept is 288mm/hr, which we accept as the value for K_{sat}. In the 'standard' approach, the average of the infiltration rate at a water level of about 50 to 70mm. This would yield a value of 325mm/hr. This is an overestimation of 13%.

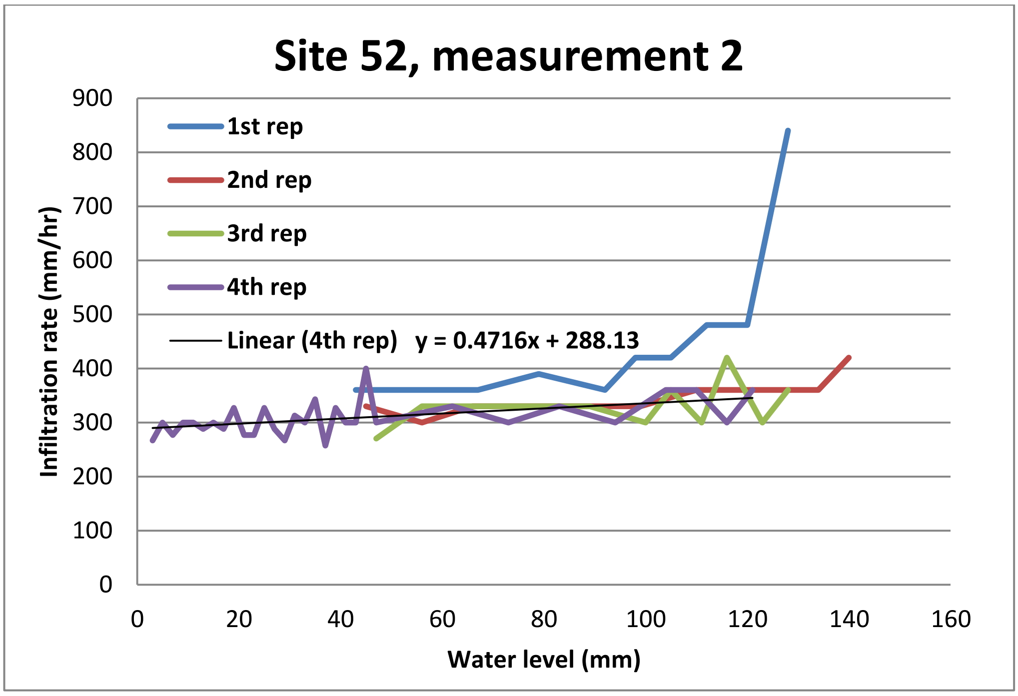

Figure 4.4: Four repetitions of measurement 2 on site 52. The infiltrometer water level was restored when the level dropped below 50mm, except for during the last repetition where it was allowed to go to zero.

The method is not always impeccable as in this example. Figure 4.5 shows another example, where measurements are available only for a small range of water levels and the infiltration rate oscillates. The oscillations are due to a measurement period which is too small. This means that sometimes, the same water level is measured for two different times and the calculated infiltration rate is 0. The linear fits of both repetitions do not yield plausible values. In cases such as this, the average infiltration rate at the end of the second repetition is used.

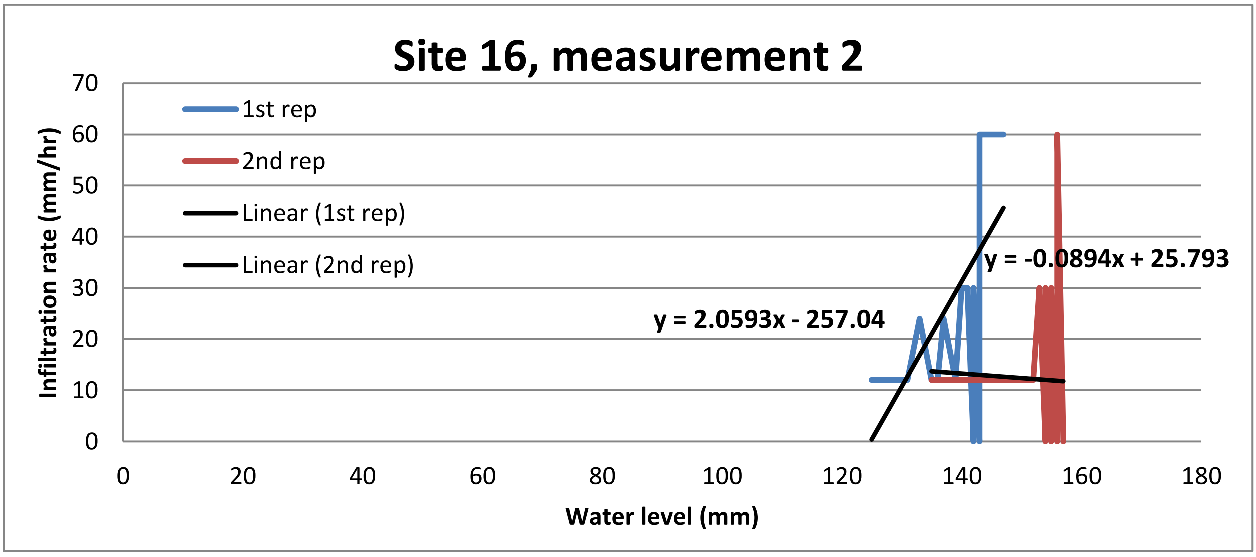

Figure 4.5: Two repetition of measurement 2 on site 16. In this case, the linear fits were ignored, and a value of 12mm/hr was adopted.

The correction for water height was only applied when it was deemed this gave reliable results. In the other cases, the average infiltration rate at the end of the last repetition was used. First, an average hydraulic conductivity of the site was determined in order to have only one value per site. These values were in turn averages which yielded a value of 99m/hr. When only taking the average at the end of the last repetition, we find 114mm/hr. This is an overestimation of 15%.

Synthesis

At low infiltration rates water level-infiltration rate relation is linear. If a bottom layer with a different conductivity is present, the water level-infiltration rate relation changes. If the bottom layer has a higher conductivity, the relation changes once the infiltration exceeds the hydraulic conductivity of the bottom layer. If the bottom layer has a lower conductivity, the relation changes once the wetting front reaches this layer. Unfortunately, for the present research we lack the information of top layer thickness and bottom layer conductivity to determine when this changes for the retention basins.

Recommendations

Data on the conductivity and depth of the underlying layer should be combined with the relations found in this research. Obviously, these characteristics influence the infiltration rate as the wetting front progresses.
In order to accurately predict the infiltration rate, it is necessary to track both the water level and the depth of the water front. SWAP is a suitable model to do this. A watershed-scale model can be evaluated by for example combining PCRaster and MODFLOW or PCRaster and SWAP. Observations of ponding height during a runoff event are needed to verify the models.

Influence of lateral flow on infiltration rate

All measurement results are given in Appendix C. Table 4.1 summarizes the results from the reference site and from the watershed for those sites where measurements with both large and small sets have been performed. For 12 out of 15 pairs, the value measured with the large set is lower than the value measured with the small set. This is in line with expectation. On average, the correction factor F_{lat} equals 0.65 (Equation (3.1)). Therefore, the values measured with small rings are multiplied by 0.65. Even though this factor doesn't correct for all lateral flow but sets the value to a value which would be measured by a large set, this factor is lower than the value found by Al-Qinna and Abu-Awwad (1998). Recall that they used a deep driving depth (15cm) and possibly a fixed amount of water. Possibly, during their experiments most flow occurred while the wetting front did not reach the bottom of the cylinders. Another reason for this difference may be that the experiments were conducted in a different soil type.

Table 4.1: Measurements with large and small double ring infiltrometers at the reference site (IRA) and in the watershed

Site	Measurement	Size	Infiltration capacity corrected for water height (mm/hr)	Factor per pair
IRA 1	1	LARGE	**43**	*0.37*
	2	small	**115**	
	3	LARGE	**59**	*0.54*
	4	small	**110**	
	5	LARGE	**76**	*1.04*
	6	small	**73**	
	7	LARGE	**57**	*0.58*
	8	small	**99**	
IRA 2	1	LARGE	**103**	*0.60*
	2	small	**172**	
	3	LARGE	**65**	*0.54*

	4	small	**121**	
IRA 3	1	LARGE	**130**	*1.48*
	2	small	**88**	
	3	LARGE	**84**	*1.02*
	4	small	**82**	
	5	LARGE	**7.2**	*0.13*
	6	small	**55**	
Watershed 76	1	LARGE	**61**	*0.52*
	2	small	**117**	
Watershed 254	1	LARGE	**32**	*0.20*
	2	small	**157**	
Watershed 280	1	LARGE	**25**	*0.56*
	2	small	**45**	

Application of corrections

The effect of applying the corrections to the data on the average conductivity is given in *Table 4.2*. The uncorrected values are 75% higher than the corrected values.

Table 4.2: Average saturated hydraulic conductivity of measured sites after several corrections (mm/hr)

	Average saturated hydraulic conductivity (mm/hr)
Uncorrected	114
Corrected for water height	99
Corrected for water height and lateral flow	65

Texture in the watershed

During a large campaign, Halifa (2014) measured texture in retention basins in the watershed (*Table 4.3*). Sandy loam and sandy clay loam are most prevalent, with loamy sand close behind.

Table 4.3: Number of occurences of each texture type throughout the watershed. Source: Halifa (2014)

Texture	**Count**
Sand	3
Loamy sand	9
sandy loam	16
loam	2
sandy clay loam	13
clay loam	2
silty clay	2

Comparison of results from the reference sites

Texture

The results of the texture measurements are shown in Table 4.4. More detailed information is given in Appendix C. The third column of the table gives an indication of the quality of the measurements. It corresponds to the addition of the measured mass percentages of clay, silt and sand. 7 out of 9 measurements have a value between 97.3% and 97.8% and are therefore deemed of good quality. For site IRA 1, the texture 'sand' is chosen as the representative texture since 2 out of 3 measurements have this texture and measurement 3 was taken within the perimeter where the disk infiltrometer measurements were conducted. At site IRA 3, the quality of measurement is lower for measurements 2 and 3. Therefore, the texture of measurement 1 is chosen as representative for the site.

Table 4.4: Texture at the three reference sites at the IRA

Site	Measurement	volume % when adding three classes	Texture	Site texture
IRA 1	1	97.3	Sand	Sand
	2	97.4	Loamy sand	
	3	97.6	Sand	
IRA 2	1	97.8	Sand	Sand
	2	97.5	Sand	
	3	97.7	Sand	
IRA 3	1	97.8	Loamy sand	Loamy sand
	2	90.3	Loamy sand	
	3	101.5	Sandy loam	

Hydraulic conductivity

The results of the double ring infiltrometer measurements for the three reference sites are given in *Table 4.5*. All measurements are corrected for water height. The measurements conducted with the small set are corrected for lateral flow by multiplication with 0.65, as previously determined. All values of site 1 are between 43 and 76mm/hr. The site is therefore relatively homogeneous and the precision of the measurement is high. The values of site 2 are between 79 and 103mm/hr. For site 3, the values are between 7 and 130mm/hr. Site 3 is therefore quite heterogeneous. This is in accord with the fact that the infiltration rate during measurement with double ring infiltrometer tests stabilized less quickly than for the other sites.

Table 4.5: Hydraulic conductivity as measured by double ring infiltrometers at the three reference sites.

Site	Measurement	Hydraulic conductivity, corrected for water height and lateral flow (mm/hr)	Arithmetic average (mm/hr)
IRA 1	1	43	62
	2	75	
	3	59	
	4	72	
	5	76	
	6	47	
	7	57	
	8	64	
IRA 2	1	103	90
	2	112	
	3	65	
	4	79	
IRA 3	1	130	61
	2	57	
	3	84	

	4	53	
	5	7	
	6	36	

The hydraulic conductivity values as measured by the disk infiltrometer are given in *Table 4.6*. In general, measurements made with a pressure of -5cm yielded lower values. This is consistent with expectation, since the bigger pores and flow paths which are filled at a pressure of -2cm are not filled at a pressure of -5cm. There are therefore less flow paths available for flow at a pressure of -5cm which means the conductivity is less. For one measurement, a value of -19mm/hr is registered. For this measurement, the amount of sand added to level the surface was too great. This led to a rapid outflow of water until the sand layer was saturated. This measurement has not been considered in further analyses.

Table 4.6: Disk infiltrometer hydraulic conductivity measurements for the three reference sites. Corrected for water height and lateral flow.

Site	Measurement	Pressure(cm)	K (mm/hr)	Arithmetic average (mm/hr)
1	1	-2	189	253
	2	-2	166	
	3	-2	526	
	4	-5	135	
	5	-5	489	
	6	-5	152	
	7	-2	114	
2	1	-2	81	232
	2	-2	142	
	3	-2	35	
	4	-5	107	
	5	-5	225	
	6	-5	804	
3	1	-2	**-19**	122
	2	-2	44	
	3	-2	173	
	4	-5	85	
	5	-5	114	
	6	-5	192	

The results from the pedotransfer functions are given in *Table 4.7*. The S1986 does not support textures with less than 5% clay. On average, values calculated with S2001 are about twice as high as those calculated with S1986.

Table 4.7: Hydraulic conductivity (mm/hr) as determined by pedotransfer functions for the three reference sites. N/A (not available) indicates the mass percentage of clay is less than 5%. Measurements 3.2 and 3.3 are not included since the texture measurements were considered unreliable

Site	Measurement	Hydraulic conductivity S1986	Average S1986	Hydraulic conductivity S2001	Average S2001
IRA 1	1	N/A	46	104	93

	2	41		70	
	3	51.7		104	
	1	77.8		154	
IRA 2	2	76.4	76	176	161
	3	73.5		152	
IRA 3	1	N/A	N/A	76	76

The averaged results of every method are shown in *Table 4.8*. Except for the disk infiltrometer, all methods yield the highest values at site 2. A possible explanation is that at the first site, the disk infiltrometer measurements were conducted less rigorously. For example, it may have been better to add sand in some of the measurements. The highest values are measured by the disk infiltrometer. Although according to the user manual the measurements are corrected for lateral flow, the small size of the infiltrometer disk may cause an overestimation. The values measured with the double ring infiltrometer are in between those measured with the two pedotransfer function, and closer to the (lower) values calculated with S1986. The conclusions from this table are that the double ring infiltrometer measures in the right order of magnitude, and that the disk infiltrometer probably overestimates the hydraulic conductivity. If a PTF is used to predict hydraulic conductivity, it should be the S1986 function based on the results from the reference sites. In the next chapter, the suitability of PTFs is assessed using both these results and the results from the watershed (Halifa, 2014).

Table 4.8: hydraulic conductivity as determined by different methods for the three reference sites

Site	Double ring infiltrometer	Disk infiltrometer	S1986	S2001
IRA 1	62	253	46	93
IRA 2	90	232	76	161
IRA 3	61	122	N/A	76

Spatial variation of clogging, texture and conductivity in the watershed

Figure 4.6 shows the altitude of the retention basins. Since the dots are clustered, we conclude that the taking the distance northeast from site 1 gives a good representation of the distance downstream. Some dots form lines. These lines correspond to a single wadi.

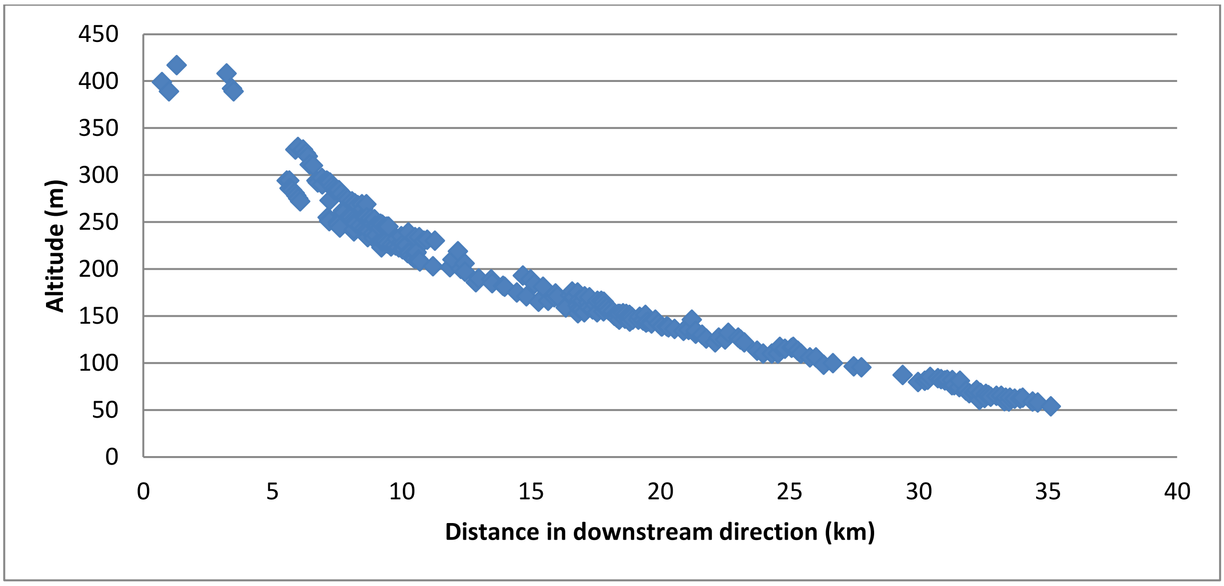

Figure 4.6: Altitude of retention basins plotted against distance in the downstream (northeast) direction. Site 1 is situated at a distance of 0km. Every dot represents a site. Data source: Halifa (2014)

Figure 4.7 shows the amount of clogging for every site and its distance downstream. Excel was used to plot a linear fit to the data. Note that this fit is not a good predictor of clogging, since the data is scattered and therefore R^2 is low. It is included in this report to show that as opposed to common expectation, the amount of clogging increases in the downstream direction. Most notably, there are few sites with a clogging index of under 0.2 in the downstream area. Since we do not have information on the age of the check dams, no futher conclusions are drawn from this table.

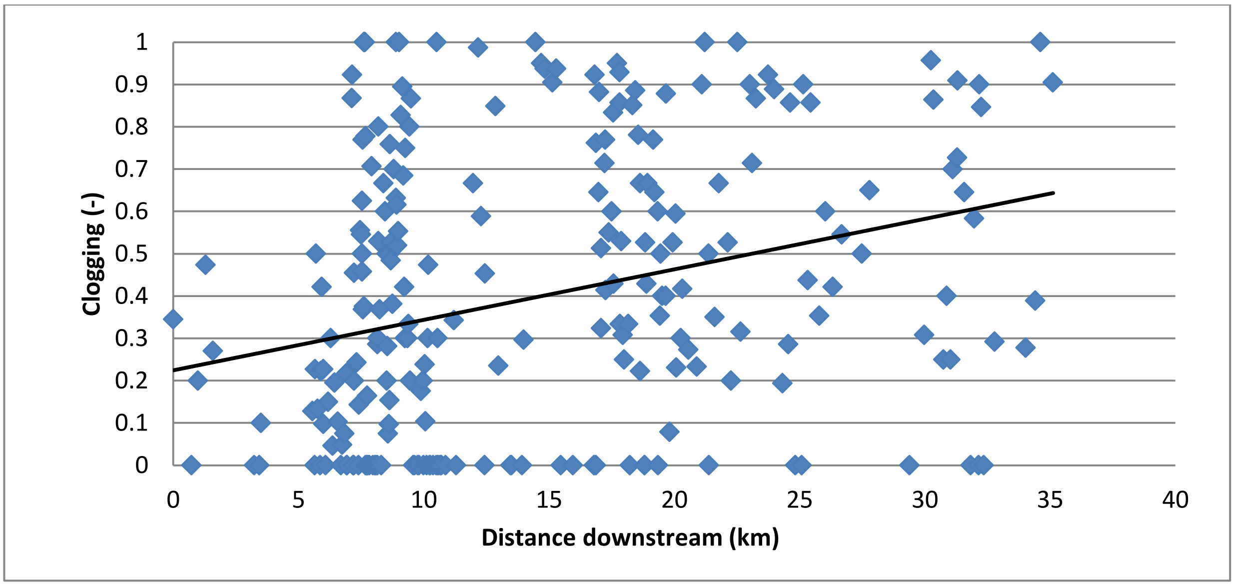

Figure 4.7: Clogging of all retention basins against distance in downstream (northeast) direction. Site 1 is situated at a distance of 0km. A value of 1 indicates a complete clogging of the basin. The line corresponds to a linear fit performed in excel. Every dot represents a site. R^2=0.09. Data source: Halifa (2014)

The mass percentage of sand in a sample is used as a measure of grain size in Figure 4.8 and Figure 4.9. The two graphs use the same basic data. Unfortunately, there was a problem with the texture data. It was unclear which measurement belonged to which site since there were multiple lists with conflicting numbering schemes of the measurements. It is therefore unclear whether Figure 4.8 (numbering scheme 1) or Figure 4.9 (numbering scheme 2) is correct. When collecting the texture data, Halifa (2014) took photos for every soil sample. For both lists, there are sites which have no photo of the soil sample so this does not help us in determining which of the lists is correct. There are less data points for numbering scheme 1, since it gave multiple values for a single basin which were then averaged. Since this seems to be the methodology used in Halifa (2014), it is more likely that numbering scheme 1 is correct. A linear fit was inserted for both numbering schemes using Excel. The grain size decreases in downstream direction for both figures. This is attributed to two factors. Firstly, particles at a downstream location usually have travelled a greater distance and have therefore been subjected to more abrasion. Secondly, in a wadi system with retention basins, stream velocity decreases in the downstream direction due to a diminishing slope and diminishing discharge. Larger particles settle at discharge rates for which smaller particles are still entrained. The smaller particles then settle preferably at downstream locations where velocity is lower.

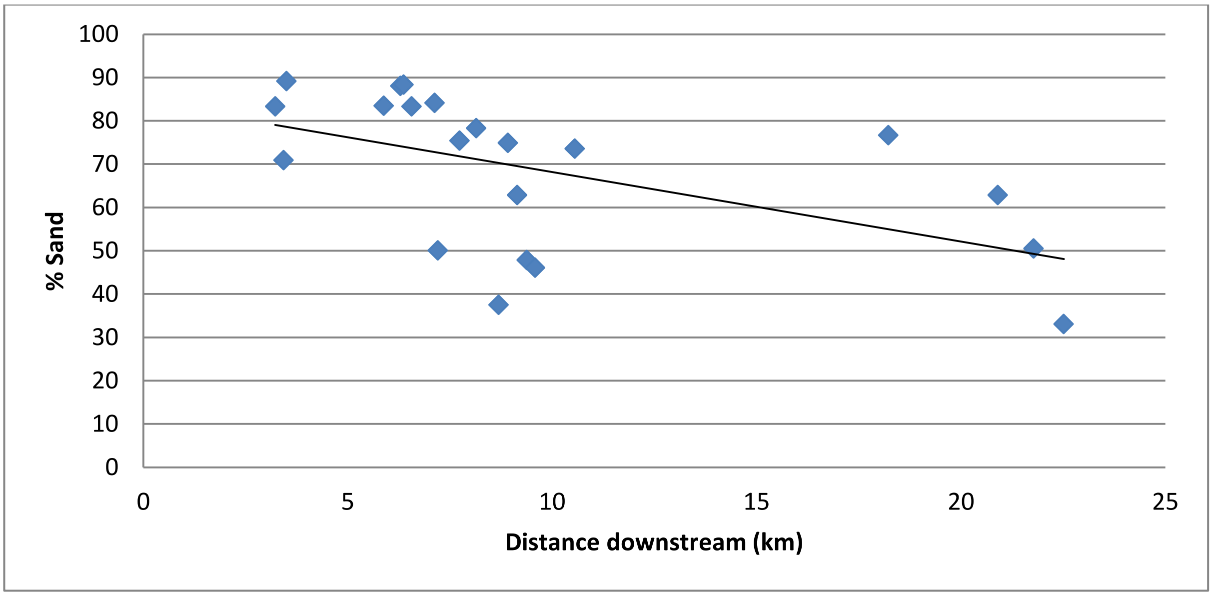

Figure 4.8: Average sand percentage of soil samples at a site as a measure of texture against distance in downstream (northeast) direction. Numbering scheme 1. Data source: Halifa (2014)

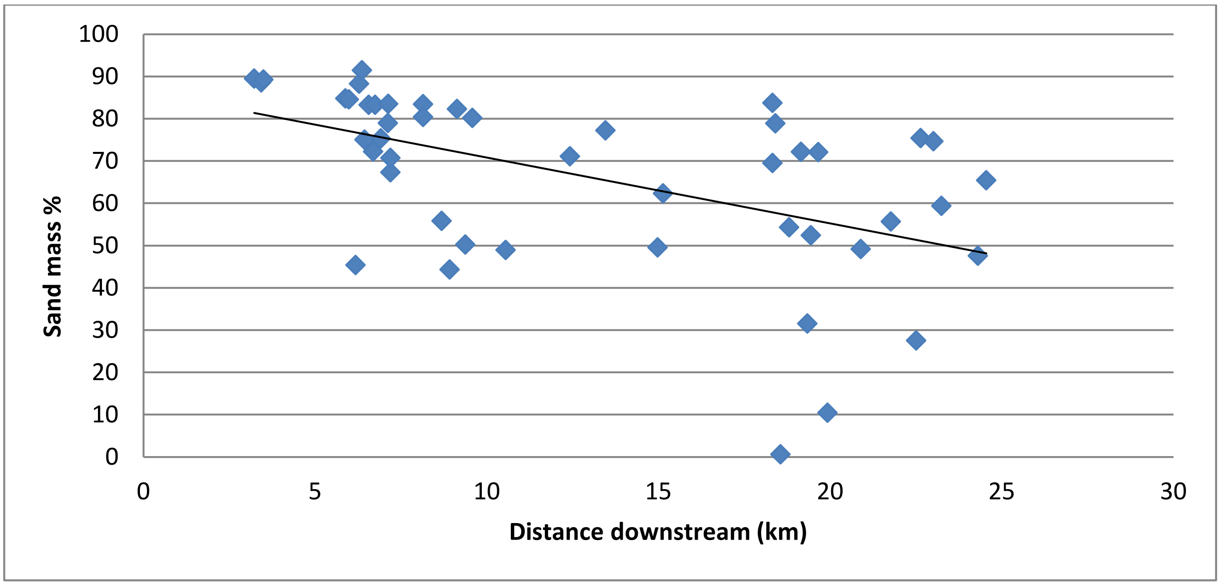

Figure 4.9: Sand percentage of soil samples as a measure of texture against distance in downstream (northeast) direction. Numbering scheme 2. Data source: Halifa (2014)

Figure 4.10 shows the measured corrected conductivity values throughout the watershed. The hydraulic conductivity is highest in the center of the area on the rendzinas. The values are lower in the downstream area and lowest in the upstream area. Figure 4.11 shows the hydraulic conductivity of the 42 measured retention basins and their approximate distance downstream. The watershed is divided into three areas based on the conductivity values. The boundary between the upstream area and center is based on a clear difference in hydraulic conductivity and is placed at 11.8km downstream of site 1. The boundary between the center and the downstream area is based on a less clear difference and is situated at 21.8km. The two sites immediately downstream of the boundary are located in the same wadi and adjacent; there are no unmeasured sites in between. Therefore, it was chosen not to place the boundary in between.

The high conductivity in the center is possibly due to coarser eolian deposits which occur in the retention basins. However, neither Figure 4.8 nor Figure 4.9 shows a higher sand percentage in the center of the watershed (between 11.8 and 22.8km). Figure 4.8 actually only contains a few points in the center area, so a possible trend is easily missed if numbering scheme 1 is true. The low values found in the upstream area may be due to the steep slopes in this area. The slopes increase erosion, thereby diminishing the thickness of the soils and/or sediment layers. The average conductivity values and locations of the boundaries as shown in

Figure 4.10 and Figure 4.11 are used to estimate non-measured values on page 52.

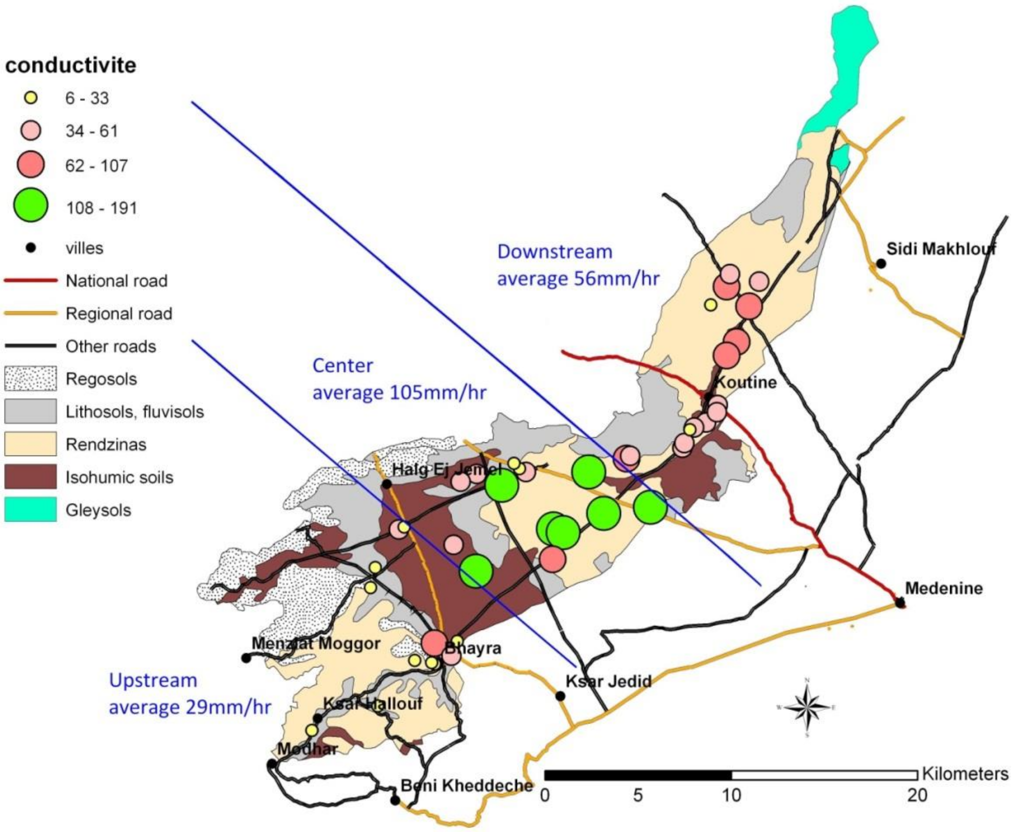

Figure 4.10: Measured corrected values throughout the watershed (mm/hr)

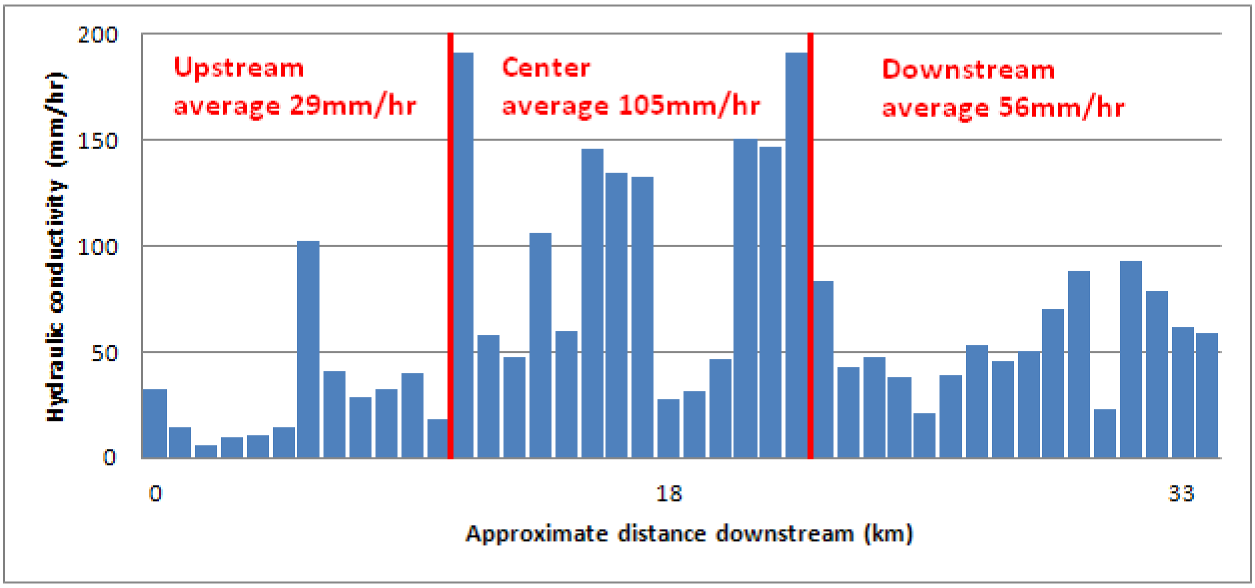

Figure 4.11: Hydraulic conductivity of all measured retention basins against distance in downstream (northeast) direction and average hydraulic conductivity of retention basins in three parts of the basin. Every bar represents a site. Since bars have a fixed width, the downstream distance is approximate. Site 1 is situated at a distance of 0km.

Influence of retention basins characteristics

The effect of several characteristics on the hydraulic conductivity is analyzed independently. These characteristics are texture, type (spread dam or check dam), wadi, location, clogging and occupation. In future, it may be useful to include geology and soil type. In this chapter, only a simple analysis is done. However, since basins with a certain characteristic may have a higher probability of having a certain other characteristic, this method may miss some trends. A better result can be obtained by performing a principal component analysis.

Texture: suitability of pedotransfer functions

From Table 4.8 we conclude that the S1986 PTF yields on average 14% lower hydraulic conductivity values than measurements with double ring infiltrometers, and S2001 yields on average 55% higher values. Note that these results are from the reference sites where only 7 texture measurements are taken into account. In Table 4.9 and Table 4.10 a comparison is shown between the results of the PTFs and the double ring infiltrometer tests for both numbering schemes. Judging from the averages, the S2001 PTF is more accurate for both schemes. However, for both PTFs and for both numbering schemes, the correlation coefficient with the measurements is negative. We therefore conclude that the use of PTFs is not recommended for prediction of hydraulic conductivity of a retention basin.

Table 4.9: Double ring and PTF results from the watershed (numbering scheme 1)

Retention basin	Texture	Measured conductivity (mm/hr)	S1986	S2001	**Measured average**	**S1986 average**	**S2001 average**
7	Sandy (clay) loam	12, 17	6, 8	8, 11	**14**	**7**	**9**
11	Sandy loam	6	13	23	**6**	**13**	**23**
16	Loamy sand	7, 8, 16	25, 31	39, 49	**10**	**28**	**44**
18	Sandy (clay) loam	23, 59	6, 12, 14	6, 18, 24	**41**	**10**	**16**
21	Loamy sand, Sandy clay loam	21, 44	18, 32, 34	15, 25, 41	**33**	**28**	**27**
173	Silty clay, Sandy clay loam	13, 17, 39, 43, 49, 63, 77	3, 4	5, 6	**43**	**3**	**5**
Averages					**24.5**	**14.9**	**21**
Correlation coefficient with measurements						**-0.30**	**-0.49**

Table 4.10: Double ring and PTF results from the watershed (numbering scheme 2)

Retention basin	Texture	Measured (mm/hr)	**Measured average (mm/hr)**	**S1986 (mm/hr)**	**S2001 (mm/hr)**
7	Loamy sand	12, 17	**14**	**46**	**91**
11	Loamy sand	6	**6**	**26**	**39**
16	Loamy sand	7, 8, 16	**10**	**25**	**39**
18	Loamy sand	23, 59	**41**	**18**	**30**

21	Loam	21, 44	**33**	**10**	**4**
29	Sandy clay loam	8, 13	**11**	**6**	**6**
173	Clay loam	13, 17, 39, 43, 49, 63	**43**	**3**	**4**
211	Sandy loam	55, 60	**58**	**10**	**12**
235	Sandy clay loam	47, 48	**48**	**6**	**8**
Averages			**29**	**17**	**26**
Correlation coefficient with measurements				**-0.56**	**-0.51**

Type of retention basin

As can be seen in Table 4.11, retention basins at spread dams have on average a higher conductivity than at check dams. Possibly, coarser material is deposited in the retention basins of the spread dams than in those of the check dams. Since the water has less tendency to stagnate in front of a spread dam, the small particles settle less. Spread dams are rarer than check dams in the study area, therefore only 5 spread dams were measured. This is deemed too little to assess the influence of retention basin type on the hydraulic conductivity.

Table 4.11: Hydraulic conductivity (mm/hr) for different types of retention basins

Type of retention basin	Check dam	Spread dam
Average	60	102
Standard deviation	44	72
Number of occurences	37	5

Wadi

In *Table 4.12*, the hydraulic conductivity per wadi is given. The number of measurements per wadi is less than 7 for all but one wadi. Therefore, this data is not used in further analysis.

Table 4.12: Hydraulic conductivity (mm/hr) per wadi

Wadi	Hallouf	Nkim	Mouggour	Battoum	Nagueb	Lahimmar	Moussa
Average	56	140	78	15	63	42	59
Standard deviation	46	37	62	-	46	15	35
Number of occurences	21	4	3	1	6	4	3

Location

This matter has previously been discussed on page 48. The results of *Figure 4.11* and the standard deviation and number of measurements for each area are represented in *Table 4.13*.

Table 4.13: Hydraulic conductivity (mm/hr) according to location within the watershed

Location	Upstream	Center	Downstream
Average (mm/hr)	29	105	56
Standard deviation	26	58	22

Number	12	14	16

Clogging

The effect of clogging on hydraulic conductivity can be assessed from *Table 4.14*. The highest conductivity values occur for the basins with the highest degree of clogging. The lowest hydraulic conductivity was found in basins with an intermediate degree of clogging. Thus, no monotonic trend can be observed. Remember from *Figure 4.7* that basins with every degree of clogging occur throughout the watershed. The category 'little or no clogging' should yield values close to the river bed conductivity. Note that the river bed may either consist of fluvial deposits or bedrock. In the case of bedrock, it is likely that clogging increases the hydraulic conductivity. In the case of fluvial deposits, clogging was expected to decrease the hydraulic conductivity. Based on this table, we conclude that on average, clogging does not decrease the hydraulic conductivity of a retention basin. A possible explanation for high conductivity for sites with much clogging is that sites with eolian deposits have a higher clogging rate. Therefore, basins with much clogging would consist of coarser material.

Table 4.14: Hydraulic conductivity (mm/hr) for different degrees of clogging

Clogging	**Little or no clogging: more than 80% initial volume left**	**Intermediate clogging: 20-80% of initial volume left**	**Much clogging: less than 20% initial volume left**
Average	68	56	83
Standard deviation	49	45	57
Number	8	24	10

Occupation

Table 4.15 shows the hydraulic conductivity measured for different occupations. There are only 3 measurements performed on retention basins with 'other cultivation'. Sites with arboriculture, usually olive trees, have on average a higher conductivity. The difference with sites with no occupation is deemed too small to be significant.

Table 4.15: Hydraulic conductivity (mm/hr) for different occupations

Occupation	**No occupation**	**Arboriculture**	**Other cultivation**
Average (mm/hr)	64	74	28
Standard deviation	45	58	16
Number	25	14	3

Conclusion

The only characteristic which has a demonstrated significant impact on the hydraulic conductivity is the location in the watershed. Which wadi it is situated in has an impact, but in general the number of measurements per wadi is too small to use this to estimate non-measured sites. Using a PTF is not a suitable predictor for hydraulic conductivity either. Therefore, for the estimation of non-measured sites, only absolute spatial information (coordinates of the site) is taken into account.

Comparison with field observations and evapotranspiration rate

The average reference evapotranspiration rate (ET0) at the city of Médenine for September for the period of 1978-2009 equals 5.8 mm/day (FAO) or 177 mm/month. This value is based on the Penman-Monteith equation and is slightly higher than the value from Ouessar (2007) (*Table 2.6*). September is the beginning of the raining season and therefore has both the potential for runoff and the highest possible ET0. The open water evaporation is arbitrarily set to 1.3 times the ET0, putting the average actual evapotranspiration in September at 7.6mm/day, or 0.3mm/hr. This is 0.5% of the average measured hydraulic conductivity in the retention basins, and 5.4% of the lowest measured hydraulic conductivity. Therefore, the evapotranspiration is not important compared to the hydraulic conductivity. Note that the infiltration rate is higher than the hydraulic conductivity because of the pressure of the water column, and initially because the wetting front is shallow (eqation (4.2)). These percentages are therefore an overestimation of the ratio between ETact and the infiltration rate.

With the estimated average infiltration rate of 65 mm/hr and the estimated actual evapotranspiration of 0.3 mm/hr, it would take about 23 h to infiltrate a water column of 1.5 m, and only 7 mm would be lost to open water evaporation. However, according to field observations (personal communication, Ouessar, M.), the infiltration of the water at a retention basin takes days to weeks. Therefore, it is plausible that there is often a deeper layer which obstructs flow.

Conductivity estimation at non-measured sites

All results are presented in Appendix D.

Determination of p

Figure 4.12 shows the average deviation of the conductivity estimates. For this particular validation subset, a power parameter of 1.8 works best and yields an average absolute deviation (equation (3.4)) of 18mm/hr.

Comparison of the three methods

The average used for the entire watershed was 68mm/hr. The averages used for the 3 averages estimation were 29, 112 and 56mm/hr. These averages are based on the validation subset of the measured sites. Working with 3 averages yields a lower average deviation than working with only 1 average for the entire watershed. Therefore, working with 3 averages is better. Also, no matter the power parameter value, spatial interpolation always yields a lower average deviation than working with 3 averages.

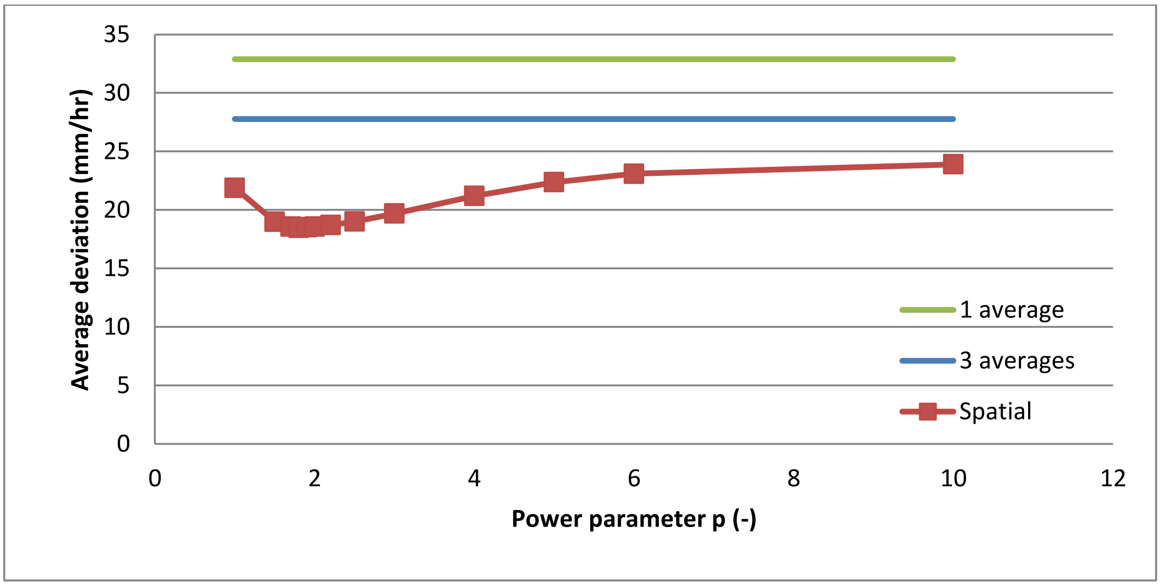

Figure 4.12: Average deviation of estimates from measured values for three methods

Final method

The conductivity values of non-measured retention basins are determined using the method of Shepard (1968) (Equations (3.2) & (3.3)), using a power parameter p of 1.8 (-) and taking into account all 42 measured sites. The results are presented in Table 4.16 and in Appendix D. This method was also applied for points situated at the periphery of the watershed which have measured retention basins situated only to one side. This means that we are not interpolating but extrapolating data. Since the extrapolated values were close (<20% deviation) to the upstream and downstream averages, the extrapolated values are used.

Table 4.16: Calculated values from the spatial interpolation, using all measured locations for the interpolation, where p=1.8. Underscored values are measured values.

Site number	Interpolated hydraulic conductivity (mm/hr)	Site number	Interpolated hydraulic conductivity (mm/hr)	Site number	Interpolated hydraulic conductivity (mm/hr)
1	<u>33</u>	101	39	201	85
2	37	102	25	202	84
3	37	103	<u>22</u>	203	79
4	35	104	<u>18</u>	204	93
5	36	105	45	205	119
6	14	106	30	206	<u>191</u>
7	<u>14</u>	107	28	207	155
8	15	108	28	208	109
9	37	109	28	209	101
10	35	110	28	210	80
11	<u>34</u>	111	<u>28</u>	211	<u>90</u>
12	31	112	46	212	94
13	29	113	48	213	100
14	28	114	55	214	111
15	27	115	80	215	103
16	<u>10</u>	116	84	216	99
17	15	117	86	217	92
18	<u>41</u>	118	89	218	85
19	24	119	<u>102</u>	219	79
20	36	120	100	220	74
21	<u>33</u>	121	95	221	69
22	37	122	91	222	65
23	42	123	88	223	55
24	47	124	77	224	51
25	60	125	70	225	<u>46</u>
26	64	126	67	226	44
27	69	127	64	227	54
28	10	128	62	228	72
29	<u>11</u>	129	61	229	90
30	23	130	27	230	106
31	26	131	24	231	131
32	41	132	23	232	<u>146</u>
33	41	133	22	233	74
34	48	134	20	234	72
35	48	135	18	235	<u>48</u>
36	50	136	17	236	55
37	53	137	16	237	60
38	108	138	<u>15</u>	238	<u>60</u>
39	106	139	22	239	<u>32</u>

40	106	140	27	240	49
41	105	141	31	241	58
42	102	142	35	242	65
43	107	143	38	243	75
44	108	144	41	244	77
45	110	145	43	245	74
46	111	146	46	246	69
47	111	147	48	247	61
48	109	148	49	248	103
49	135	149	58	249	180
50	128	150	60	250	191
51	131	151	63	251	66
52	133	152	67	252	64
53	132	153	69	253	62
54	130	154	79	254	61
55	115	155	61	255	65
56	123	156	53	256	83
57	114	157	37	257	93
58	107	158	67	258	87
59	107	159	65	259	75
60	103	160	63	260	62
61	101	161	49	261	43
62	97	162	50	262	43
63	90	163	72	263	44
64	108	164	70	264	44
65	107	165	51	265	49
66	108	166	54	266	48
67	48	167	59	267	47
68	47	168	63	268	46
69	46	169	66	269	46
70	44	170	63	270	30
71	38	171	61	271	31
72	33	172	49	272	31
73	21	173	43	273	32
74	39	174	83	274	33
75	38	175	78	275	33
76	44	176	77	276	33
77	46	177	83	277	34
78	50	178	95	278	33
79	63	179	119	279	35
80	73	180	139	280	23
81	80	181	145	281	28
82	73	182	147	282	44
83	88	183	138	283	49
84	85	184	133		
85	80	185	123		
86	80	186	99		
87	76	187	95		

88	74	188	96
89	73	189	96
90	74	190	60
91	75	191	61
92	77	192	63
93	78	193	65
94	69	194	66
95	66	195	69
96	60	196	71
97	59	197	77
98	62	198	81
99	63	199	86
100	65	200	92

Chapter 5. Conclusions

- The results of this research do not lead to the conclusion that a significant amount of water is lost to evaporation due to the stagnation of water. In a retention basin with average hydraulic conductivity, only 0.5% of the water is lost to open water evaporation. However, lower layers might cause a stagnation of the water, thereby increasing the amount of water lost to evapotranspiration (page 51).
- Equations were derived to describe the infiltration rate as a function of water level in the case of one layer and in case of a layer underlain by a layer with a lower conductivity (page 37).
- In order to correct a measurement made with a 18/30cm diameter double ring infiltrometer to that which would be measured by a 32/51cm set, a factor of 0.65 (-) was established (page 40).
- The average hydraulic conductivity in the watershed is 114mm/hr for uncorrected measurements, 99mm/hr for measurements corrected for the water height present during the infiltration experiment, and 65mm/hr for measurements corrected for water height and partially corrected for lateral flow (*Table 4.2*).
- The hydraulic conductivity is highest in the center of the water shed (105mm/hr), intermediate in the downstream area (56mm/hr), and lowest in the upstream area (29mm/hr) (Figure 4.11, Appendix C).
- The amount of clogging does not have a significant impact on the hydraulic conductivity (Table 4.14).
- The double ring infiltrometer measures in the right order of magnitude when values are corrected for water level and partly corrected for lateral flow (Table 4.8).
- The 4.5cm disk infiltrometer overestimates the hydraulic conductivity (Table 4.8).
- The Saxton et al. (1986) pedotransfer function works best for predicting hydraulic conductivity on the reference sites (Table 4.8), but the Schaap et al. (2001) pedotransfer function works best in the watershed. However, both functions show a negative correlation with hydraulic conductivity measurements in the watershed. (Table 4.9 and Table 4.10)
- Spatial interpolation works better for the prediction of hydraulic conductivity values at non-measured sites than using pedotransfer functions, or using the retention basin characteristics.
- Hydraulic conductivity was estimated at non-measured sites using the method of Shephard (1968) and a power parameter of 1.8 (-). Based on validation with a subset, the average absolute deviation of these estimations is 18 mm/hr. This means that on average, the estimations of hydraulic conductivity are 18 mm/hr lower or higher than the actual values. (Appendix D and E).

Chapter 6. Recommendations

- For recommended literature, refer to Appendix F.
- Runoff modeling for the watershed should be done in PCRaster with a cell size of 50m. It should be combined with a SWAP or MODFLOW model in order to be able to dynamically model the influence of water depth and wetting front depth.
- More information on the hydraulic conductivity of layers under retention basins is needed.
- For verification of an infiltration or runoff model, it is very important to have reliable observations of the water level in a retention basin versus time for a real event.
- This research tried to correlate retention basin characteristics with hydraulic conductivity individually. This yielded limited success. Using principal component analysis, correlating the characteristics to the hydraulic conductivity may be successful.
- Since the floor of the retention basin is not flat, the water depth varies throughout the retention basin, which means the infiltration rate also is not constant throughout the basin. However, this does not mean a higher hydraulic head is present at the sediment surface where the basin is deep, since the hydraulic head is equal to the water level in both cases. Therefore, care should be taken when applying the equations derived for this research. When taking into account the varying depth of the retention basin, both the water level and the layer thickness should be changed. If the variation of the depth of the retention basin is taken into account, it could be done by approximating the retention basin as a combination of retention basins with a different depth.

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Appendix A. Selection of measurement sites

N°	N° Site	Wadi	X	Y	Z (m)	First 53 selected?	Recharge well?	Measured?*
1	1	Hallouf	607169	3683177		yes	no	yes
2	7	Hallouf	610709	3684482	392	yes	no	yes
3	8	Hallouf	610588	3684312	408	yes	no	**no**
4	11	Hallouf	612689	3686931	310	yes	no	yes
5	12	Hallouf	612795	3686006	330	yes	no	**no**
6	16	Hallouf	613604	3686809	255	**no**	no	detailed
7	18	Hallouf	614658	3687181	240	yes	no	yes
8	21	Hallouf	614979	3687963	233	yes	no	yes
9	29	Hallouf	613768	3686743	251	yes	no	yes
10	35	Hallouf	611926	3687894	294	yes	no	**no**
11	41	Hallouf	622840	3694828	146	yes	no	detailed
12	49	Nkim	620142	3693985	153	yes	no	yes
13	52	Nkim	620667	3693804	154	yes	no	yes
14	58	Hallouf	620099	3692364	166	**no**	**yes**	yes
15	60	Hallouf	619138	3691620	175	**no**	**yes**	**no**
16	68	Hallouf	627069	3698344	115	yes	no	yes
17	69	Hallouf	627165	3698608	116	yes	no	yes
18	73	Hallouf	627462	3699318	106	**no**	**yes**	yes
19	74	Hallouf	627692	3699431	106	**no**	**yes**	yes
20	76	Hallouf	628327	3699711	99.9	**no**	**yes**	yes
21	77	Hallouf	628920	3700252	96.3	**no**	**yes**	yes
22	78	Hallouf	628957	3700648	95.3	**no**	**yes**	yes
23	80	Hallouf	629432	3703299	79.7	yes	no	yes
24	83	Hallouf	629969	3704030	82.6	yes	no	detailed
25	93	Hallouf	630648	3705945	65.7	yes	no	yes
26	97	Hallouf	631187	3707273	62.9	yes	no	yes
27	103	Nagueb	611844	3693961	231	yes	no	detailed
28	104	Nagueb	612119	3694102	230	yes	**yes**	yes
29	111	Mouggour	610574	3691912	269	yes	no	yes
30	115	Nkim	613390	3687879	261	yes	no	**no**
31	119	Nkim	613756	3687852	256	yes	no	yes
32	121	Nkim	613836	3687997	252	yes	no	**no**
33	128	Nkim	614153	3688760	238	yes	no	**no**
34	132	Battoum	610031	3690375	293	yes	no	**no**
35	138	Battoum	610312	3690835	280	yes	no	yes
36	143	Battoum	611564	3691390	253	yes	no	**no**
37	150	Battoum	613000	3691431	228	yes	no	**no**
38	166	Nagueb	626294	3698406	110	yes	no	**no**
39	167	Nagueb	626052	3698191	110	yes	no	**no**
40	171	Nagueb	624650	3698234	127	yes	no	**no**
41	173	Nagueb	624258	3697923	125	**no**	**yes**	detailed
42	174	Nagueb	624065	3697763	127	yes	no	yes
43	175	Nagueb	623924	3697713	122	yes	no	**no**
44	182	Mouggour	622031	3697046	138	yes	no	yes
45	184	Nagueb	621645	3697097	139	yes	no	**no**
46	188	Mouggour	620507	3696202	151	yes	no	**no**
47	193	Nkim	614521	3689435	226	yes	no	**no**
48	204	Battoum	614614	3690870	208	yes	no	**no**
49	206	Nkim	615991	3691725	200	yes	no	yes
50	211	Mouggour	614783	3693135	206	yes	no	yes
51	225	Nagueb	618654	3697053	159	yes	no	yes
52	226	Nagueb	618515	3697109	158	yes	no	**no**
53	232	Nagueb	617361	3696338	172	yes	no	yes
54	235	Lahimmar	615160	3696533	184	yes	no	yes
55	238	Lahimmar	616014	3696944	171	yes	no	yes
56	239	Lahimmar	618319	3697234	161	yes	no	yes
57	240	Lahimmar	618014	3697506	165	yes	no	yes
58	250	Hallouf	625340	3695154	134	yes	no	yes
59	254	Moussa	629619	3707672	65	yes	no	yes
60	257	Moussa	629433	3707006	67	yes	no	yes
61	278	Bo enla	612610	3685707	294	yes	no	**no**
62	280	Moussa	628586	3706024	81.6	yes	no	yes

Explanation

*yes	Measured
no	Selected, but too rocky or vegetated for measurement with double ring infiltrometer
detailed	Many measurements on one site

First, several random selections were made. One of the selections was chosen because it had a good spread over the study area and several other characteristics. These characteristics were: condition, occupation (none, arboriculture, other) and type (check dam or spread dam). 53 sites were thus selected. An additional 8 sites were selected because they include a recharge well. One more site (site 16) was added for more detailed measurement. 4 sites which had already been selected were also chosen for for detailed measurement. Of these 62 sites, 20 sites were too rocky to measure with the double ring infiltrometers.

Appendix B. Data from Halifa (2014)

Altitude

Site number	Wadi	X	Y	Z	Distance in northeast direction of site 1 (km)
1	Hallouf	607169	3683177		0
2	Hallouf	607103	3684268	399	0.727138785
3	Hallouf	607424	3684322	389	0.991340001
5	Hallouf	608801	3683362	417	1.288481016
4	Hallouf	609816	3682756		1.590474917
8	Hallouf	610588	3684312	408	3.229180526
7	Hallouf	610709	3684482	392	3.434553635
6	Hallouf	610778	3684508	389	3.502059545
277	Bo enla	612714	3685458	294	5.551940609
278	Bo enla	612610	3685707	294	5.650753223
276	Bo enla	612673	3685664	286	5.665961996
275	Bo enla	612671	3685713	285	5.69867401
274	Bo enla	612701	3685770	284	5.759915238
273	Bo enla	612737	3685886	281	5.866597462
9	Hallouf	612168	3686496	327	5.886504252
272	Bo enla	612760	3685953	278	5.929807508
12	Hallouf	612795	3686006	330	5.991855915
271	Bo enla	612795	3686009	275	5.993948599
270	Bo enla	612866	3686053	272	6.075515543
13	Hallouf	612899	3686180	327	6.187759027
14	Hallouf	612921	3686304	323	6.29006388
15	Hallouf	612967	3686368	320	6.367680179
10	Hallouf	612572	3686880	311	6.443800639
11	Hallouf	612689	3686931	310	6.562977109
35	Hallouf	611926	3687894	294	6.699132345
34	Hallouf	611997	3687896	292	6.750768486
161	Nkim	612034	3687972		6.830659769
130	Battoum	609789	3690286	297	6.913407999
36	Hallouf	612145	3687990	290	6.921913057
162	Nkim	612188	3687976		6.942455934
131	Battoum	609977	3690360	294	7.096926654
28	Hallouf	613600	3686802		7.123917622
16	Hallouf	613604	3686809	255	7.131666785
132	Battoum	610031	3690375	293	7.145134763
156	Nkim	612515	3687993		7.186091665

17	Hallouf	613768	3686743	252	7.203214938
29	Hallouf	613768	3686743	251	7.203214938
37	Hallouf	612525	3688022	273	7.213635474
133	Battoum	610106	3690405	292	7.218712227
134	Battoum	610129	3690517	288	7.315448892
106	Mouggour	609410	3691311	284	7.394583893
135	Battoum	610200	3690573	286	7.405011645
136	Battoum	610240	3690619	284	7.465897767
155	Nkim	612983	3687963		7.49710599
30	Hallouf	614223	3686746	250	7.53198101
19	Hallouf	614227	3686747	247	7.535551169
160	Nkim	613044	3687961		7.539048841
137	Battoum	610308	3690693	284	7.566373382
159	Nkim	613106	3687951		7.576090201
31	Hallouf	614298	3686778	244	7.608136958
158	Nkim	613157	3687954		7.614464534
164	Nkim	613214	3687947		7.650086115
138	Battoum	610312	3690835	280	7.671646325
163	Nkim	613260	3687937		7.675786193
154	Nkim	613388	3687877		7.724766612
115	Nkim	613390	3687879	261	7.727594966
116	Nkim	613465	3687806	262	7.729799497
117	Nkim	613519	3687763	261	7.738135234
118	Nkim	613580	3687738	260	7.764111024
107	Mouggour	609832	3691515	276	7.832835707
108	Mouggour	609900	3691571	274	7.920257511
119	Nkim	613756	3687852	256	7.969554443
120	Nkim	613805	3687916	255	8.049358677
139	Battoum	610606	3691116	272	8.077943728
121	Nkim	613836	3687997	252	8.12823851
33	Hallouf	614651	3687186	241	8.145526477
18	Hallouf	614658	3687181	240	8.147080062
32	Hallouf	614669	3687174	242	8.150118346
109	Mouggour	610180	3691673	270	8.186959497
122	Nkim	613876	3688048	250	8.192515078
123	Nkim	613895	3688091	248	8.236207795
140	Battoum	610831	3691214	268	8.304405117
124	Nkim	613968	3688244	246	8.395534967
110	Mouggour	610429	3691811	269	8.458507507
141	Battoum	611113	3691239	264	8.517801357
261	Battoum	611812	3690575	256	8.526927691

125	Nkim	614035	3688394	243	8.548504218
262	Battoum	611836	3690620	256	8.575907531
263	Battoum	611866	3690647	254	8.616181429
111	Mouggour	610574	3691912	269	8.631615243
126	Nkim	614069	3688494	241	8.642898297
264	Battoum	611882	3690673	255	8.645969937
157	Nkim	614790	3687823		8.688819823
22	Hallouf	614794	3687821	234	8.690293414
127	Nkim	614104	3688611	240	8.749954541
142	Battoum	611418	3691336	254	8.799225848
128	Nkim	614153	3688760	238	8.889475525
269	Bo enla	612024	3690885	248	8.896920393
21	Hallouf	614979	3687963	233	8.921923945
143	Battoum	611564	3691390	253	8.93944116
268	Battoum	612063	3690963	246	8.980016868
129	Nkim	614264	3688834	236	9.020461998
267	Battoum	612120	3691052	246	9.083554068
20	Hallouf	615163	3688092	229	9.143783357
144	Battoum	611801	3691494	248	9.178869237
266	Battoum	612200	3691117	244	9.185929646
190	Nkim	614388	3688989	223	9.217593922
265	Battoum	612255	3691121	247	9.227156971
145	Battoum	611922	3691475	247	9.249303856
191	Nkim	614361	3689074	229	9.258103123
146	Battoum	612102	3691435	245	9.345778951
23	Hallouf	615349	3688245	229	9.383806221
147	Battoum	612208	3691453	245	9.43249256
192	Nkim	614409	3689298	227	9.449728603
148	Battoum	612301	3691444	245	9.490806006
24	Hallouf	615456	3688421	224	9.583193048
193	Nkim	614521	3689435	226	9.625704204
194	Nkim	614601	3689542	225	9.757834953
149	Battoum	612842	3691369	232	9.814525064
195	Nkim	614650	3689673	223	9.884834571
150	Battoum	613000	3691431	228	9.969294323
101	Hallouf	610795	3693572	235	9.990016853
196	Nkim	614810	3689728	221	10.03722055
151	Battoum	613165	3691411	227	10.07039526
25	Hallouf	615767	3688863	221	10.11430359
152	Battoum	613359	3691333	225	10.15052914
153	Battoum	613475	3691266	225	10.18404458

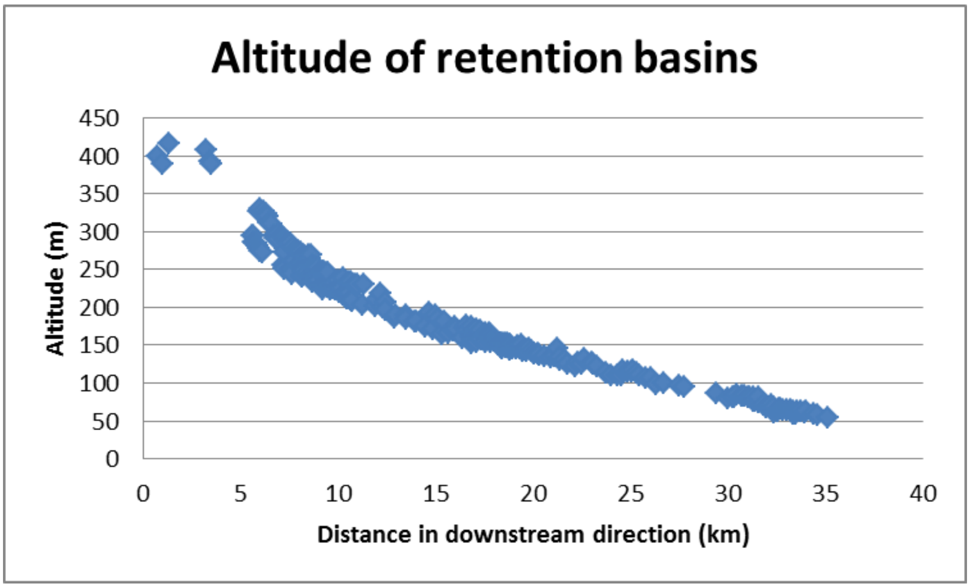
197	Nkim	614882	3689939	217	10.23686152
112	Mouggour	612237	3692570	239	10.25630551
26	Hallouf	615931	3688979	217	10.31273963
198	Nkim	614880	3690126	214	10.36714175
203	Battoum	613988	3691139	212	10.45389588
199	Nkim	614896	3690307	211	10.50607193
113	Mouggour	612479	3692694	234	10.51339749
201	Nkim	614286	3690984	217	10.55364479
27	Hallouf	616158	3689100	217	10.55984013
202	Battoum	614208	3691094	218	10.57675694
200	Nkim	614954	3690465	210	10.65862656
114	Mouggour	612869	3692540	234	10.67320569
204	Battoum	614614	3690870	208	10.70428353
102	Nagueb	611745	3693886	230	10.86988598
103	Nagueb	611844	3693961	231	10.99239078
205	Nkim	615243	3690952	203	11.20708181
104	Nagueb	612119	3694102	230	11.28377834
63	Hallouf	617259	3689842	202	11.86670698
210	Mouggour	614254	3693002	210	11.96941223
105	Nagueb	613091	3694407	219	12.17416122
206	Nkim	615991	3691725	200	12.2825669
211	Mouggour	614783	3693135	206	12.43420837
62	Hallouf	617629	3690293	197	12.44627862
207	Nkim	616546	3691996	186	12.86701951
212	Mouggour	615294	3693399	190	12.98040835
213	Mouggour	615920	3693461	189	13.46357091
247	Lahimmar	613577	3695769	185	13.49675416
208	Nkim	617243	3692784	182	13.91691955
61	Hallouf	618794	3691302	181	13.98506657
60	Hallouf	619138	3691620	175	14.45340506
234	Nagueb	615606	3695473	193	14.68429576
209	Nkim	617917	3693396	171	14.82635563
233	Nagueb	615874	3695630	189	14.98342065
235	Lahimmar	615160	3696533	184	15.14057661
59	Hallouf	619737	3692210	165	15.29414942
236	Lahimmar	615408	3696750	181	15.46875642
58	Hallouf	620099	3692364	166	15.66137951
248	Mouggour	618647	3694181	170	15.89753169
237	Lahimmar	615913	3696935	174	15.95125923
238	Lahimmar	616014	3696944	171	16.02756981
57	Hallouf	620565	3692877	159	16.3529852

232	Nagueb	617361	3696338	172	16.52701756
246	Lahimmar	616386	3697377	176	16.5976081
231	Nagueb	617594	3696288	170	16.65387568
245	Lahimmar	616680	3697376	175	16.80023117
54	Nkim	620349	3693756	161	16.8108391
49	Nkim	620142	3693985	153	16.82311157
56	Hallouf	620855	3693317	158	16.86738687
230	Nagueb	617818	3696384	167	16.87907348
53	Nkim	620563	3693768	157	16.97235739
229	Nagueb	618013	3696366	166	17.00257522
52	Nkim	620667	3693804	154	17.07195319
244	Lahimmar	617017	3697444	171	17.08268281
228	Nagueb	618144	3696545	164	17.22212472
51	Nkim	620819	3693897	159	17.24571943
243	Lahimmar	617303	3697417	170	17.26158411
50	Nkim	620956	3693952	157	17.38223942
227	Nagueb	618291	3696785	162	17.49647331
55	Hallouf	621619	3693532	154	17.56615436
242	Lahimmar	617617	3697547	166	17.57316444
241	Lahimmar	617820	3697559	166	17.72287308
186	Mouggour	620016	3695521	155	17.81312415
240	Lahimmar	618014	3697506	165	17.81976366
239	Lahimmar	618319	3697234	161	17.83730679
226	Nagueb	618515	3697109	158	17.88474013
225	Nagueb	618654	3697053	159	17.94190365
224	Nagueb	618909	3696888	156	18.0026668
223	Nagueb	619088	3696935	155	18.16167897
47	Nkim	621882	3694211	150	18.22707478
48	Nkim	622161	3694072	150	18.33114324
46	Nkim	621865	3694380	148	18.33245319
64	Hallouf	622327	3693964	152	18.3757787
45	Nkim	621971	3694390	146	18.41553116
187	Mouggour	620393	3696031	152	18.44014473
222	Nagueb	619466	3697128	153	18.56441379
44	Hallouf	622188	3694482	147	18.63542552
188	Mouggour	620507	3696202	151	18.64160909
221	Nagueb	619619	3697158	152	18.69319919
220	Nagueb	619804	3697143	151	18.81251153
43	Hallouf	622328	3694603	144	18.82017632
189	Mouggour	620597	3696386	150	18.83527815
219	Nagueb	619998	3697064	149	18.89281035

218	Nagueb	620226	3696889	146	18.92921031
217	Nagueb	620528	3696914	146	19.15998779
65	Hallouf	623314	3694142	149	19.21143073
41	Hallouf	622840	3694828	146	19.34470374
216	Nagueb	620790	3696918	145	19.34787814
66	Hallouf	623467	3694295	151	19.42774922
215	Nagueb	620920	3696935	143	19.45180052
40	Hallouf	623051	3694864	144	19.52156499
214	Nagueb	621176	3696973	144	19.65975893
39	Hallouf	623236	3694884	142	19.66868796
38	Hallouf	623428	3694899	146	19.81747396
185	Nagueb	621452	3697086	142	19.93497109
183	Mouggour	621762	3696940	139	20.05178648
184	Nagueb	621645	3697097	139	20.0794827
181	Nagueb	621908	3697083	139	20.2561467
182	Mouggour	622031	3697046	138	20.31740908
180	Nagueb	622167	3697256	136	20.56184735
179	Nagueb	622403	3697501	134	20.90193763
249	Hallouf	625131	3694977	135	21.10332941
42	Hallouf	622599	3697758	146	21.22208956
178	Nagueb	622857	3697713	131	21.37363337
250	Hallouf	625340	3695154	134	21.37678187
177	Nagueb	623240	3697670	130	21.61582998
176	Nagueb	623515	3697625	126	21.78016465
175	Nagueb	623924	3697713	122	22.13360493
174	Nagueb	624065	3697763	127	22.26928556
173	Nagueb	624258	3697923	125	22.519116
172	Nagueb	624347	3698006	132	22.64077506
171	Nagueb	624650	3698234	127	23.0167738
170	Nagueb	624811	3698197	125	23.10596844
169	Nagueb	625145	3698067	122	23.25422992
168	Nagueb	625848	3698053	113	23.74886026
167	Nagueb	626052	3698191	110	23.99142406
166	Nagueb	626294	3698406	110	24.31484399
165	Nagueb	626448	3698587	110	24.55137629
67	Hallouf	626926	3698200	117	24.6269186
68	Hallouf	627069	3698344	115	24.82980282
69	Hallouf	627165	3698608	116	25.08196438
70	Hallouf	627170	3698697	117	25.14727947
71	Hallouf	627199	3698928	113	25.32844107
72	Hallouf	627235	3699061	110	25.44669287

73	Hallouf	627462	3699318	106	25.7885051
74	Hallouf	627692	3699431	106	26.03247634
75	Hallouf	627971	3699561	98.2	26.32356518
76	Hallouf	628327	3699711	99.9	26.68406937
77	Hallouf	628920	3700252	96.3	27.48649327
78	Hallouf	628957	3700648	95.3	27.78784205
79	Hallouf	629394	3702495	87.1	29.38770602
80	Hallouf	629432	3703299	79.7	29.97740704
82	Hallouf	629993	3703101	81.1	30.2396491
81	Hallouf	629709	3703552	82.1	30.35230945
283	Moussa	628122	3705283	85	30.44924464
282	Moussa	628403	3705420	83.8	30.74435988
83	Hallouf	629969	3704030	82.6	30.8728329
84	Hallouf	629934	3704280	81.4	31.02336486
281	Moussa	628516	3705821	82.1	31.10877199
85	Hallouf	630045	3704550	76.1	31.29203787
280	Moussa	628586	3706024	81.6	31.30233437
86	Hallouf	630192	3704521	76.3	31.37628514
87	Hallouf	630312	3704688	74.1	31.57899512
279	Moussa	628766	3706259	80.9	31.59601033
88	Hallouf	630508	3704845	70.5	31.82878415
260	Moussa	628953	3706591	67.9	31.96364326
89	Hallouf	630697	3705100	68.4	32.14242084
259	Moussa	629086	3706758	68.4	32.1759319
90	Hallouf	630625	3705325	71	32.24936047
91	Hallouf	630553	3705542	60.7	32.35092199
258	Moussa	629256	3706887	68	32.38715814
92	Hallouf	630616	3705770	62.6	32.55624421
257	Moussa	629433	3707006	67	32.59619155
93	Hallouf	630648	3705945	65.7	32.70229312
256	Moussa	629477	3707240	64	32.79366847
255	Moussa	629519	3707508	65	33.01407612
254	Moussa	629619	3707672	65	33.20111518
94	Hallouf	630871	3706597	59.2	33.32039952
253	Moussa	629727	3707798	63	33.36667826
95	Hallouf	630992	3706722	59	33.49434447
252	Moussa	629899	3707859	63	33.53079157
251	Moussa	630126	3707898	62	33.71787892
96	Hallouf	631197	3707124	61.9	33.92345718
97	Hallouf	631187	3707273	62.9	34.02174434
98	Hallouf	631297	3707718	59	34.41442245

99	Hallouf	631417	3707875	58	34.6103361
100	Hallouf	631623	3708385	53.7	35.11714206



Clogging

Site number		Z	Nom de l'Oued	Distance in northeast direction of site 1 (km)	Hi	Clogging
1	1		Hallouf	0	2.9	0.344827586
2	2	399	Hallouf	0.727138785	0.9	0
3	3	389	Hallouf	0.991340001	1	0.2
5	4	417	Hallouf	1.288481016	1.9	0.473684211
4	5		Hallouf	1.590474917	1.85	0.27027027
8	6	408	Hallouf	3.229180526	0.65	0
7	7	392	Hallouf	3.434553635	2	0
6	8	389	Hallouf	3.502059545	2	0.1
277	9	294	Bo enla	5.551940609	1.95	0.128205128
278	10	294	Bo enla	5.650753223	1.6	0
276	11	286	Bo enla	5.665961996	2.2	0.227272727
275	12	285	Bo enla	5.69867401	1.2	0.5
274	13	284	Bo enla	5.759915238	3	0.133333333
273	14	281	Bo enla	5.866597462	0.4	0
9	15	327	Hallouf	5.886504252	0.9	0.222222222
272	16	278	Bo enla	5.929807508	1.9	0.421052632
12	17	330	Hallouf	5.991855915	2.2	0.227272727
271	18	275	Bo enla	5.993948599	2.05	0.097560976
270	19	272	Bo enla	6.075515543	2	0
13	20	327	Hallouf	6.187759027	2	0.15
14	21	323	Hallouf	6.29006388	2	0.3

15	22	320	Hallouf	6.367680179	2.15	0.046511628
10	23	311	Hallouf	6.443800639	2.05	0.195121951
11	24	310	Hallouf	6.562977109	1.95	0.102564103
35	25	294	Hallouf	6.699132345	2	0
34	26	292	Hallouf	6.750768486	2.05	0.048780488
161	27		Nkim	6.830659769	2	0.075
130	28	297	Battoum	6.913407999	1.15	0.217391304
36	29	290	Hallouf	6.921913057	1.05	0
162	30		Nkim	6.942455934	0.75	0
28	32		Hallouf	7.123917622	0.98	0.867346939
132	34	293	Battoum	7.145134763	0.65	0.923076923
156	35		Nkim	7.186091665	0.75	0
17	36	252	Hallouf	7.203214938	0.9	0
29	37	251	Hallouf	7.203214938	0.88	0
37	38	273	Hallouf	7.213635474	1.1	0.454545455
133	39	292	Battoum	7.218712227	1	0.2
134	40	288	Battoum	7.315448892	1.03	0.242718447
106	41	284	Mouggour	7.394583893	1.07	0
135	42	286	Battoum	7.405011645	1.75	0.142857143
136	43	284	Battoum	7.465897767	1.08	0.555555556
155	44		Nkim	7.49710599	1.1	0.545454545
30	45	250	Hallouf	7.53198101	0.8	0.625
19	46	247	Hallouf	7.535551169	1.42	0.457746479
160	47		Nkim	7.539048841	1	0.5
137	48	284	Battoum	7.566373382	1.3	0.769230769
159	49		Nkim	7.576090201	0.95	0.368421053
31	50	244	Hallouf	7.608136958	0.32	1
158	51		Nkim	7.614464534	0.8	0.375
164	52		Nkim	7.650086115	0.78	1
138	53	280	Battoum	7.671646325	0.45	0.777777778
163	54		Nkim	7.675786193	0.12	0
154	55		Nkim	7.724766612	1.05	0
115	56	261	Nkim	7.727594966	0.97	0
116	57	262	Nkim	7.729799497	0.75	0
117	58	261	Nkim	7.738135234	1.22	0.163934426
118	59	260	Nkim	7.764111024	0.92	0
107	60	276	Mouggour	7.832835707	1.17	0
108	61	274	Mouggour	7.920257511	0.92	0.706521739
119	62	256	Nkim	7.969554443	0.87	0
120	63	255	Nkim	8.049358677	1.37	0
139	64	272	Battoum	8.077943728	0.75	0

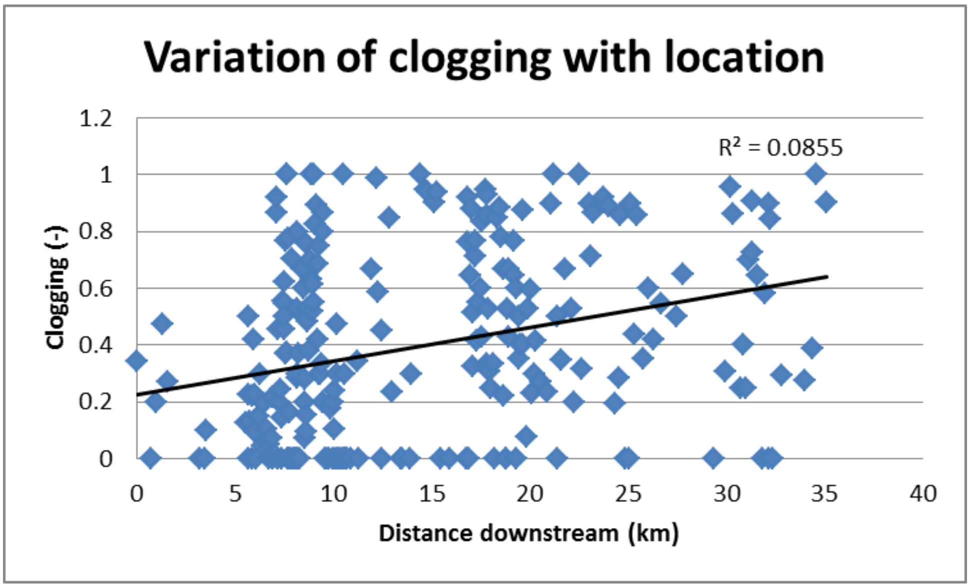
121	65	252	Nkim	8.12823851	1.62	0
33	66	241	Hallouf	8.145526477	1.87	0
18	67	240	Hallouf	8.147080062	1.05	0.285714286
32	68	242	Hallouf	8.150118346	1	0.3
109	69	270	Mouggour	8.186959497	0.85	0.529411765
122	70	250	Nkim	8.192515078	1	0.8
123	71	248	Nkim	8.236207795	0.95	0.368421053
140	72	268	Battoum	8.304405117	0.4	0
124	73	246	Nkim	8.395534967	0.9	0.666666667
110	74	269	Mouggour	8.458507507	1	0.6
141	75	264	Battoum	8.517801357	1	0.5
261	76	256	Battoum	8.526927691	2	0.2
125	77	243	Nkim	8.548504218	1.6	0.28125
262	78	256	Battoum	8.575907531	2	0.075
263	79	254	Battoum	8.616181429	1.55	0.096774194
111	80	269	Mouggour	8.631615243	1.95	0.153846154
126	81	241	Nkim	8.642898297	1.45	0.75862069
264	82	255	Battoum	8.645969937	1	0.5
157	83		Nkim	8.688819823	0.95	0.526315789
22	84	234	Hallouf	8.690293414	1.55	0.483870968
127	85	240	Nkim	8.749954541	1.05	0.380952381
142	86	254	Battoum	8.799225848	1	0.7
128	87	238	Nkim	8.889475525	1	1
269	88	248	Bo enla	8.896920393	0.95	0.631578947
21	89	233	Hallouf	8.921923945	1.3	0.615384615
143	90	253	Battoum	8.93944116	1.25	0.52
268	91	246	Battoum	8.980016868	1.175	0.553191489
129	92	236	Nkim	9.020461998	1	1
267	93	246	Battoum	9.083554068	0.725	0.827586207
20	94	229	Hallouf	9.143783357	0.95	0.894736842
266	96	244	Battoum	9.185929646	0.95	0.684210526
190	97	223	Nkim	9.217593922	0.95	0.421052632
145	99	247	Battoum	9.249303856	1	0.3
191	100	229	Nkim	9.258103123	0.4	0.75
146	101	245	Battoum	9.345778951	1	0.3
23	102	229	Hallouf	9.383806221	0.9	0.333333333
147	103	245	Battoum	9.43249256	0.5	0.8
192	104	227	Nkim	9.449728603	1.5	0.2
148	105	245	Battoum	9.490806006	1.5	0.866666667
24	106	224	Hallouf	9.583193048	1.8	0
193	107	226	Nkim	9.625704204	1.575	0

194	108	225	Nkim	9.757834953	1.825	0
149	109	232	Battoum	9.814525064	0.225	0
195	110	223	Nkim	9.884834571	1.425	0.175438596
150	111	228	Battoum	9.969294323	1.5	0.2
101	112	235	Hallouf	9.990016853	1	0
196	113	221	Nkim	10.03722055	1.05	0.238095238
151	114	227	Battoum	10.07039526	1.45	0.103448276
25	115	221	Hallouf	10.11430359	0.75	0
152	116	225	Battoum	10.15052914	0.5	0.3
153	117	225	Battoum	10.18404458	0.95	0.473684211
197	118	217	Nkim	10.23686152	0.8	0
112	119	239	Mouggour	10.25630551	0.45	0
198	121	214	Nkim	10.36714175	0.125	0
199	123	211	Nkim	10.50607193	0.25	0
113	124	234	Mouggour	10.51339749	0.4	1
201	125	217	Nkim	10.55364479	0.5	0.3
27	126	217	Hallouf	10.55984013	0.45	0
202	127	218	Battoum	10.57675694	1.475	0
200	128	210	Nkim	10.65862656	0.6	0
114	129	234	Mouggour	10.67320569	0.05	0
204	130	208	Battoum	10.70428353	0.2	0
102	131	230	Nagueb	10.86988598	0.1	0
205	133	203	Nkim	11.20708181	0.875	0.342857143
48	135	150	Nkim	11.29086033	0.45	0
210	137	210	Mouggour	11.96941223	0.9	0.666666667
105	138	219	Nagueb	12.17416122	0.76	0.986842105
206	139	200	Nkim	12.2825669	0.85	0.588235294
211	140	206	Mouggour	12.43420837	0.725	0
62	141	197	Hallouf	12.44627862	1.325	0.452830189
207	142	186	Nkim	12.86701951	0.825	0.848484848
212	143	190	Mouggour	12.98040835	0.85	0.235294118
213	144	189	Mouggour	13.46357091	0.75	0
247	145	185	Lahimmar	13.49675416	0.95	0
208	146	182	Nkim	13.91691955	0.8	0
61	147	181	Hallouf	13.98506657	0.675	0.296296296
60	148	175	Hallouf	14.45340506	0.5	1
234	149	193	Nagueb	14.68429576	1	0.95
209	150	171	Nkim	14.82635563	0.8	0.9375
235	152	184	Lahimmar	15.14057661	1.05	0.904761905
59	153	165	Hallouf	15.29414942	0.8	0.9375
236	154	181	Lahimmar	15.46875642	0.65	0

237	157	174	Lahimmar	15.95125923	1.025	0
245	163	175	Lahimmar	16.80023117	1	0
54	164	161	Nkim	16.8108391	0.15	0
49	165	153	Nkim	16.82311157	0.975	0.923076923
56	166	158	Hallouf	16.86738687	0.525	0.761904762
230	167	167	Nagueb	16.87907348	0.1	0
53	168	157	Nkim	16.97235739	0.775	0.64516129
229	169	166	Nagueb	17.00257522	0.85	0.882352941
52	170	154	Nkim	17.07195319	1.7	0.323529412
244	171	171	Lahimmar	17.08268281	0.975	0.512820513
228	172	164	Nagueb	17.22212472	1.05	0.714285714
51	173	159	Nkim	17.24571943	0.975	0.769230769
243	174	170	Lahimmar	17.26158411	1.45	0.413793103
50	175	157	Nkim	17.38223942	1	0.55
227	176	162	Nagueb	17.49647331	1	0.6
55	177	154	Hallouf	17.56615436	0.6	0.833333333
242	178	166	Lahimmar	17.57316444	1.4	0.428571429
241	179	166	Lahimmar	17.72287308	1	0.95
186	180	155	Mouggour	17.81312415	1.4	0.857142857
240	181	165	Lahimmar	17.81976366	0.7	0.928571429
239	182	161	Lahimmar	17.83730679	1.5	0.333333333
226	183	158	Nagueb	17.88474013	1.7	0.529411765
225	184	159	Nagueb	17.94190365	1.3	0.307692308
224	185	156	Nagueb	18.0026668	1.4	0.25
223	186	155	Nagueb	18.16167897	0.9	0.333333333
47	187	150	Nkim	18.22707478	0.8	0
46	188	148	Nkim	18.33245319	1.175	0.85106383
187	191	152	Mouggour	18.44014473	0.79	0.886075949
222	192	153	Nagueb	18.56441379	1.025	0.780487805
44	193	147	Hallouf	18.63542552	0.6	0.666666667
188	194	151	Mouggour	18.64160909	1.35	0.222222222
220	196	151	Nagueb	18.81251153	0.725	0
43	197	144	Hallouf	18.82017632	1.1	0
189	198	150	Mouggour	18.83527815	0.95	0.526315789
219	199	149	Nagueb	18.89281035	0.7	0.428571429
218	200	146	Nagueb	18.92921031	0.45	0.666666667
217	201	146	Nagueb	19.15998779	0.65	0.769230769
65	202	149	Hallouf	19.21143073	0.775	0.64516129
41	203	146	Hallouf	19.34470374	1	0.6
216	204	145	Nagueb	19.34787814	0.575	0
66	205	151	Hallouf	19.42774922	0.85	0.352941176

215	206	143	Nagueb	19.45180052	0.6	0.5
40	207	144	Hallouf	19.52156499	0.75	0.4
214	208	144	Nagueb	19.65975893	0.5	0.4
39	209	142	Hallouf	19.66868796	1.025	0.87804878
38	210	146	Hallouf	19.81747396	1.9	0.078947368
185	211	142	Nagueb	19.93497109	0.95	0.526315789
183	212	139	Mouggour	20.05178648	0.925	0.594594595
184	213	139	Nagueb	20.0794827	1.3	0.230769231
181	214	139	Nagueb	20.2561467	1.5	0.3
182	215	138	Mouggour	20.31740908	1.2	0.416666667
180	216	136	Nagueb	20.56184735	1.1	0.272727273
179	217	134	Nagueb	20.90193763	1.5	0.233333333
249	218	135	Hallouf	21.10332941	0.5	0.9
42	219	146	Hallouf	21.22208956	0.5	1
178	220	131	Nagueb	21.37363337	1	0.5
250	221	134	Hallouf	21.37678187	1	0
177	222	130	Nagueb	21.61582998	1	0.35
176	223	126	Nagueb	21.78016465	0.9	0.666666667
175	224	122	Nagueb	22.13360493	0.95	0.526315789
174	225	127	Nagueb	22.26928556	2	0.2
173	226	125	Nagueb	22.519116	0.15	1
172	227	132	Nagueb	22.64077506	0.95	0.315789474
171	228	127	Nagueb	23.0167738	0.5	0.9
170	229	125	Nagueb	23.10596844	0.35	0.714285714
169	230	122	Nagueb	23.25422992	0.75	0.866666667
168	231	113	Nagueb	23.74886026	0.65	0.923076923
167	232	110	Nagueb	23.99142406	0.9	0.888888889
166	233	110	Nagueb	24.31484399	1.55	0.193548387
165	234	110	Nagueb	24.55137629	1.4	0.285714286
67	235	117	Hallouf	24.6269186	1.4	0.857142857
68	236	115	Hallouf	24.82980282	0.9	0
69	237	116	Hallouf	25.08196438	1	0
70	238	117	Hallouf	25.14727947	1	0.9
71	239	113	Hallouf	25.32844107	0.8	0.4375
72	240	110	Hallouf	25.44669287	0.7	0.857142857
73	241	106	Hallouf	25.7885051	0.85	0.352941176
74	242	106	Hallouf	26.03247634	1	0.6
75	243	98.2	Hallouf	26.32356518	0.95	0.421052632
76	244	99.9	Hallouf	26.68406937	1.1	0.545454545
77	245	96.3	Hallouf	27.48649327	1	0.5
78	246	95.3	Hallouf	27.78784205	1	0.65

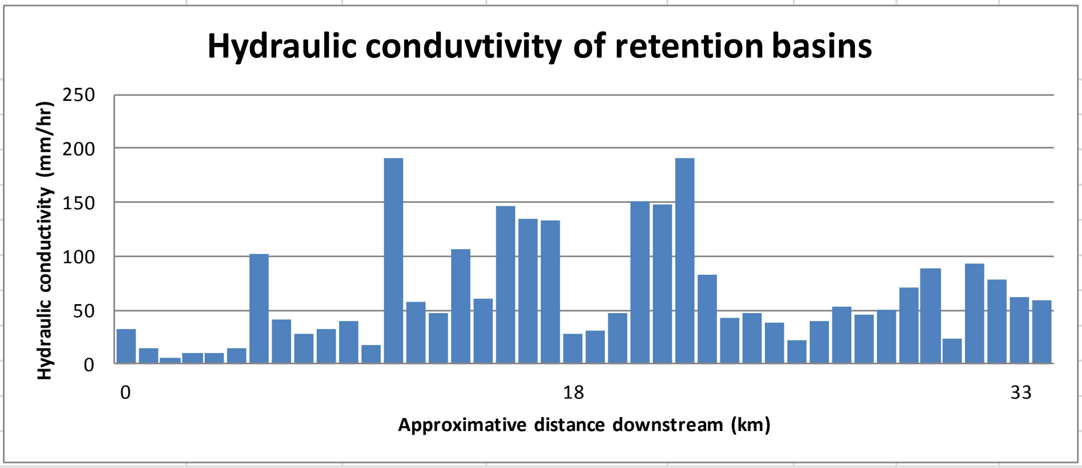
79	247	87.1	Hallouf	29.38770602	1.6	0
80	248	79.7	Hallouf	29.97740704	1.3	0.307692308
82	249	81.1	Hallouf	30.2396491	1.15	0.956521739
81	250	82.1	Hallouf	30.35230945	1.1	0.863636364
282	252	83.8	Moussa	30.74435988	1.6	0.25
83	253	82.6	Hallouf	30.8728329	1	0.4
84	254	81.4	Hallouf	31.02336486	2.4	0.25
281	255	82.1	Moussa	31.10877199	1	0.7
85	256	76.1	Hallouf	31.29203787	1.1	0.727272727
280	257	81.6	Moussa	31.30233437	1.1	0.909090909
87	259	74.1	Hallouf	31.57899512	1.55	0.64516129
88	261	70.5	Hallouf	31.82878415	0.4	0
260	262	67.9	Moussa	31.96364326	0.6	0.583333333
89	263	68.4	Hallouf	32.14242084	0.5	0
259	264	68.4	Moussa	32.1759319	0.5	0.9
90	265	71	Hallouf	32.24936047	0.65	0.846153846
91	266	60.7	Hallouf	32.35092199	0.5	0
256	271	64	Moussa	32.79366847	1.2	0.291666667
97	280	62.9	Hallouf	34.02174434	0.9	0.277777778
98	281	59	Hallouf	34.41442245	0.9	0.388888889
99	282	58	Hallouf	34.6103361	0.9	1
100	283	53.7	Hallouf	35.11714206	1.05	0.904761905



Hydraulic conductivity

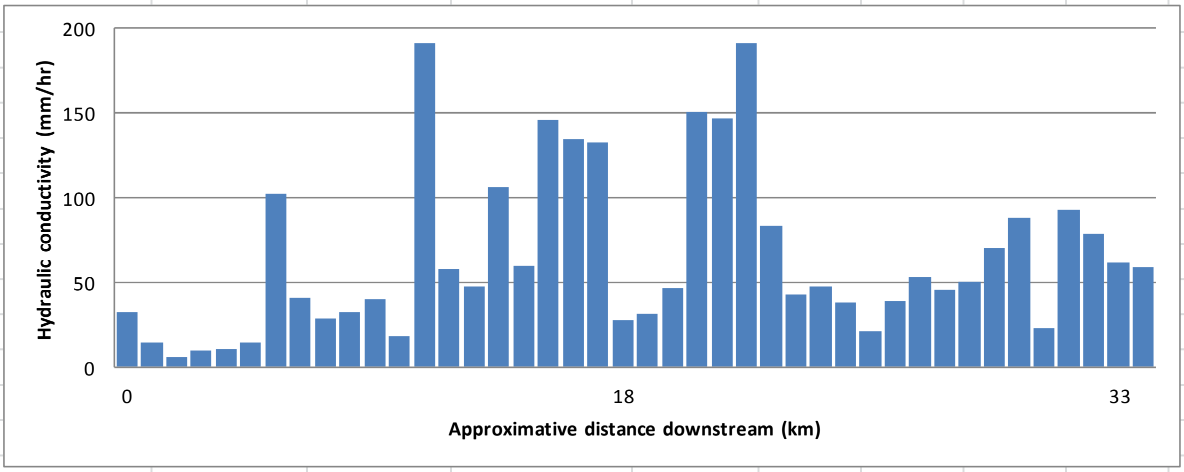
Site number	Z	Nom de l'Oued	Distance in northeast direction of site 1 (km)	Value to be used with correction for water height and correction for ring size, average per site (mm/hr)
1		Hallouf	0	33
7	392	Hallouf	3.434553635	14
11	310	Hallouf	6.562977109	6
16	255	Hallouf	7.131666785	10
29	251	Hallouf	7.203214938	11
138	280	Battoum	7.671646325	15
119	256	Nkim	7.969554443	102
18	240	Hallouf	8.147080062	41
111	269	Mouggour	8.631615243	28
21	233	Hallouf	8.921923945	33
103	231	Nagueb	10.99239078	40
104	230	Nagueb	11.28377834	18
206	200	Nkim	12.2825669	191
211	206	Mouggour	12.43420837	58
235	184	Lahimmar	15.14057661	48
58	166	Hallouf	15.66137951	107
238	171	Lahimmar	16.02756981	60
232	172	Nagueb	16.52701756	146
49	153	Nkim	16.82311157	135
52	154	Nkim	17.07195319	133
240	165	Lahimmar	17.81976366	27
239	161	Lahimmar	17.83730679	32
225	159	Nagueb	17.94190365	46
41	146	Hallouf	19.34470374	150
182	138	Mouggour	20.31740908	147
250	134	Hallouf	21.37678187	191
174	127	Nagueb	22.26928556	83
173	125	Nagueb	22.519116	43
68	115	Hallouf	24.82980282	47
69	116	Hallouf	25.08196438	38
73	106	Hallouf	25.7885051	21
74	106	Hallouf	26.03247634	39
76	99.9	Hallouf	26.68406937	54
77	96.3	Hallouf	27.48649327	46
78	95.3	Hallouf	27.78784205	50
80	79.7	Hallouf	29.97740704	70
83	82.6	Hallouf	30.8728329	88

280	81.6	Moussa	31.30233437	23
257	67	Moussa	32.59619155	93
93	65.7	Hallouf	32.70229312	78
254	65	Moussa	33.20111518	61
97	62.9	Hallouf	34.02174434	59



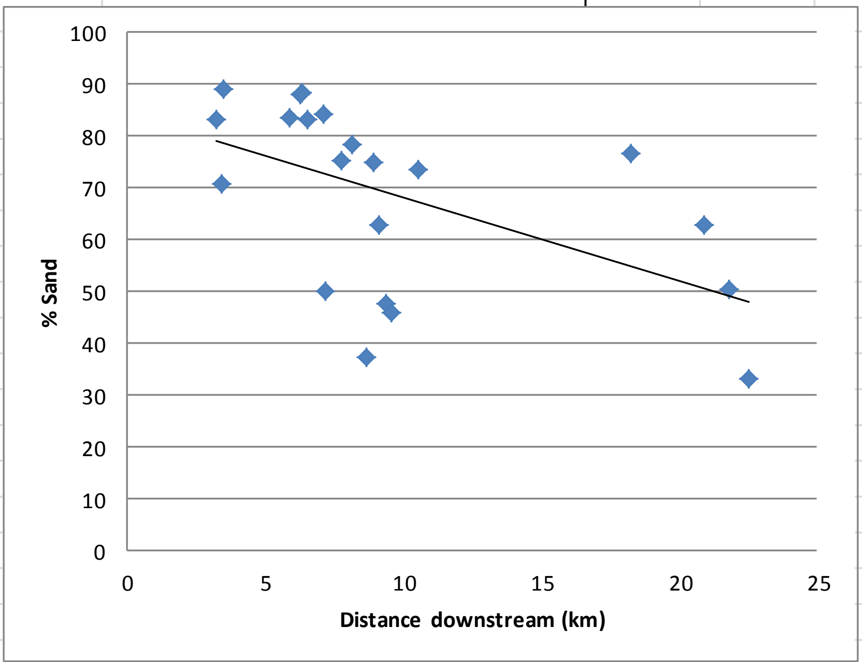
Upstream:	site 1 until 104	0-11.8km	average: 29mm/hr
Centre:	site 206 until 2	11.8-21.8km	average: 105mm/hr
Downstream:	174 until 97	>21.8km	average: 56mm/hr

	Upstream	Center	Downstream
Average (mm/hr)	29	105	56
Standard deviation	26	58	22
Number	12	14	16



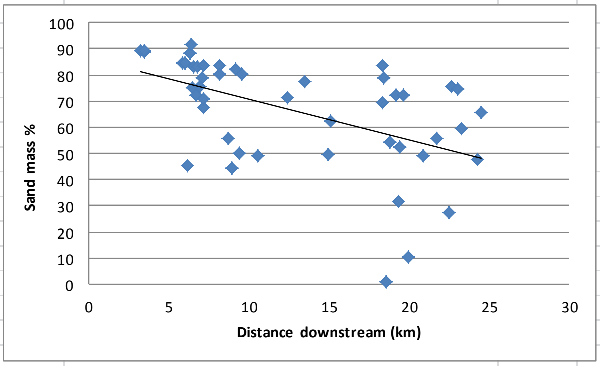
Texture scheme 1 spatial

Site number	Distance in northeast direction of site 1 (km)	Corrected sand mass %
6	3.502059545	89
7	3.434553635	71
8	3.229180526	83
9	5.886504252	83
11	6.562977109	83
14	6.29006388	88
15	6.367680179	88
16	7.131666785	84
17	7.203214938	50
18	8.147080062	78
20	9.143783357	63
21	8.921923945	75
22	8.690293414	37
23	9.383806221	48
24	9.583193048	46
27	10.55984013	74
47	18.22707478	77
117	7.738135234	75
173	22.519116	33
176	21.78016465	50
179	20.90193763	63



Texture scheme 2 spatial

Site number	Distance in northeast direction of site 1 (km)	Sand mass % corrected
8	3.229180526	89
7	3.434553635	89
6	3.502059545	89
9	5.886504252	85
12	5.991855915	85
13	6.187759027	45
14	6.29006388	88
15	6.367680179	91
10	6.443800639	75
11	6.562977109	83
35	6.699132345	72
34	6.750768486	83
36	6.921913057	75
28	7.123917622	79
16	7.131666785	84
17	7.203214938	67
29	7.203214938	71
18	8.147080062	83
32	8.150118346	80
22	8.690293414	56
21	8.921923945	44
20	9.143783357	82
23	9.383806221	50
24	9.583193048	80
27	10.55984013	49
211	12.43420837	71
213	13.46357091	77
233	14.98342065	50
235	15.14057661	62
48	18.33114324	70
46	18.33245319	84
45	18.41553116	79
222	18.56441379	1
220	18.81251153	54
217	19.15998779	72
216	19.34787814	32
215	19.45180052	52
214	19.65975893	72
185	19.93497109	10
179	20.90193763	49
176	21.78016465	56
173	22.519116	28
172	22.64077506	75
171	23.0167738	75
169	23.25422992	59
166	24.31484399	48
165	24.55137629	65



Appendix C. Measurement results watersheds and reference sites

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	Site	Measurement	Remarks	GPS coordinate X	GPS coordinate Y	Infiltration rate at the end of every repetition (mm/hr)	Infiltration capacity at the end of last repetition (mm/hr)	Average of the site, no correction (mm/hr)	Correction for water height: intercept (mm/hr)	Correction for water height: slope (hr^-1)	Correction for water height useable?	Value to be used with correction for water height (mm/hr)	Average of the site, corrected for water height (mm/hr)	Value to be used with correction for water height, and correction for ring size: *.65 (mm/hr)	Value to be used with correction for water height and correction for ring size, average per site (mm/hr)
1	**1**	1		607137	3782719	72, 60 , 60	60	54.5	52	0.11		52	50.5	33.8	**33**
	1	2		607154	3782710		49		49	0.004		49		31.85	
2	**7**	1		610649	3684014		38	33	18	0.27		18	22	11.7	**14**
	7	2		610639	3683999	42, 31, 28, 26	28		26	0.025		26		16.9	
3	**11**	1	Water level inner ring decrease	612644	3686472	12	12	12	9	0.021		9	9	5.85	**6**
4	**16**	1		613537	3686361	19	19	18.33333333	10	0.094		10	15.33333333	6.5	**10**
	16	2		613526	3686346	12, 12	12		2.9	0.066	no	12		7.8	
	16	3		613499	3686361	24, 24	24		13	0.11	**no**	24		15.6	
5	**18**	1		614591	3686712	87, 93	93	69	90.3	0.032		90.3	62.65	58.695	**41**
	18	2		614618	3686698	40, 45	45		35	0.11		35		22.75	
6	**21**	2		614909	3687502	52, 60	52	62	68	0.23		68	50	44.2	**33**
	21	1		614912	3687513	88, 72	72		32	0.23		32		20.8	
7	**29**	1		613702	3686298	13, 12, 13	13	16.5	-1.8	0.1	no	13	16.5	8.45	**11**
	29	2		613700	3686288	18, 25, 20	20		20.6	0	no	20		13	
8	**41**	1		622785	3694375	144, 144	144	250	134	0.13		134	231.375	87.1	**150**
	41	2		622764	3694376	240, 199	199		173	0.42		173		112.45	
	41	5		622742	3694346	248, 250	250		232	0.38		232		150.8	
	41	6		622739	3694370	320, 300, 300	300		272	0.44		272		176.8	
	41	7		622701	3694370	160, 160	160		146	0.33		146		94.9	
	41	3		622779	3694400	312, 300	300		300	0		300		195	
	41	4		622785	3694353	450, 450	450		424	0.48		424		275.6	
	41	8		622704	3694336	200, 197, 198	197		170	0.46		170		110.5	
9	**49**	2	Soil around outer ring is wet at	620290	3693297	360, 300, 275	275	287.5	215	0.82		215	207	139.75	**135**
	49	1		620291	3693295	300, 300, 400	300		199	0.81		199		129.35	
10	**52**	2		620605	3693340	367, 324, 318, 336	330	237	288	0.47		288	204.5	187.2	**133**
	52	1		620605	3693355	164, 144, 132	144		121	0.21		121		78.65	
11	**58**	1		620050	3691895	171, 180	180	183.5	140	0.43		140	164	91	**107**
	58	2		620056	3691890	180, 187	187		188	0.02		188		122.2	
12	**68**	2		626997	3697845	85, 85	85	77.5	60	0.21		60	72.5	39	**47**
	68	1		627011	3697877	87, 70	70		85	0.12		85		55.25	
13	**69**	1		627113	3698129	80, 87	85	61.5	87.9	0.015		87.9	58.45	57.135	**38**
	69	2		627115	3698106	38, 38	38		29	0.083		29		18.85	
14	**73**	1		627400	3698835	28, 28	28	33	21	0.053	**no**	28	33	18.2	**21**
	73	2		627391	3698821	36, 38	38		14.2	0.16	**no**	38		24.7	
15	**74**	1		627692	3699431	46, 43	44	74.33333333	27	0.28	**no**	44	60.33333333	28.6	**39**
	74	2		627610	3698964		99		67	0.32		67		43.55	
	74	3		627590	3698952		80		70	0.13		70		45.5	
16	***76***	*1*	Large set (32/51cm diameter)	*628860*	*3699783*		*72*	*97.5*	*48*	*0.31*		*48*	*82.5*	*31.2*	**54**
	76	2		628895	3699768		123		117	0.078		117		76.05	
17	**77**	1		628890	3700166	180, 144, 126, 130	130	82	115	0.14		115	71	74.75	**46**
	77	2		628901	3700179	37, 34	34		27	0.08		27		17.55	
18	**78**	1		628766	3700555	51, 39, 40	39	89.5	35	0.058		35	77	22.75	**50**
	78	2		628783	3700538	140, 140, 140	140		119	0.25		119		77.35	
19	**80**	1		629383	3702829	155, 150	150	136	107	0.55		107	108	69.55	**70**
	80	2		6299380	3702811	122, 122	122		109	0.16		109		70.85	
20	**83**	8		629960	3703569	248, 250	250	152.875	201	0.78		201	136.125	130.65	**88**
	83	5		629953	3703444	80, 88	80		62	0.33		62		40.3	
	83	1		629947	3703562	102, 96	96		87	0.19		87		56.55	
	83	3		629959	3703488	90, 90	90		82	0.075		82		53.3	
	83	7		629928	3703555	180, 180	180		180	0		180		117	
	83	4		629936	3703499	300, 264	264		235	0.62		235		152.75	
	83	6		629972	3703495	57, 58	58		52	0.049		52		33.8	
	83	2		629939	3703574	217, 205, 192	205		190	0.086		190		123.5	

21	**93**	1		630611	3705473	24, 27	27	159	21	0.039		21	120.5	13.65	**78**
	93	2		630606	3705455	325, 291, 248	291		220	0.64		220		143	
22	**97**	1		631126	3706803	134, 138 , 132 , 140	136	107.5	114	0.42		114	90.5	74.1	**59**
	97	2	Water level inner ring decrease	631145	3606768	66, 76, 82	79		67	0.16		67		43.55	
23	**103**	1		611778	3693498	49, 60	60	70.6	38	0.21		38	61.6	24.7	**40**
	103	2		611784	3693503	56, 60	60		46	0.11		46		29.9	
	103	5		611779	3693479	72, 64	64		61	0.077		61		39.65	
	103	4		611776	3693491	84, 90	87		81	0.11		81		52.65	
	103	3		611784	3693492	80, 84	82		62	0.19	**no**	82		53.3	
24	**104**	1		612052	3693639	29, 30	30	27	*37*	*-0.06*	no	30	28	19.5	**18**
	104	2		612040	3693631	30, 24	24		26	0.032		26		16.9	
25	**111**	1		610521	3691441	30, 30	30	48	*36*	*-0.04*	no	30	43.5	19.5	**28**
	111	2		610501	3691429	67, 66	66		57	0.13		57		37.05	
26	**119**	2		613755	3687444	153, 147, 144, 138	147	154.5	137	0.27		137	157	89.05	**102**
	119	1		613757	3687451	162, 180	162		177	0.14		177		115.05	
27	**138**	1		610259	3690369	42, 46	46	46	23	0.26		23	23	14.95	**15**
28	**173**	1		624195	3697444	36, 34	34	73.42857143	25	0.084		25	66.14285714	16.25	**43**
	173	2		624179	3697427	71, 69	69		60	0.14		60		39	
	173	5		624182	3697403	90, 87	87		76	0.19		76		49.4	
	173	7		624156	3697384	101.102	102		97	0.075		97		63.05	
	173	4		624162	3697406	66, 66	66		66	0.027		66		42.9	
	173	3		624207	3697433	28, 24	24		20	0.034		20		13	
	173	6		624193	3697455	150, 132	132		119	0.2		119		77.35	
29	**174**	1		623998	3697303	173, 177, 180	180	142.5	170	0.14		170	128	110.5	**83**
	174	2		624008	3697288	107,104,105	105		86	0.21		86		55.9	
30	**182**	2		621958	3696550	126, 122, 124	124	227	112	0.14		112	226.5	72.8	**147**
	182	1		621947	3696580	368, 330, 350	330		341	0.17		341		221.65	
31	**206**	2		613938	3690685	334, 330	330	350	287	0.64		287	294.5	186.55	**191**
	206	1		615936	3691263	410, 370	370		302	0.91		302		196.3	
32	**211**	1		614726	3692655	42, 41, 41	41	68.5	93	0.091		93	89	60.45	**58**
	211	2	Water level inner ring decrease	614714	3692670	114, 102, 96, 96	96		85	0.17		85		55.25	
33	**225**	1		618595	3696601	96, 84	84	78	61	0.2	no	84	71.5	54.6	**46**
	225	2		618589	3696605	76, 72	72		59	0.19		59		38.35	
34	**232**	1		617292	3695892	**205, 217, 224**	224	250.5	205	0.26		205	225	133.25	**146**
	232	2		617292	3695894	300, 292, 277	277		245	0.5		245		159.25	
35	**235**	1		615099	3696064	104, 96	96	92	73	0.3		73	73.5	47.45	**48**
	235	2		615089	3696069	98, 88	88		74	0.23		74		48.1	
36	**238**	1		615949	3696486	112, 108	108	108	92	0.19		92	92	59.8	**60**
37	**239**	2		618254	3646773	44, 52	52	56	37	0.17		37	48.5	24.05	**32**
	239	1		618260	3696775	54, 60	60		60	0.01		60		39	
38	**240**	1		617961	3697048	50, 60	60	60	42	0.16		42	42	27.3	**27**
39	**250**	2		624261	3694667	380, 390, 351	350	315	307	0.7		307	294	199.55	**191**
	250	1		625256	3694687	280,300	280		281	0.28		281		182.65	
40	***254***	*1*	Large set (32/51cm diameter)	*629570*	*3707195*	*34, 38*	*38*	*114*	*32*	*0.058*		*32*	*94.5*	*20.8*	**61**
	254	2		629551	3707167	240 , 210, 190, 160, 156	190		157	0.056		157		102.05	
41	**257**	1		629376	3706354	120, 106	106	149	93	0.24		93	142.5	60.45	**93**
	257	2		629369	3706518	198, 192, 192	192		192	0.18		192		124.8	
42	***280***	*1*	Large set (32/51cm diameter)	*628532*	*3705561*	*40, 33*	*35*	*44.5*	*25*	*0.13*		*25*	*35*	*16.25*	**23**
	280	2		628545	3705538	88, 54	54		45	0.11		45		29.25	

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Site	GPS coordinate X	GPS coordinate Y	Value to be used with correction for water height and correction for ring size, average per site (mm/hr)
1	607169	3683177	33
7	610709	3684482	14
11	612689	3686931	6
16	613604	3686809	10
18	614658	3687181	41
21	614979	3687963	33
29	613768	3686743	11
41	622840	3694828	150
49	620142	3693985	135
52	620667	3693804	133
58	620099	3692364	107
68	627069	3698344	47
69	627165	3698608	38
73	627462	3699318	21
74	627692	3699431	39
76	628327	3699711	54
77	628920	3700252	46
78	628957	3700648	50
80	629432	3703299	70
83	629969	3704030	88
93	630648	3705945	78
97	631187	3707273	59
103	611844	3693961	40
104	612119	3694102	18
111	610574	3691912	28
119	613756	3687852	102
138	610312	3690835	15
173	624258	3697923	43
174	624065	3697763	83
182	622031	3697046	147
206	615991	3691725	191
211	614783	3693135	58
225	618654	3697053	46
232	617361	3696338	146
235	615160	3696533	48
238	616014	3696944	60
239	618319	3697234	32
240	618014	3697506	27
250	625340	3695154	191
254	629619	3707672	61
257	629433	3707006	93
280	628586	3706024	23

Disk infiltrometer IRA

Site	Test	Pressure (cm)	Remarks	C1 constant (cm/s)	Average	Texture	A (correction parameter) (-)	K (cm/s)	K (mm/hr)	Arithmetic average (mm/hr)
	1	-2		0.0091			1.73	0.005260116	**189**	
	2	-2		0.008	1.20E-02		1.73	0.004624277	**166**	
	3	-2		0.0253			1.73	0.014624277	**526**	
1	4	-5		0.0024		Sand	0.64	0.00375	**135**	**253**
	5	-5		0.0087	4.60E-03		0.64	0.01359375	**489**	
	6	-5		0.0027			0.64	0.00421875	**152**	
	7	-2		0.0055			1.73	0.003179191	**114**	
	1	-2	Sand added to	0.0039			1.73	0.002254335	**81**	
	2	-2	Sand added to	0.0068	4.13E-03		1.73	0.003930636	**142**	
	3	-2	Sand added to	0.0017		Sand	1.73	0.000982659	**35**	
2	4	-5	Sand added to	0.0019			0.64	0.00296875	**107**	**232**
	5	-5	Sand added to	0.004	6.73E-03		0.64	0.00625	**225**	
	6	-5	Sand added to	0.0143			0.64	0.02234375	**804**	
	1	*-2*	*Too much sana*	*-0.0013*			*2.43*	*-0.000534979*	*-19*	
	2	-2		0.003	7.35E-03		2.43	0.001234568	**44**	
3	3	-2		0.0117		Loamy sand	2.43	0.004814815	**173**	**122**
	4	-5		0.0038			1.61	0.002360248	**85**	
	5	-5		0.0051	5.83E-03		1.61	0.003167702	**114**	
	6	-5	Sand added to	0.0086			1.61	0.005341615	**192**	

Large&Small, IRA; watershed

Site	Measurement	GPS coordinate X	GPS coordinate Y	Size	Remarks	Infiltration capacity corrected for water height (mm/hr)	Factor per pair	Factor per site		
	1	652734	3707789	LARGE		**43**	*0.37*			
	2	652732	3707791	SMALL		**115**				
	3	652725	3707774	LARGE		**59**	*0.54*			
IRA 1	4	652724	3707778	SMALL		**110**		*0.59*		
	5	652723	3707790	LARGE		**76**	*1.04*			
	6	652726	3707793	SMALL		**73**				
	7	652726	3707772	LARGE		**57**	*0.58*			
	8	652726	3707775	SMALL		**99**				
	1	652338	3708007	LARGE		**103**	*0.60*		Weighted site average	0.65
IRA 2	2	652330	3708003	SMALL		**172**		*0.57*	Average of every pair	0.63
	3	652335	3707990	LARGE		**65**	*0.54*		Average large/average small	0.60
	4	652334	3707995	SMALL		**121**				
	1	652445	3707917	LARGE	very little water added to outer ring	**130**	*1.48*			
	2	652446	3707912	SMALL	very little water added to outer ring, 2nd	**88**				
IRA 3	3	652439	3707923	LARGE		**84**	*1.02*	*0.98*		
	4	652448	3707923	SMALL		**82**				
	5	652440	3707917	LARGE		**7.2**	*0.13*			
	6	652437	3707917	SMALL	intercept of water height-infiltration rate	**55**				
Watershed 76	1	628860	3699783	LARGE		**61**	*0.52*	*0.52*		
	2	628895	3699768	SMALL		**117**				
Watershed 254	1	629570	3707195	LARGE		**32**	*0.20*	*0.20*		
	2	629551	3707167	SMALL		**157**				
Watershed 280	1	628532	3705561	LARGE		**25**	*0.56*	*0.56*		
	2	628545	3705538	SMALL		**45**				

Double ring, corrected, IRA

Site	Measurement	Infiltration capacity corrected for water height (mm/hr)	Hydraulic conductivity, corrected for water height and lateral flow (*.65) (mm/hr)
	1	43	43
	2	115	75
	3	59	59
IRA 1	4	110	72
	5	76	76
	6	73	47
	7	57	57
	8	99	64
	1	103	103
IRA 2	2	172	112
	3	65	65
	4	121	79
	1	130	130
	2	88	57
IRA 3	3	84	84
	4	82	53
	5	7	7
	6	55	36

Texture at IRA

Site	Measurement	% Clay	% Silt	% Sand	Total		% Clay - corrected	% Silt - corrected	% Sand - corrected	Total	Texture
IRA 1	1	3.5	8.3	85.5	97.3		3.6	8.5	87.9	100	**Sand**
	2	8.1	4.8	84.5	97.4		8.3	4.9	86.8	100	**Loamy sand**
	3	7.0	3.5	87.1	97.6		7.2	3.6	89.2	100	**Sand**
IRA 2	1	5.1	3.7	89.0	97.8		5.2	3.8	91.0	100	**Sand**
	2	5.2	2.6	89.7	97.5		5.4	2.6	92.0	100	**Sand**
	3	5.3	3.4	89.0	97.7		5.5	3.5	91.0	100	**Sand**
IRA 3	1	4.1	9.9	83.8	97.8		4.2	10.1	85.7	100	**Loamy sand**
	2	4.4	10.8	75.2	90.3		4.8	12.0	83.2	100	**Loamy sand**
	3	11.5	10.2	79.7	101.5		11.4	10.1	78.6	100	**Sandy loam**

N° Ordre	P1+T	Tare	P1-T (c)	P2+T	Tare	P2-T(F)	Tém éxam(g)	F-g (h)	% Argile(h*250)	% Limon(c-f)*250
1	36.4395	36.3651	0.0744	36.0895	36.0483	0.0412	0.0273	0.0139	3.48	8.3
2	30.4354	30.3567	0.0787	37.2876	37.228	0.0596	0.0273	0.0323	8.07	4.775
3	31.1929	31.1234	0.0695	37.625	37.5696	0.0554	0.0273	0.0281	7.02	3.525
4	30.8042	30.7417	0.0625	36.3803	36.3325	0.0478	0.0273	0.0205	5.12	3.675
5	36.4094	36.351	0.0584	31.4866	31.4384	0.0482	0.0273	0.0209	5.22	2.55
6	31.569	31.5067	0.0623	36.7937	36.7451	0.0486	0.0273	0.0213	5.33	3.425
7	37.7145	37.6314	0.0831	38.4501	38.4065	0.0436	0.0273	0.0163	4.07	9.875
8	38.6721	38.5841	0.088	31.1979	31.1532	0.0447	0.0273	0.0174	4.35	10.825
9	38.697	38.61	0.087	38.9019	38.8558	0.0461	0.0273	0.0461	11.52	10.225
T	37.2968	37.2695	0.0273							

PTF at IRA

Site	Measurement	% Clay - corrected	% Silt - corrected	% Sand - corrected	Total	Texture	Hydraulic conductivity Schaap et al. (2001) (mm/hr)	Average S2001	Hydraulic conductivity Saxton et al. (1986) (mm/hr)	Average S1986
IRA 1	1	3.6	8.5	87.9	100	Sand	104	93	N/A	46
	2	8.3	4.9	86.8	100	Loamy sand	70		41	
	3	7.2	3.6	89.2	100	Sand	104		51.7	
IRA 2	1	5.2	3.8	91.0	100	Sand	154	161	77.8	76
	2	5.4	2.6	92.0	100	Sand	176		76.4	
	3	5.5	3.5	91.0	100	Sand	152		73.5	
IRA 3	1	4.2	10.1	85.7	100	Loamy sand	76	76	N/A	N/A
	2	*4.8*	*12.0*	*83.2*	*100*	*Loamy sand*	*55*		N/A	
	3	*11.4*	*10.1*	*78.6*	*100*	*Sandy loam*	*26*		*22.8*	

Cursive: *Measurement not reliable, because total measured mass % was not between 95 and 100%*

Schaap et al. (2001) or S2001 Schaap, M. G., Leij, F. J., & van Genuchten, M. T. (2001). ROSETTA: a computer program for estimating soil hydraulic parameters with hierarchical pedotransfer functions. *Journal of hydrology*, 251(3), 163-176.

Saxton et al. (1986) or S1986 Saxton, K. E., Rawls, W., Romberger, J. S., & Papendick, R. I. (1986). Estimating generalized soil-water characteristics from texture. *Soil Science Society of America Journal*, *50*(4), 1031-1036.

Site	Measurement	Hydraulic conductivity Schaap et al. (2001)	Average S2001	Hydraulic conductivity S1986 (mm/hr)	Average S1986
IRA 1	1	104	93	N/A	46
	2	70		41	
	3	104		51.7	
IRA 2	1	154	161	77.8	76
	2	176		76.4	
	3	152		73.5	
IRA 3	1	76	76	N/A	N/A
	2	*55*		N/A	
	3	*26*		*22.8*	

Appendix D. Validation and interpolation results

P1.8 all measured points

Site number	Interpolated hydraulic conductivity, p=1.8, all points (mm/hr)
1	33
2	36.777515
3	36.891136
4	34.875404
5	35.61282
6	14.190517
7	14
8	15.153865
9	36.639301
10	35.329807
11	34.37532
12	30.816435
13	28.658129
14	27.650116
15	26.572039
16	10
17	14.581982
18	40.754299
19	23.550978
20	36.136971
21	33
22	37.201485
23	41.860371
24	46.867256
25	59.709274
26	63.988823
27	68.986916
28	10.023625
29	11
30	23.411171
31	26.159796
32	40.69413
33	40.804504
34	48.184902
35	47.879833
36	49.592434
37	53.041851
38	*107.90114*
39	106.48498
40	105.72327
41	105.41885

42	102.49236	
43	106.78778	
44	107.84152	
45	109.70885	
46	110.68608	
47	111.29485	
48	109.13934	
49	135	
50	128.00931	
51	130.98331	
52	133	
53	132.12692	
54	130.47841	
55	115.14725	
56	123.07051	
57	113.68167	
58	107	
59	106.91598	
60	102.79172	
61	100.74633	
62	96.502335	
63	90.104828	
64	108.09524	
65	107.11855	
66	108.37875	
67	47.727703	
68	47	
69	45.631897	
70	44.105644	
71	37.824505	
72	33.218884	
73	21	
74	39	
75	38.410336	
76	43.577354	
77	46	
78	50	
79	63.034405	
80	72.873222	
81	79.669586	
82	73.162476	
83	88	
84	85.140816	
85	79.502266	
86	79.557739	
87	76.279366	
88	74.088791	

89	73.069267	
90	73.563133	
91	74.831604	
92	77.037773	
93	78	
94	69.174538	
95	66.360023	
96	59.733219	
97	*59*	
98	61.899063	
99	62.969898	
100	64.86158	
101	*39.021*	
102	25.059336	
103	22.262049	
104	*18*	
105	45.055286	
106	30.31439	
107	*28.253735*	
108	28.424641	
109	28.470423	
110	*28.325775*	
111	28	
112	45.697014	
113	*47.590565*	
114	54.605892	
115	79.592964	
116	*83.615929*	
117	86.180656	
118	89.450272	
119	*102*	
120	99.79953	
121	95.027512	
122	*90.680901*	
123	87.529076	
124	77.14679	
125	*69.776077*	
126	66.579094	
127	64.05162	
128	*62.097378*	
129	60.523891	
130	26.871004	
131	*23.827879*	
132	23.067038	
133	21.918041	
134	*19.791996*	
135	18.304804	

136	17.333464
137	*16.083412*
138	15
139	22.007895
140	*26.877207*
141	30.936348
142	35.476967
143	*37.685646*
144	41.31979
145	43.215
146	*46.063038*
147	47.705853
148	49.170296
149	*57.833027*
150	60.434772
151	63.299236
152	*66.771393*
153	68.850807
154	79.424843
155	*61.106876*
156	52.651196
157	37.280407
158	*67.332832*
159	65.183449
160	63.034813
161	*48.861103*
162	49.753765
163	72.174835
164	*69.900887*
165	50.649223
166	53.769852
167	*58.935642*
168	62.79451
169	65.720482
170	*62.752277*
171	60.824234
172	48.671749
173	*43*
174	83
175	77.720772
176	*77.425217*
177	83.029259
178	94.589958
179	*119.16831*
180	139.17734
181	144.60417
182	*147*

183	137.99055
184	132.84113
185	*123.20608*
186	98.829971
187	95.47924
188	*95.596085*
189	96.027008
190	60.025249
191	*60.867458*
192	62.839138
193	64.632355
194	*66.492195*
195	68.957672
196	71.192657
197	*76.529076*
198	81.024292
199	86.016113
200	*91.747757*
201	85.332085
202	84.490768
203	*79.258621*
204	92.903069
205	119.00323
206	*191*
207	154.79327
208	109.12132
209	*100.98325*
210	79.918999
211	90.26313
212	*94.432899*
213	99.616425
214	111.38358
215	*102.71759*
216	99.009628
217	92.327766
218	*85.428719*
219	79.007446
220	73.820511
221	*68.960663*
222	64.891846
223	55.295872
224	*51.246815*
225	46
226	43.935665
227	*53.649761*
228	72.386688
229	89.524872

230	*106.41193*
231	131.31335
232	146
233	*74.188026*
234	71.958
235	48
236	*54.685524*
237	60.445549
238	60
239	*32*
240	49.108757
241	57.599144
242	*65.00753*
243	75.278793
244	76.856491
245	*74.289322*
246	68.863884
247	61.137581
248	*102.72744*
249	180.13089
250	191
251	*65.768166*
252	64.345261
253	62.446178
254	*61*
255	65.208054
256	82.875771
257	*93*
258	86.506172
259	75.289108
260	*62.023529*
261	43.181091
262	43.396057
263	*43.775463*
264	43.943035
265	48.815834
266	*47.964535*
267	46.810692
268	46.071182
269	*45.615871*
270	29.825325
271	30.800901
272	*31.403734*
273	31.908148
274	32.663048
275	*33.055824*
276	33.227943

277	33.840881
278	*33.380421*
279	34.800911
280	23
281	*28.144411*
282	43.611515
283	49.108799

Validation varying p

	ALL CONDUCTIVITY VALUES IN MM/HR				3 averages	3 average	Validation											
	X	Y	Distance in nort	Area			p=1	p=1.5	p=1.7	**p=1.8**	p=1.9	p=2	p=2.2	p=2.5	p=3	p=4	p=5	p=6	p=10
1	607169	3683177	0	Upstream	29	29	33	33	33	**33**	33	33	33	33	33	33	33	33	33
2	607103	3684268	0.727138785	Upstream	29	29	51.0596	40.8251	37.91563	**36.77752**	35.83695	35.07494	33.99594	33.15824	32.77435	32.85976	32.95258	32.98536	32.99988
3	607424	3684322	0.991340001	Upstream	29	29	51.16967	41.03849	38.07337	**36.89114**	35.90083	35.08741	33.9133	32.97727	32.55034	32.72283	32.89188	32.9608	32.99937
4	609816	3682756	1.590474917	Upstream	29	29	51.77574	40.73909	36.71766	**34.8754**	33.15994	31.57638	28.8054	25.56715	22.0667	18.80977	17.35449	16.46104	14.7337
5	608801	3683362	1.288481016	Upstream	29	29	51.00266	40.46013	37.06178	**35.61282**	34.33432	33.22174	31.45616	29.76043	28.59218	28.71976	29.51862	30.27513	32.08069
6	610778	3684508	3.502059545	Upstream	29	29	22.04277	14.79947	14.30689	**14.19052**	14.11855	14.07397	14.02904	14.00731	14.00078	14.00001	14	14	14
7	610709	3684482	3.434553635	Upstream	29	29	14	14	14	**14**	14	14	14	14	14	14	14	14	14
8	610588	3684312	3.229180526	Upstream	29	29	30.93593	17.41797	15.66166	**15.15387**	14.80091	14.55628	14.26969	14.09267	14.0165	14.00062	14.00003	14	14
9	612168	3686496	5.886504252	Upstream	29	29	50.92685	41.24816	38.06017	**36.6393**	35.33064	34.12871	32.01624	29.45501	26.31306	22.16526	19.25676	17.02181	12.22937
10	612572	3686880	6.443800639	Upstream	29	29	49.82678	39.81614	36.69234	**35.32981**	34.08972	32.9617	30.99733	28.62133	25.63805	21.44578	18.41387	16.13721	11.64237
11	612689	3686931	6.562977109	Upstream	29	29	49.17167	38.88874	35.73964	**34.37532**	33.13785	32.01507	30.06379	27.70302	24.72302	20.51799	17.5224	15.33169	11.26916
12	612795	3686006	5.991855915	Upstream	29	29	48.18768	36.34067	32.50523	**30.81644**	29.27438	27.87059	25.43604	22.55197	19.1655	15.23024	13.115	11.91829	10.48488
13	612899	3686180	6.187759027	Upstream	29	29	46.78773	34.26608	30.35327	**28.65813**	27.12595	25.74453	23.37985	20.63069	17.48132	13.98057	12.23497	11.32325	10.35391
14	612921	3686304	6.29006388	Upstream	29	29	46.026	33.23529	29.32737	**27.65012**	26.14256	24.79023	22.49025	19.83885	16.82989	13.5346	11.93352	11.12062	10.28688
15	612967	3686368	6.367680179	Upstream	29	29	45.23472	32.14626	28.23497	**26.57204**	25.086	23.76016	21.52136	18.96714	16.10825	13.05293	11.62423	10.926	10.24167
16	613604	3686809	7.131666785	Upstream	29	29	10	10	10	**10**	10	10	10	10	10	10	10	10	10
17	613768	3686743	7.203214938	Upstream	29	29	35.98349	18.93429	15.70984	**14.58198**	13.68925	12.98086	11.96566	11.07496	10.40779	10.06224	10.00974	10.00154	10
18	614658	3687181	8.147080062	Upstream	29	29	52.17339	43.91256	41.66697	**40.7543**	39.96328	39.27903	38.17467	37.00015	35.78164	34.42484	33.53378	32.85456	31.58775
19	614227	3686747	7.535551169	Upstream	29	29	42.26331	28.65054	25.03134	**23.55098**	22.25441	21.11643	19.22871	17.11454	14.79082	12.43881	11.49527	11.13129	10.96308
20	615163	3688092	9.143783357	Upstream	29	29	49.94447	39.22302	36.94535	**36.13697**	35.49704	34.99191	34.27877	33.67437	33.24621	33.03721	33.00595	33.00097	33
21	614979	3687963	8.921923945	Upstream	29	29	33	33	33	**33**	33	33	33	33	33	33	33	33	33
22	614794	3687821	8.690293414	Upstream	29	29	49.67059	40.14229	38.00241	**37.20149**	36.54047	35.994	35.16317	34.35717	33.646	33.15211	33.0357	33.00827	33.00002
23	615349	3688245	9.383806221	Upstream	29	29	56.42898	46.46693	43.23031	**41.86037**	40.65374	39.60076	37.90146	36.14864	34.54501	33.40726	33.1144	33.03284	33.00023
24	615456	3688421	9.583193048	Upstream	29	29	59.7776	51.53901	48.34258	**46.86726**	45.49178	44.22263	42.00748	39.43281	36.67475	34.25151	33.44734	33.16395	33.00313
25	615767	3688863	10.11430359	Upstream	29	29	65.96285	62.50095	60.68184	**59.70927**	58.70669	57.68306	55.60692	52.53204	47.85981	41.03514	37.15673	35.11514	33.1432
26	615931	3688979	10.31273963	Upstream	29	29	67.72067	65.82713	64.65376	**63.98882**	63.27773	62.52564	60.9204	58.34427	53.94055	46.19385	40.77564	37.41437	33.40479
27	616158	3689100	10.55984013	Upstream	29	29	69.67616	69.59398	69.23798	**68.98692**	68.68764	68.34124	67.51396	65.97271	62.80361	55.5783	48.92276	43.71735	34.77962
28	613600	3686802	7.123917622	Upstream	29	29	11.95936	10.11276	10.03924	**10.02363**	10.01442	10.00891	10.00354	10.00097	10.00014	10.00001	10	10	10
29	613768	3686743	7.203214938	Upstream	29	29	11	11	11	**11**	11	11	11	11	11	11	11	11	11
30	614223	3686746	7.53198101	Upstream	29	29	42.14744	28.50543	24.88872	**23.41117**	22.11805	20.98398	19.10489	17.0045	14.70357	12.38982	11.47096	11.1205	10.96364
31	614298	3686778	7.608136958	Upstream	29	29	44.23599	31.26016	27.66004	**26.1598**	24.82969	23.64782	21.65071	19.34016	16.65248	13.59936	12.13687	11.45462	10.9617
32	614669	3687174	8.150118346	Upstream	29	29	52.19408	43.88814	41.61857	**40.69413**	39.89175	39.19677	38.07292	36.87425	35.62697	34.24011	33.34088	32.66824	31.49855
33	614651	3687186	8.145526477	Upstream	29	29	52.16479	43.93729	41.70879	**40.8045**	40.02151	39.34489	38.25446	37.09735	35.90015	34.56747	33.68552	33.00507	31.67921
34	611997	3687896	6.750768486	Upstream	29	29	55.8667	50.32507	48.79219	**48.1849**	47.67991	47.27231	46.72453	46.4666	47.09376	50.20999	53.94206	57.56685	69.77444
35	611926	3687894	6.699132345	Upstream	29	29	55.80857	50.13988	48.52988	**47.87983**	47.33001	46.87609	46.23291	45.83164	46.23699	49.00561	52.48639	55.90773	67.48065
36	612145	3687990	6.921913057	Upstream	29	29	56.32193	51.31361	50.05387	**49.59243**	49.23812	48.98492	48.75327	48.97606	50.38781	54.93369	59.91235	64.62726	79.61981
37	612525	3688022	7.213635474	Upstream	29	29	57.13483	53.5572	53.08262	**53.04185**	53.12005	53.30639	53.95816	55.46946	58.8172	66.33317	73.31554	79.28793	93.90029
38	623428	3694899	19.81747396	Center	105	112	88.58542	100.7309	105.5392	**107.9011**	110.2271	112.512	116.9441	123.212	132.5984	147.7812	159.2432	167.9361	185.1939

39	623236	3694884	19.66868796	Center	105	112	88.30398	99.84689	104.3133	**106.485**	108.6087	110.6807	114.6585	120.1901	128.2708	140.9083	150.3402	157.7589	176.0833
40	623051	3694864	19.52156499	Center	105	112	88.20882	99.40908	103.669	**105.7233**	107.7209	109.6584	113.3444	118.3893	125.563	136.2035	143.6025	149.1049	162.2988
41	622840	3694828	19.34470374	Center	105	112	88.27426	99.30376	103.439	**105.4189**	107.3342	109.1819	112.6671	117.3633	123.8539	132.8803	138.4849	142.11	147.9535
42	622599	3697758	21.22208956	Center	105	112	85.39709	96.18595	100.4347	**102.4924**	104.4925	106.4276	110.0837	115.0043	121.7824	131.2752	137.2508	141.0276	146.2139
43	622328	3694603	18.82017632	Center	105	112	89.1942	100.6171	104.808	**106.7878**	108.6833	110.4912	113.8366	118.18	123.7605	130.2519	133.0773	134.1466	133.9458
44	622188	3694482	18.63542552	Center	105	112	89.72869	101.5179	105.8193	**107.8415**	109.7701	111.601	114.9621	119.2564	124.6006	130.3801	132.603	133.3408	133.3047
45	621971	3694390	18.41553116	Center	105	112	90.68809	103.1286	107.6174	**109.7089**	111.6888	113.553	116.9268	121.1197	126.0759	130.9119	132.5302	133.0275	133.1202
46	621865	3694380	18.33245319	Center	105	112	91.20345	103.9838	108.5635	**110.6861**	112.6871	114.5622	117.9295	122.0532	126.802	131.22	132.6125	133.0241	133.0995
47	621882	3694211	18.22707478	Center	105	112	91.47156	104.4966	109.1473	**111.2949**	113.3132	115.1978	118.5613	122.6308	127.2152	131.3154	132.5615	132.939	133.0639
48	622161	3694072	18.33114324	Center	105	112	90.26698	102.5765	107.049	**109.1393**	111.1223	112.9929	116.3877	120.6229	125.6497	130.5703	132.2365	132.7856	133.0528
49	620142	3693985	16.82311157	Center	105	112	135	135	135	**135**	135	135	135	135	135	135	135	135	135
50	620956	3693952	17.38223942	Center	105	112	105.0938	122.6286	126.5834	**128.0093**	129.1401	130.0282	131.2571	132.2351	132.8254	133.0134	133.0144	133.0071	133.0002
51	620819	3693897	17.24571943	Center	105	112	111.7304	127.655	130.1912	**130.9833**	131.5586	131.9737	132.4852	132.8237	132.9783	133.0052	133.002	133.0006	133
52	620667	3693804	17.07195319	Center	105	112	133	133	133	**133**	133	133	133	133	133	133	133	133	133
53	620563	3693768	16.97235739	Center	105	112	117.2765	130.1841	131.7009	**132.1269**	132.4175	132.6149	132.8381	132.9653	133.0077	133.0049	133.0013	133.0003	133
54	620349	3693756	16.8108391	Center	105	112	110.3925	126.4394	129.4498	**130.4784**	131.2736	131.8866	132.7226	133.3914	133.831	134.0435	134.0943	134.1206	134.202
55	621619	3693532	17.56615436	Center	105	112	93.63001	108.0844	112.9723	**115.1473**	117.1345	118.9347	121.9976	125.4086	128.8055	131.4554	132.3079	132.6688	132.9885
56	620855	3693317	16.86738687	Center	105	112	100.4333	116.8766	121.311	**123.0705**	124.5612	125.815	127.7403	129.5889	131.1629	132.3171	132.721	132.8871	132.9983
57	620565	3692877	16.3529852	Center	105	112	96.27187	109.2443	112.4742	**113.6817**	114.65	115.4076	116.4059	116.9888	116.6969	114.8438	113.0233	111.5474	108.388
58	620099	3692364	15.66137951	Center	105	112	107	107	107	**107**	107	107	107	107	107	107	107	107	107
59	619737	3692210	15.29414942	Center	105	112	93.56359	104.2673	106.2917	**106.916**	107.3433	107.6175	107.8528	107.8052	107.4837	107.1169	107.0252	107.0054	107
60	619138	3691620	14.45340506	Center	105	112	86.69878	97.45429	101.1496	**102.7917**	104.2817	105.6136	107.7994	109.9584	111.2735	110.1938	108.664	107.7801	107.0319
61	618794	3691302	13.98506657	Center	105	112	84.76485	95.02787	98.91053	**100.7463**	102.4956	104.1482	107.1327	110.7422	114.4762	115.7902	113.7505	111.4732	107.5866
62	617629	3690293	12.44627862	Center	105	112	80.50691	90.00381	94.2805	**96.50234**	98.77223	101.084	105.8068	113.0376	125.0316	146.3962	162.1988	172.7315	188.0008
63	617259	3689842	11.86670698	Center	105	112	77.71529	85.07172	88.383	**90.10483**	91.86565	93.66126	97.33978	103.0085	112.5656	130.4848	145.2232	156.5256	179.5497
64	622327	3693964	18.3757787	Center	105	112	89.65836	101.6391	106.0308	**108.0952**	110.0622	111.9266	115.3367	119.6522	124.9014	130.2607	132.1523	132.7723	133.0419
65	623314	3694142	19.21143073	Center	105	112	88.26015	100.1464	104.8268	**107.1186**	109.3697	111.575	115.8317	121.7935	130.5514	144.1459	153.9492	161.3047	177.8812
66	623467	3694295	19.42774922	Center	105	112	88.54418	100.9437	105.92	**108.3788**	110.8089	113.2046	117.8739	124.5213	134.5389	150.6986	162.5879	171.2332	186.7189
67	626926	3698200	24.6269186	Downstre	56	56	56.80488	49.45089	48.13765	**47.7277**	47.43587	47.23323	47.00703	46.90286	46.91898	46.98124	46.99669	46.99945	47
68	627069	3698344	24.82980282	Downstre	56	56	47	47	47	**47**	47	47	47	47	47	47	47	47	47
69	627165	3698608	25.08196438	Downstre	56	56	54.94402	47.43112	46.05094	**45.6319**	45.35167	45.18146	45.07458	45.23803	45.75048	46.50349	46.81791	46.93423	46.99888
70	627170	3698697	25.14727947	Downstre	56	56	54.81699	46.53302	44.72444	**44.10564**	43.64457	43.31643	42.9692	42.95271	43.5189	44.90119	45.83602	46.37111	46.9491
71	627199	3698928	25.32844107	Downstre	56	56	52.43004	41.83577	38.97612	**37.82451**	36.83202	35.97774	34.60521	33.14344	31.58088	29.63113	28.13388	26.84381	23.40488
72	627235	3699061	25.44669287	Downstre	56	56	49.58273	37.62726	34.48262	**33.21888**	32.12701	31.18203	29.64406	27.95776	26.08469	23.88525	22.6442	21.92875	21.09393
73	627462	3699318	25.7885051	Downstre	56	56	21	21	21	**21**	21	21	21	21	21	21	21	21	21
74	627692	3699431	26.03247634	Downstre	56	56	39	39	39	**39**	39	39	39	39	39	39	39	39	39
75	627971	3699561	26.32356518	Downstre	56	56	50.23193	41.01632	39.08383	**38.41034**	37.89209	37.50174	37.01239	36.74881	36.88665	37.61175	38.18607	38.54073	38.95795
76	628327	3699711	26.68406937	Downstre	56	56	54.77005	46.62323	44.44491	**43.57735**	42.83941	42.21608	41.25502	40.33882	39.6197	39.31347	39.37867	39.49577	39.73203
77	628920	3700252	27.48649327	Downstre	56	56	46	46	46	**46**	46	46	46	46	46	46	46	46	46
78	628957	3700648	27.78784205	Downstre	56	56	50	50	50	**50**	50	50	50	50	50	50	50	50	50

79	629394	3702495	29.38770602	Downstre	56	56	65.36801	63.57796	63.16336	**63.03441**	62.95731	62.93039	63.01617	63.44136	64.68971	67.91134	70.93818	73.44148	79.86536
80	629432	3703299	29.97740704	Downstre	56	56	68.35181	70.55393	72.03994	**72.87322**	73.74678	74.64526	76.45856	79.03965	82.51254	86.20242	87.44387	87.82838	87.99829
81	629709	3703552	30.35230945	Downstre	56	56	71.01978	76.2416	78.57118	**79.66959**	80.69708	81.6416	83.26145	85.04499	86.7156	87.76923	87.95821	87.99227	87.99999
82	629993	3703101	30.2396491	Downstre	56	56	68.52374	70.81764	72.32365	**73.16248**	74.03861	74.93679	76.74171	79.29511	82.7031	86.28305	87.47231	87.83746	87.99831
83	629969	3704030	30.8728329	Downstre	56	56	88	88	88	**88**	88	88	88	88	88	88	88	88	88
84	629934	3704280	31.02336486	Downstre	56	56	75.52072	82.57755	84.43721	**85.14082**	85.71583	86.18121	86.8539	87.43028	87.82159	87.98157	87.99798	87.99974	88
85	630045	3704550	31.29203787	Downstre	56	56	71.53695	76.45963	78.53056	**79.50227**	80.41424	81.25897	82.7348	84.43431	86.18319	87.5308	87.87357	87.96428	87.99969
86	630192	3704521	31.37628514	Downstre	56	56	71.61026	76.52824	78.59059	**79.55774**	80.46517	81.3055	82.77307	84.46188	86.19717	87.53111	87.87095	87.9622	87.99958
87	630312	3704688	31.57899512	Downstre	56	56	70.40071	73.85223	75.47156	**76.27937**	77.07159	77.83985	79.2805	81.15458	83.4991	86.04044	87.09683	87.55637	87.96234
88	630508	3704845	31.82878415	Downstre	56	56	69.77881	72.27395	73.47852	**74.08879**	74.69408	75.28816	76.42386	77.95388	79.98978	82.49027	83.76385	84.47475	85.78618
89	630697	3705100	32.14242084	Downstre	56	56	69.55754	71.62428	72.58965	**73.06927**	73.53805	73.99086	74.83393	75.91299	77.20698	78.39247	78.63483	78.56446	78.13815
90	630625	3705325	32.24936047	Downstre	56	56	69.79633	72.09504	73.0884	**73.56313**	74.01489	74.43954	75.19828	76.10439	77.08027	77.84334	78.00336	78.02131	78.00176
91	630553	3705542	32.35092199	Downstre	56	56	70.46246	73.31245	74.3651	**74.8316**	75.25372	75.63106	76.25794	76.92456	77.53409	77.91679	77.9857	77.9977	78.00002
92	630616	3705770	32.55624421	Downstre	56	56	72.70565	76.0378	76.774	**77.03777**	77.24701	77.41192	77.64247	77.83083	77.951	77.99571	77.99961	77.99996	78
93	630648	3705945	32.70229312	Downstre	56	56	78	78	78	**78**	78	78	78	78	78	78	78	78	78
94	630871	3706597	33.32039952	Downstre	56	56	68.31867	68.82697	69.06272	**69.17454**	69.27995	69.37801	69.55076	69.75462	69.98469	70.26797	70.52387	70.81125	72.10015
95	630992	3706722	33.49434447	Downstre	56	56	67.40938	66.77143	66.50214	**66.36002**	66.21237	66.05924	65.73828	65.23108	64.3717	62.84477	61.70153	60.889	59.44155
96	631197	3707124	33.92345718	Downstre	56	56	63.20541	60.45678	59.92228	**59.73322**	59.58297	59.46365	59.29364	59.14839	59.04778	59.00499	59.00053	59.00005	59
97	631187	3707273	34.02174434	Downstre	56	56	59	59	59	**59**	59	59	59	59	59	59	59	59	59
98	631297	3707718	34.41442245	Downstre	56	56	65.51743	63.06504	62.25456	**61.89906**	61.57608	61.28411	60.78558	60.21966	59.63076	59.15972	59.03913	59.00947	59.00003
99	631417	3707875	34.6103361	Downstre	56	56	66.10777	64.06202	63.3152	**62.9699**	62.64443	62.33894	61.78682	61.09744	60.26754	59.42839	59.13734	59.04314	59.0004
100	631623	3708385	35.11714206	Downstre	56	56	66.9041	65.6006	65.10109	**64.86158**	64.62884	64.40244	63.96686	63.35084	62.41587	60.94058	60.01667	59.50863	59.02793
101	610795	3693572	9.990016853	Upstream	29	29	55.35657	44.96544	40.91814	**39.021**	37.23109	35.55957	32.59414	29.08029	25.30487	22.17721	21.20043	20.75018	19.66639
102	611745	3693886	10.86988598	Upstream	29	29	48.1404	31.49052	26.84312	**25.05934**	23.59657	22.4135	20.71603	19.29574	18.37949	18.0365	18.00428	18.0006	18
103	611844	3693961	10.99239078	Upstream	29	29	44.47407	27.4217	23.59758	**22.26205**	21.22786	20.43557	19.37804	18.58426	18.14207	18.00941	18.00074	18.00007	18
104	612119	3694102	11.28377834	Upstream	29	29	18	18	18	**18**	18	18	18	18	18	18	18	18	18
105	613091	3694407	12.17416122	Center	105	112	61.20958	51.82275	47.33097	**45.05529**	42.80516	40.61136	36.49384	31.23353	25.13403	19.89678	18.50215	18.13727	18.00105
106	609410	3691311	7.394583893	Upstream	29	29	49.35316	36.38469	32.13699	**30.31439**	28.69505	27.27124	24.95543	22.55541	20.36534	18.68089	17.92235	17.37306	15.98317
107	609832	3691515	7.832835707	Upstream	29	29	46.72947	33.4346	29.7255	**28.25374**	27.01222	25.97584	24.41279	22.98486	21.92694	21.41987	21.32922	21.28697	21.14372
108	609900	3691571	7.920257511	Upstream	29	29	46.45094	33.32985	29.79902	**28.42464**	27.28131	26.34138	24.95976	23.76693	23.01479	22.95916	23.25373	23.57672	24.76163
109	610180	3691673	8.186959497	Upstream	29	29	44.36894	32.037	29.38623	**28.47042**	27.77206	27.25136	26.60648	26.25271	26.3487	26.96709	27.41321	27.67434	27.97098
110	610429	3691811	8.458507507	Upstream	29	29	39.25394	29.75719	28.62655	**28.32578**	28.13305	28.01388	27.90594	27.88731	27.93421	27.98661	27.99756	27.99956	28
111	610574	3691912	8.631615243	Upstream	29	29	28	28	28	**28**	28	28	28	28	28	28	28	28	28
112	612237	3692570	10.25630551	Upstream	29	29	58.808	50.77268	47.3714	**45.69701**	44.05892	42.46895	39.47028	35.51084	30.43084	24.76003	22.3592	21.27356	19.79162
113	612479	3692694	10.51339749	Upstream	29	29	60.03705	52.56224	49.25352	**47.59057**	45.94074	44.31677	41.1898	36.9205	31.17068	24.2861	21.17533	19.75456	18.31146
114	612869	3692540	10.67320569	Upstream	29	29	62.96584	58.07385	55.79056	**54.60589**	53.40184	52.18529	49.7403	46.12839	40.54075	31.82977	26.2834	22.95541	18.72678
115	613390	3687879	7.727594966	Upstream	29	29	65.05096	73.44848	77.58126	**79.59296**	81.5245	83.35541	86.67151	90.7486	95.44592	99.86723	101.3173	101.7814	101.9976
116	613465	3687806	7.729799497	Upstream	29	29	66.9085	77.17785	81.57716	**83.61593**	85.51625	87.26809	90.32229	93.86723	97.63869	100.7821	101.6623	101.906	101.9994
117	613519	3687763	7.738135234	Upstream	29	29	68.34952	79.72958	84.18312	**86.18066**	88.00611	89.65794	92.46545	95.6009	98.76236	101.1888	101.7972	101.949	101.9998
118	613580	3687738	7.764111024	Upstream	29	29	70.5982	83.20129	87.5743	**89.45027**	91.11877	92.59041	95.00426	97.55707	99.94024	101.5624	101.9067	101.98	102

119	613756	3687852	7.969554443	Upstream	29	29	102	102	102	**102**	102	102	102	102	102	102	102	102	102
120	613805	3687916	8.049358677	Upstream	29	29	85.01811	97.05505	99.1142	**99.79953**	100.3227	100.7214	101.2563	101.669	101.9135	101.994	101.9996	102	102
121	613836	3687997	8.12823851	Upstream	29	29	76.23189	89.85677	93.57574	**95.02751**	96.24494	97.25932	98.7958	100.2287	101.3433	101.9098	101.9876	101.9983	102
122	613876	3688048	8.192515078	Upstream	29	29	72.14881	84.6171	88.87313	**90.6809**	92.27637	93.67172	95.93016	98.26221	100.356	101.6865	101.9402	101.9885	102
123	613895	3688091	8.236207795	Upstream	29	29	70.04596	81.26293	85.59679	**87.52908**	89.28617	90.86738	93.52947	96.45052	99.30758	101.381	101.8581	101.9672	101.9999
124	613968	3688244	8.395534967	Upstream	29	29	65.5033	71.91253	75.38618	**77.14679**	78.88129	80.56683	83.72922	87.8383	92.96996	98.47974	100.6429	101.4713	101.9858
125	614035	3688394	8.548504218	Upstream	29	29	63.52465	66.37406	68.55908	**69.77608**	71.04307	72.33884	74.94762	78.72234	84.23793	91.98711	96.40752	98.85614	101.6558
126	614069	3688494	8.642898297	Upstream	29	29	62.9448	64.21913	65.69824	**66.57909**	67.52837	68.5281	70.6176	73.8011	78.77944	86.59514	91.80699	95.21183	100.5929
127	614104	3688611	8.749954541	Upstream	29	29	62.67832	62.66505	63.496	**64.05162**	64.68189	65.37286	66.88587	69.32605	73.39247	80.35046	85.53057	89.35074	97.41812
128	614153	3688760	8.889475525	Upstream	29	29	62.73323	61.65121	61.86656	**62.09738**	62.39877	62.76119	63.63162	65.17551	67.97569	73.15929	77.27905	80.51808	88.99784
129	614264	3688834	9.020461998	Upstream	29	29	62.75938	60.85458	60.56833	**60.52389**	60.53822	60.60488	60.8684	61.49264	62.80832	65.32896	67.1525	68.37277	70.6879
130	609789	3690286	6.913407999	Upstream	29	29	47.80696	33.47505	28.83635	**26.871**	25.14285	23.6409	21.24399	18.84684	16.80136	15.5099	15.18375	15.07324	15.00222
131	609977	3690360	7.096926654	Upstream	29	29	45.43108	30.06831	25.61181	**23.82788**	22.31701	21.05158	19.13387	17.36122	15.99532	15.2375	15.07243	15.02423	15.00036
132	610031	3690375	7.145134763	Upstream	29	29	44.72745	29.14907	24.78469	**23.06704**	21.62803	20.43544	18.65403	17.04269	15.83511	15.18909	15.05474	15.01735	15.0002
133	610106	3690405	7.218712227	Upstream	29	29	43.53938	27.69308	23.51584	**21.91804**	20.60329	19.53232	17.96954	16.60411	15.62491	15.13024	15.03469	15.01008	15.00008
134	610129	3690517	7.315448892	Upstream	29	29	40.73096	24.72078	21.09214	**19.792**	18.76394	17.95738	16.8375	15.92727	15.32989	15.05905	15.01337	15.00326	15.00001
135	610200	3690573	7.405011645	Upstream	29	29	38.01687	22.37215	19.33053	**18.3048**	17.52225	16.92847	16.13928	15.53758	15.17349	15.02593	15.00486	15.00097	15
136	610240	3690619	7.465897767	Upstream	29	29	35.57711	20.65398	18.13861	**17.33346**	16.73743	16.29764	15.734	15.32665	15.09665	15.01223	15.00193	15.00032	15
137	610308	3690693	7.566373382	Upstream	29	29	30.65072	18.09726	16.53519	**16.08341**	15.7677	15.54693	15.28308	15.11145	15.0273	15.00238	15.00026	15.00003	15
138	610312	3690835	7.671646325	Upstream	29	29	15	15	15	**15**	15	15	15	15	15	15	15	15	15
139	610606	3691116	8.077943728	Upstream	29	29	41.5266	26.75575	23.29376	**22.0079**	20.96044	20.10974	18.85604	17.70011	16.70504	15.84039	15.43674	15.2262	15.01561
140	610831	3691214	8.304405117	Upstream	29	29	45.62008	31.98051	28.31488	**26.87721**	25.67025	24.66499	23.14518	21.72685	20.57237	19.70929	19.2323	18.82014	17.44647
141	611113	3691239	8.517801357	Upstream	29	29	49.1142	36.45775	32.56075	**30.93635**	29.52056	28.29966	26.37133	24.47832	22.9411	22.1836	22.17032	22.27431	22.77221
142	611418	3691336	8.799225848	Upstream	29	29	52.35093	41.09809	37.20152	**35.47697**	33.91222	32.50769	30.15873	27.63891	25.34469	24.11325	24.2334	24.60943	26.03367
143	611564	3691390	8.93944116	Upstream	29	29	53.7404	43.23069	39.41753	**37.68565**	36.08534	34.62154	32.10256	29.26681	26.47964	24.71545	24.69065	25.049	26.47472
144	611801	3691494	9.178869237	Upstream	29	29	55.81245	46.56329	42.99742	**41.31979**	39.72942	38.23499	35.55318	32.30442	28.69978	25.76145	25.25291	25.45408	26.78946
145	611922	3691475	9.249303856	Upstream	29	29	56.78663	48.2211	44.83397	**43.215**	41.66186	40.18353	37.4752	34.06844	30.03071	26.24222	25.23809	25.21048	26.45434
146	612102	3691435	9.345778951	Upstream	29	29	58.1524	50.61916	47.55497	**46.06304**	44.61126	43.20781	40.5704	37.09225	32.60584	27.5808	25.64419	25.08405	25.89183
147	612208	3691453	9.43249256	Upstream	29	29	58.92352	51.97348	49.11102	**47.70585**	46.32986	44.99039	42.44421	39.01324	34.41135	28.82023	26.33547	25.40807	25.8218
148	612301	3691444	9.490806006	Upstream	29	29	59.5813	53.15665	50.48815	**49.1703**	47.87359	46.60455	44.17031	40.83277	36.20797	30.17913	27.15652	25.80884	25.64558
149	612842	3691369	9.814525064	Upstream	29	29	63.2269	59.89313	58.51691	**57.83303**	57.15517	56.48515	55.17405	53.29218	50.39669	45.4067	41.24961	37.77669	29.51532
150	613000	3691431	9.969294323	Upstream	29	29	64.32243	61.89042	60.91386	**60.43477**	59.96388	59.50238	58.61026	57.35307	55.45944	52.20216	49.30751	46.60212	37.7504
151	613165	3691411	10.07039526	Upstream	29	29	65.444	64.0295	63.52861	**63.29924**	63.08508	62.88654	62.53669	62.1247	61.69111	61.38006	61.26918	61.05679	58.75352
152	613359	3691333	10.15052914	Upstream	29	29	66.74021	66.57403	66.67788	**66.77139**	66.89302	67.04261	67.42361	68.18687	69.89018	74.34743	79.42847	84.64339	104.619
153	613475	3691266	10.18404458	Upstream	29	29	67.49448	68.08101	68.55691	**68.85081**	69.18205	69.55025	70.39436	71.91264	75.01733	82.70006	91.38061	100.3688	133.9939
154	613388	3687877	7.724766612	Upstream	29	29	64.97117	73.29816	77.41668	**79.42484**	81.35505	83.18664	86.50884	90.60297	95.33612	99.81594	101.2961	101.7732	101.9974
155	612983	3687963	7.49710599	Upstream	29	29	58.94598	58.94315	60.24736	**61.10688**	62.07418	63.12746	65.41402	69.06057	75.0489	84.9353	91.64005	95.85644	101.2943
156	612515	3687993	7.186091665	Upstream	29	29	56.97591	53.2596	52.7236	**52.6512**	52.69723	52.85097	53.43649	54.84708	58.02916	65.25502	72.03857	77.91495	92.83024
157	614790	3687823	8.688819823	Upstream	29	29	49.74951	40.23557	38.08683	**37.28041**	36.61365	36.06144	35.21966	34.39945	33.67105	33.16009	33.03804	33.00893	33.00002
158	613157	3687954	7.614464534	Upstream	29	29	60.70863	63.47788	65.93848	**67.33283**	68.795	70.29791	73.33793	77.74966	84.1694	92.93435	97.57525	99.8765	101.8892

159	613106	3687951	7.576090201	Upstream	29	29	60.05299	61.87178	63.95728	**65.18345**	66.49367	67.86242	70.68921	74.91386	81.31215	90.63784	96.01912	98.91328	101.7885
160	613044	3687961	7.539048841	Upstream	29	29	59.46731	60.31733	61.99652	**63.03481**	64.1713	65.38229	67.94528	71.90326	78.15462	87.8837	93.99544	97.56049	101.6024
161	612034	3687972	6.830659769	Upstream	29	29	56.13825	50.83631	49.41205	**48.8611**	48.4137	48.0648	47.6373	47.56596	48.51632	52.30022	56.69114	60.93338	74.90205
162	612188	3687976	6.942455934	Upstream	29	29	56.32711	51.39531	50.18665	**49.75377**	49.42933	49.2069	49.0377	49.35134	50.89397	55.61321	60.68795	65.46317	80.53428
163	613260	3687937	7.675786193	Upstream	29	29	62.25214	67.21994	70.4573	**72.17484**	73.91107	75.63802	78.98065	83.52651	89.56697	96.68602	99.8026	101.1001	101.9743
164	613214	3687947	7.650086115	Upstream	29	29	61.50719	65.43651	68.32402	**69.90089**	71.52136	73.15751	76.38943	80.92006	87.20322	95.13728	98.93349	100.6475	101.9487
165	626448	3698587	24.55137629	Downstre	56	56	61.71622	54.31246	51.75948	**50.64922**	49.65758	48.78435	47.37544	45.98952	45.02286	45.21249	45.88894	46.37634	46.94927
166	626294	3698406	24.31484399	Downstre	56	56	63.86446	57.38628	54.90592	**53.76985**	52.71711	51.75314	50.09736	48.25713	46.5486	45.80846	46.12027	46.47504	46.95687
167	626052	3698191	23.99142406	Downstre	56	56	66.77612	62.02579	59.94844	**58.93564**	57.95475	57.01377	55.27302	53.05138	50.3526	47.67251	46.84882	46.69766	46.92723
168	625848	3698053	23.74886026	Downstre	56	56	68.69315	65.25728	63.6182	**62.79451**	61.98102	61.18522	59.66885	57.63004	54.90782	51.50361	49.72487	48.74245	47.35492
169	625145	3698067	23.25422992	Downstre	56	56	70.69595	67.93965	66.47113	**65.72048**	64.97481	64.24332	62.84934	60.98403	58.50549	55.2356	53.07908	51.39979	46.91983
170	624811	3698197	23.10596844	Downstre	56	56	69.8794	65.68748	63.71269	**62.75228**	61.82844	60.94983	59.34542	57.32345	54.79457	51.53257	49.35419	47.72911	44.35116
171	624650	3698234	23.0167738	Downstre	56	56	69.20941	64.08639	61.86733	**60.82423**	59.84152	58.92447	57.29004	55.29086	52.8477	49.71524	47.66545	46.22145	43.67769
172	624347	3698006	22.64077506	Downstre	56	56	60.59945	51.61148	49.49239	**48.67175**	47.975	47.38016	46.42741	45.41214	44.37293	43.45272	43.14886	43.04878	43.00056
173	624258	3697923	22.519116	Downstre	56	56	43	43	43	**43**	43	43	43	43	43	43	43	43	43
174	624065	3697763	22.26928556	Downstre	56	56	83	83	83	**83**	83	83	83	83	83	83	83	83	83
175	623924	3697713	22.13360493	Downstre	56	56	75.54453	76.77907	77.39489	**77.72077**	78.05029	78.37783	79.00996	79.86087	80.96343	82.19209	82.68903	82.88145	82.99754
176	623515	3697625	21.78016465	Center	105	112	77.80162	78.20874	77.71983	**77.42522**	77.12165	76.82325	76.28103	75.67963	75.28096	75.94833	77.30111	78.64088	81.76933
177	623240	3697670	21.61582998	Center	105	112	79.91325	82.71433	83.01494	**83.02926**	82.97102	82.85351	82.48935	81.76867	80.51732	78.7643	78.04483	77.98793	79.91919
178	622857	3697713	21.37363337	Center	105	112	83.25116	90.79061	93.39337	**94.58996**	95.71698	96.7764	98.70577	101.1912	104.5433	109.7012	113.9769	117.7886	129.4919
179	622403	3697501	20.90193763	Center	105	112	91.69857	109.3374	116.0631	**119.1683**	122.0639	124.7346	129.3854	134.7447	140.3485	144.9778	146.3576	146.791	146.9975
180	622167	3697256	20.56184735	Center	105	112	106.3375	131.1025	137.0277	**139.1773**	140.8866	142.2328	144.1073	145.6256	146.5895	146.9588	146.9954	146.9995	147
181	621908	3697083	20.2561467	Center	105	112	118.7057	140.4475	143.6395	**144.6042**	145.2932	145.7835	146.3798	146.7711	146.9548	146.998	146.9999	147	147
182	622031	3697046	20.31740908	Center	105	112	147	147	147	**147**	147	147	147	147	147	147	147	147	147
183	621762	3696940	20.05178648	Center	105	112	104.6302	129.2531	135.615	**137.9906**	139.9093	141.4409	143.6057	145.3877	146.5273	146.9561	146.9956	146.9995	147
184	621645	3697097	20.0794827	Center	105	112	99.39742	122.6352	129.8839	**132.8411**	135.3659	137.491	140.7178	143.6742	145.8524	146.8566	146.981	146.9974	147
185	621452	3697086	19.93497109	Center	105	112	93.43572	112.6418	119.9007	**123.2061**	126.2478	129.0077	133.6722	138.7202	143.3774	146.3164	146.8675	146.9737	146.9999
186	620016	3695521	17.81312415	Center	105	112	86.42482	94.78722	97.56628	**98.82997**	100.013	101.119	103.1181	105.6598	109.0036	113.9043	117.7804	121.1019	129.7619
187	620393	3696031	18.44014473	Center	105	112	84.88904	92.12009	94.44239	**95.47924**	96.4365	97.31772	98.869	100.7386	102.9438	105.4838	107.0308	108.2574	112.3257
188	620507	3696202	18.64160909	Center	105	112	84.73441	92.07378	94.49667	**95.59609**	96.62386	97.58326	99.31276	101.4998	104.3487	108.5067	111.9745	115.2902	127.3897
189	620597	3696386	18.83527815	Center	105	112	84.63619	92.21749	94.81991	**96.02701**	97.17407	98.26407	100.287	102.9881	106.8554	113.4032	119.283	124.6182	138.8035
190	614388	3688989	9.217593922	Upstream	29	29	63.38073	61.00339	60.30956	**60.02525**	59.78072	59.57323	59.25628	58.97054	58.77959	58.57822	58.05854	57.18667	52.30531
191	614361	3689074	9.258103123	Upstream	29	29	63.82042	61.72108	61.11408	**60.86746**	60.65727	60.48129	60.22062	60.00984	59.9416	60.03627	59.87541	59.38379	55.79211
192	614409	3689298	9.449728603	Upstream	29	29	65.0868	63.5573	63.05921	**62.83914**	62.63779	62.45406	62.13365	61.74524	61.23695	60.30592	59.24277	58.05987	53.03119
193	614521	3689435	9.625704204	Upstream	29	29	66.14803	65.15865	64.80187	**64.63236**	64.46771	64.30684	63.99177	63.5178	62.66338	60.58558	58.19243	55.77797	47.83682
194	614601	3689542	9.757834953	Upstream	29	29	67.05968	66.68646	66.55666	**66.4922**	66.42595	66.35629	66.20029	65.90353	65.18102	62.85635	59.79878	56.58048	46.3684
195	614650	3689673	9.884834571	Upstream	29	29	68.09238	68.58571	68.83227	**68.95767**	69.08095	69.19947	69.41211	69.63694	69.66145	68.25813	65.39706	61.85665	48.90134
196	614810	3689728	10.03722055	Upstream	29	29	69.12518	70.36507	70.91698	**71.19266**	71.46359	71.72628	72.21465	72.81428	73.34045	72.46048	69.57838	65.63561	49.86596
197	614882	3689939	10.23686152	Upstream	29	29	71.0465	74.23238	75.74145	**76.52908**	77.33203	78.14513	79.78178	82.1946	85.869	91.18687	93.8422	94.58971	89.53296
198	614880	3690126	10.36714175	Upstream	29	29	72.50732	77.37172	79.75666	**81.02429**	82.33394	83.67915	86.45039	90.71616	97.76547	110.265	120.0337	127.6115	147.4745
199	614896	3690307	10.50607193	Upstream	29	29	74.0957	80.83434	84.20663	**86.01611**	87.89762	89.84266	93.88802	100.2099	110.8789	130.259	145.405	156.6681	179.5808
200	614954	3690465	10.65862656	Upstream	29	29	75.91881	84.82389	89.32532	**91.74776**	94.2698	96.8788	102.303	110.7435	124.7419	148.5503	164.7323	174.797	188.4606

201	614286	3690984	10.55364479	Upstream	29	29	73.35234	79.94127	83.41953	**85.33209**	87.35416	89.47971	94.01279	101.3905	114.5894	140.2479	160.1429	173.166	189.2112
202	614208	3691094	10.57675694	Upstream	29	29	73.05684	79.32909	82.65643	**84.49077**	86.4338	88.48032	92.85861	100.0248	112.9724	138.628	158.9807	172.5145	189.2541
203	613988	3691139	10.45389588	Upstream	29	29	71.2449	75.59391	77.94894	**79.25862**	80.65418	82.13313	85.32833	90.65415	100.6274	122.2889	142.454	158.5529	186.0378
204	614614	3690870	10.70428353	Upstream	29	29	75.95184	85.36935	90.24926	**92.90307**	95.68459	98.58044	104.6543	114.2187	130.2334	156.9361	173.4264	182.1729	190.3905
205	615243	3690952	11.20708181	Upstream	29	29	84.67312	104.3743	114.0068	**119.0032**	124.0373	129.0464	138.758	151.872	168.3798	184.2647	189.0328	190.406	190.9932
206	615991	3691725	12.2825669	Center	105	112	191	191	191	**191**	191	191	191	191	191	191	191	191	191
207	616546	3691996	12.86701951	Center	105	112	101.5518	135.626	148.8479	**154.7933**	160.1847	164.9861	172.8319	180.772	187.2629	190.5197	190.9368	190.9914	191
208	617243	3692784	13.91691955	Center	105	112	86.56216	100.155	106.0895	**109.1213**	112.1809	115.2563	121.408	130.4675	144.4648	165.825	178.2356	184.6333	190.5481
209	617917	3693396	14.82635563	Center	105	112	85.49651	95.42534	99.18005	**100.9833**	102.731	104.42	107.613	111.9274	117.892	126.0358	130.7384	133.388	135.6207
210	614254	3693002	11.96941223	Center	105	112	72.98976	77.02783	78.91813	**79.919**	80.95495	82.02396	84.25198	87.77882	93.95017	106.1269	116.6277	125.0603	146.3158
211	614783	3693135	12.43420837	Center	105	112	76.85706	84.56416	88.27805	**90.26313**	92.3288	94.47031	98.95806	106.0994	118.5651	142.1309	160.0502	171.8568	188.0795
212	615294	3693399	12.98040835	Center	105	112	79.07271	88.03655	92.22269	**94.4329**	96.71514	99.064	103.9367	111.5758	124.6502	148.6481	166.149	177.0347	189.6989
213	615920	3693461	13.46357091	Center	105	112	81.73612	92.30625	97.11029	**99.61643**	102.1836	104.8047	110.1781	118.4397	132.154	155.9494	171.9811	181.1508	190.3234
214	621176	3696973	19.65975893	Center	105	112	88.72631	102.7696	108.5514	**111.3836**	114.1448	116.8136	121.8029	128.2449	136.0584	143.5691	145.9497	146.6763	146.9968
215	620920	3696935	19.45180052	Center	105	112	85.90902	96.39216	100.6208	**102.7176**	104.7942	106.844	110.8388	116.484	124.6835	135.9963	141.8651	144.6409	146.8895
216	620790	3696918	19.34787814	Center	105	112	84.78629	93.79218	97.2915	**99.00963**	100.7047	102.3756	105.6397	110.3258	117.4966	128.9881	136.5818	141.129	146.4228
217	620528	3696914	19.15998779	Center	105	112	82.77768	89.17989	91.33402	**92.32777**	93.27016	94.16503	95.82928	98.07704	101.4169	107.5941	113.6013	119.2353	135.023
218	620226	3696889	18.92921031	Center	105	112	80.74799	84.46722	85.20688	**85.42872**	85.56009	85.60811	85.48413	84.86157	83.1059	78.83684	75.0172	71.92928	63.59439
219	619998	3697064	18.89281035	Center	105	112	78.56682	79.8549	79.40816	**79.00745**	78.50311	77.90723	76.48918	73.97093	69.36839	61.05148	55.17284	51.39549	46.25731
220	619804	3697143	18.81251153	Center	105	112	76.81659	76.07199	74.6896	**73.82051**	72.85649	71.81568	69.57376	66.04208	60.44793	52.32217	48.04136	46.06869	45.14684
221	619619	3697158	18.69319919	Center	105	112	75.13284	72.40835	70.20754	**68.96066**	67.65038	66.30098	63.57134	59.65227	54.21549	47.89285	45.49178	44.80114	45.31833
222	619466	3697128	18.56441379	Center	105	112	73.62362	69.18204	66.38121	**64.89185**	63.38518	61.88843	59.0116	55.1998	50.50489	46.04829	44.86667	44.77195	45.57595
223	619088	3696935	18.16167897	Center	105	112	68.96864	60.41148	56.88731	**55.29587**	53.84662	52.5476	50.39436	48.1433	46.20974	45.33136	45.46211	45.66648	45.96773
224	618909	3696888	18.0026668	Center	105	112	65.67891	55.74169	52.54614	**51.24682**	50.14029	49.21148	47.80981	46.55505	45.72945	45.61414	45.78596	45.89766	45.99583
225	618654	3697053	17.94190365	Center	105	112	46	46	46	**46**	46	46	46	46	46	46	46	46	46
226	618515	3697109	17.88474013	Center	105	112	55.39825	46.08978	44.45821	**43.93567**	43.55627	43.28861	42.99278	42.90822	43.16776	43.95125	44.59902	45.06277	45.82864
227	618291	3696785	17.49647331	Center	105	112	67.25617	58.46833	55.14223	**53.64976**	52.28116	51.03545	48.88957	46.40571	43.65806	40.92667	39.79906	39.30845	38.90935
228	618144	3696545	17.22212472	Center	105	112	75.39791	74.01765	72.94817	**72.38669**	71.82578	71.2748	70.22588	68.81947	66.88946	63.94507	61.51158	59.31001	52.10181
229	618013	3696366	17.00257522	Center	105	112	80.89148	86.47955	88.52228	**89.52487**	90.5205	91.51206	93.49008	96.45187	101.339	110.5422	118.5488	125.1931	140.0695
230	617818	3696384	16.87907348	Center	105	112	86.30843	98.99743	104.0012	**106.4119**	108.7458	110.9941	115.213	120.8151	128.2795	137.5779	142.1112	144.2257	145.9244
231	617594	3696288	16.65387568	Center	105	112	99.30505	122.0468	128.6427	**131.3134**	133.6053	135.5583	138.6122	141.6138	144.1544	145.6658	145.938	145.9883	146
232	617361	3696338	16.52701756	Center	105	112	146	146	146	**146**	146	146	146	146	146	146	146	146	146
233	615874	3695630	14.98342065	Center	105	112	74.25539	74.82021	74.46226	**74.18803**	73.86246	73.49448	72.66428	71.28516	68.9277	64.7391	61.3884	58.71189	52.49167
234	615606	3695473	14.68429576	Center	105	112	73.22587	73.08763	72.40436	**71.958**	71.4549	70.90495	69.70233	67.76428	64.55895	59.27393	55.61274	53.1413	49.11767
235	615160	3696533	15.14057661	Center	105	112	48	48	48	**48**	48	48	48	48	48	48	48	48	48
236	615408	3696750	15.46875642	Center	105	112	64.53903	57.73254	55.57912	**54.68552**	53.90607	53.23027	52.14206	51.00241	49.88377	48.8739	48.44249	48.22908	48.01664
237	615913	3696935	15.95125923	Center	105	112	64.89278	61.20553	60.62518	**60.44555**	60.31564	60.22231	60.10805	60.03392	60.00245	59.99903	59.99981	59.99997	60
238	616014	3696944	16.02756981	Center	105	112	60	60	60	**60**	60	60	60	60	60	60	60	60	60

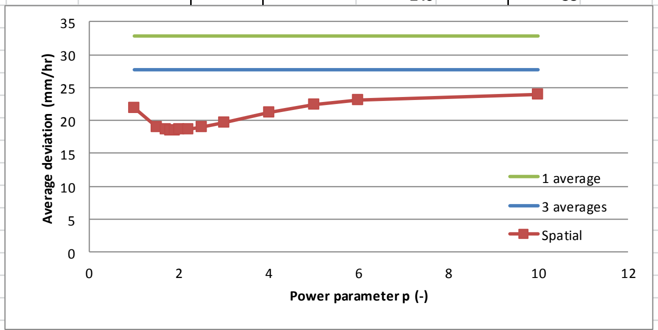
239	618319	3697234	17.83730679	Center	105	112	32	32	32	**32**	32	32	32	32	32	32	32	32	32
240	618014	3697506	17.81976366	Center	105	112	65.24947	54.94064	50.92735	**49.10876**	47.434	45.90583	43.27235	40.24408	36.97635	33.94389	32.81958	32.36746	32.02148
241	617820	3697559	17.72287308	Center	105	112	69.05522	62.35415	59.16862	**57.59914**	56.07332	54.60515	51.87444	48.3297	43.76236	38.13703	35.20812	33.68219	32.14461
242	617617	3697547	17.57316444	Center	105	112	71.5716	68.04146	66.04596	**65.00753**	63.96303	62.92423	60.89707	58.04911	53.88035	47.31643	42.48557	39.00634	33.21592
243	617303	3697417	17.26158411	Center	105	112	74.59228	75.3262	75.31104	**75.27879**	75.24047	75.20179	75.1396	75.11417	75.26185	75.88688	76.41068	76.61928	74.8401
244	617017	3697444	17.08268281	Center	105	112	74.82747	76.33437	76.69544	**76.85649**	77.01271	77.16884	77.49361	78.03665	79.09579	81.44279	83.59201	85.34074	88.98908
245	616680	3697376	16.80023117	Center	105	112	74.03524	74.58418	74.41953	**74.28932**	74.13637	73.96612	73.58947	72.96999	71.85291	69.40823	66.97338	64.90479	60.94575
246	616386	3697377	16.5976081	Center	105	112	72.09283	70.47427	69.41519	**68.86388**	68.31443	67.77568	66.75449	65.4074	63.67176	61.63404	60.70151	60.2939	60.00819
247	613577	3695769	13.49675416	Center	105	112	66.74464	63.62371	61.99789	**61.13758**	60.25792	59.36757	57.58781	55.02297	51.32686	46.59753	44.58883	44.03817	45.51364
248	618647	3694181	15.89753169	Center	105	112	87.26969	97.39328	101.0246	**102.7274**	104.3523	105.8988	108.7601	112.5056	117.5039	124.2433	128.3609	130.9284	134.4218
249	625131	3694977	21.10332941	Center	105	112	126.2273	167.4016	176.8163	**180.1309**	182.7114	184.6998	187.3777	189.4226	190.598	190.9715	190.9978	190.9998	191
250	625340	3695154	21.37678187	Center	105	112	191	191	191	**191**	191	191	191	191	191	191	191	191	191
251	630126	3707898	33.71787892	Downstre	56	56	67.03059	66.22006	65.91934	**65.76817**	65.61516	65.4599	65.14282	64.65791	63.87196	62.61149	61.84238	61.42613	61.02559
252	629899	3707859	33.53079157	Downstre	56	56	66.52974	65.11826	64.5945	**64.34526**	64.10536	63.87546	63.44792	62.89241	62.19239	61.44091	61.15649	61.05475	61.00079
253	629727	3707798	33.36667826	Downstre	56	56	65.27663	63.2258	62.67279	**62.44618**	62.24832	62.076	61.79639	61.50302	61.2302	61.04665	61.00927	61.00184	61
254	629619	3707672	33.20111518	Downstre	56	56	61	61	61	**61**	61	61	61	61	61	61	61	61	61
255	629519	3707508	33.01407612	Downstre	56	56	67.30322	66.06504	65.49345	**65.20805**	64.92752	64.65458	64.13941	63.46048	62.59261	61.63046	61.24184	61.09176	61.00186
256	629477	3707240	32.79366847	Downstre	56	56	74.34063	80.19193	82.05872	**82.87577**	83.62156	84.30193	85.49054	86.92426	88.65691	90.70833	91.77956	92.35255	92.95052
257	629433	3707006	32.59619155	Downstre	56	56	93	93	93	**93**	93	93	93	93	93	93	93	93	93
258	629256	3706887	32.38715814	Downstre	56	56	75.43376	83.12737	85.507	**86.50617**	87.38631	88.15683	89.4108	90.72564	91.94462	92.77234	92.95001	92.98881	92.99997
259	629086	3706758	32.1759319	Downstre	56	56	69.16961	72.65768	74.40105	**75.28911**	76.17417	77.04832	78.74031	81.08186	84.35768	88.68961	90.92561	92.01543	92.95074
260	628953	3706591	31.96364326	Downstre	56	56	64.57102	62.63872	62.1893	**62.02353**	61.89115	61.78798	61.65442	61.59235	61.72811	62.45491	63.42493	64.46391	68.58046
261	611812	3690575	8.526927691	Upstream	29	29	56.36973	48.05549	44.76707	**43.18109**	41.64591	40.16829	37.40445	33.76988	29.03606	23.35458	20.56543	19.09853	16.88059
262	611836	3690620	8.575907531	Upstream	29	29	56.4941	48.24295	44.97384	**43.39606**	41.86814	40.39685	37.64331	34.01936	29.29584	23.62939	20.85895	19.41139	17.21782
263	611866	3690647	8.616181429	Upstream	29	29	56.68152	48.55951	45.33426	**43.77546**	42.26432	40.80755	38.07616	34.46943	29.74252	24.02065	21.20104	19.7283	17.52392
264	611882	3690673	8.645969937	Upstream	29	29	56.77294	48.70312	45.49464	**43.94304**	42.43824	40.98701	38.26439	34.66589	29.94371	24.22104	21.40483	19.9414	17.77282
265	612255	3691121	9.227156971	Upstream	29	29	59.23167	52.77361	50.12163	**48.81583**	47.5327	46.27789	43.87127	40.56387	35.93554	29.69165	26.30875	24.58673	23.38455
266	612200	3691117	9.185929646	Upstream	29	29	58.85117	52.08991	49.3231	**47.96454**	46.63254	45.33326	42.85223	39.47159	34.81705	28.7534	25.64034	24.14452	23.27481
267	612120	3691052	9.083554068	Upstream	29	29	58.29469	51.13935	48.23201	**46.81069**	45.42177	44.07188	41.5093	38.05541	33.39051	27.53355	24.66769	23.33743	22.49271
268	612063	3690963	8.980016868	Upstream	29	29	57.90831	50.51446	47.52729	**46.07118**	44.65122	43.27407	40.66843	37.17613	32.50042	26.70421	23.88429	22.54602	21.36994
269	612024	3690885	8.896920393	Upstream	29	29	57.65624	50.12287	47.09113	**45.61587**	44.17893	42.78693	40.15755	36.64252	31.95178	26.14846	23.30012	21.90418	20.37325
270	612866	3686053	6.075515543	Upstream	29	29	47.59626	35.41763	31.52719	**29.82533**	28.27783	26.87488	24.45561	21.6144	18.31929	14.58035	12.64951	11.60231	10.42848
271	612795	3686009	5.993948599	Upstream	29	29	48.17667	36.32525	32.48956	**30.8009**	29.25907	27.85558	25.4218	22.53897	19.1543	15.22171	13.10864	11.91369	10.48337
272	612760	3685953	5.929807508	Upstream	29	29	48.54525	36.89033	33.08558	**31.40373**	29.86417	28.45934	26.01521	23.10653	19.67098	15.63389	13.41771	12.13329	10.53291
273	612737	3685886	5.866597462	Upstream	29	29	48.86052	37.3662	33.58528	**31.90815**	30.36956	28.96277	26.50872	23.57777	20.10193	15.9878	13.69285	12.33554	10.58453
274	612701	3685770	5.759915238	Upstream	29	29	49.32829	38.07454	34.33169	**32.66305**	31.12747	29.71935	27.25381	24.29499	20.76935	16.56196	14.16132	12.69435	10.68195
275	612671	3685713	5.69867401	Upstream	29	29	49.56056	38.43636	34.71763	**33.05582**	31.52426	30.11793	27.65119	24.68448	21.14261	16.90199	14.45371	12.92849	10.74884
276	612673	3685664	5.665961996	Upstream	29	29	49.68078	38.60477	34.8902	**33.22794**	31.69476	30.28588	27.81256	24.83527	21.28014	17.02737	14.56752	13.02526	10.78466
277	612714	3685458	5.551940609	Upstream	29	29	50.13932	39.21966	35.50989	**33.84088**	32.29656	30.87347	28.36684	25.33926	21.72377	17.42947	14.95006	13.37051	10.94182
278	612610	3685707	5.650753223	Upstream	29	29	49.71513	38.71469	35.02935	**33.38042**	31.85948	30.46176	28.00754	25.05139	21.51552	17.26237	14.77299	13.18972	10.82124
279	628766	3706259	31.59601033	Downstre	56	56	53.32434	40.43612	36.47366	**34.80091**	33.31988	32.0152	29.86781	27.56198	25.3182	23.61826	23.17161	23.04893	23.00036
280	628586	3706024	31.30233437	Downstre	56	56	23	23	23	**23**	23	23	23	23	23	23	23	23	23
281	628516	3705821	31.10877199	Downstre	56	56	47.6346	32.82974	29.40411	**28.14441**	27.12606	26.30689	25.12414	24.09811	23.3717	23.0449	23.00569	23.00075	23
282	628403	3705420	30.74435988	Downstre	56	56	59.32112	49.48079	45.50107	**43.61152**	41.84177	40.11305	37.04301	33.26682	28.91476	24.86395	23.57626	23.17851	23.00176
283	628122	3705283	30.44924464	Downstre	56	56	61.59462	54.04266	50.74641	**49.1088**	47.49704	45.92275	42.92344	38.88831	33.54355	27.30946	24.68574	23.65171	23.01491

Deviation

Site number	1 average	3 averages (validation)	3 averages	Measured	Spatial interpolation, varying power parameter p												
					p=1	p=1.5	p=1.7	**p=1.8**	p=1.9	p=2	p=2.2	p=2.5	p=3	p=4	p=5	p=6	p=10
11	**68**	**29**	29	6	49.171669	38.88874	35.73964	**34.37532**	33.13785	32.01507	30.06379	27.70302	24.72302	20.51799	17.5224	15.33169	11.26916
18	**68**	**29**	29	41	52.173386	43.91256	41.66697	**40.7543**	39.96328	39.27903	38.17467	37.00015	35.78164	34.42484	33.53378	32.85456	31.58775
103	**68**	**29**	29	40	44.474072	27.4217	23.59758	**22.26205**	21.22786	20.43557	19.37804	18.58426	18.14207	18.00941	18.00074	18.00007	18
211	**68**	**105**	112	58	76.857063	84.56416	88.27805	**90.26313**	92.3288	94.47031	98.95806	106.0994	118.5651	142.1309	160.0502	171.8568	188.0795
240	**68**	**105**	112	27	65.249466	54.94064	50.92735	**49.10876**	47.434	45.90583	43.27235	40.24408	36.97635	33.94389	32.81958	32.36746	32.02148
41	**68**	**105**	112	150	88.274261	99.30376	103.439	**105.4189**	107.3342	109.1819	112.6671	117.3633	123.8539	132.8803	138.4849	142.11	147.9535
69	**68**	**56**	56	38	54.944019	47.43112	46.05094	**45.6319**	45.35167	45.18146	45.07458	45.23803	45.75048	46.50349	46.81791	46.93423	46.99888
76	**68**	**56**	56	54	54.770046	46.62323	44.44491	**43.57735**	42.83941	42.21608	41.25502	40.33882	39.6197	39.31347	39.37867	39.49577	39.73203
80	**68**	**56**	56	70	68.351814	70.55393	72.03994	**72.87322**	73.74678	74.64526	76.45856	79.03965	82.51254	86.20242	87.44387	87.82838	87.99829
DIFFERENCE																	
11	62	23	23	0	43	33	30	**28**	27	26	24	22	19	15	12	9	5
18	27	-12	-12	0	11	3	1	**0**	-1	-2	-3	-4	-5	-7	-7	-8	-9
103	28	-11	-11	0	4	-13	-16	**-18**	-19	-20	-21	-21	-22	-22	-22	-22	-22
211	10	47	54	0	19	27	30	**32**	34	36	41	48	61	84	102	114	130
240	41	78	85	0	38	28	24	**22**	20	19	16	13	10	7	6	5	5
41	-82	-45	-38	0	-62	-51	-47	**-45**	-43	-41	-37	-33	-26	-17	-12	-8	-2
69	30	18	18	0	17	9	8	**8**	7	7	7	7	8	9	9	9	9
76	14	2	2	0	1	-7	-10	**-10**	-11	-12	-13	-14	-14	-15	-15	-15	-14
80	-2	-14	-14	0	-2	1	2	**3**	4	5	6	9	13	16	17	18	18
sum	128	86	107	0	70	30	22	20	19	19	21	28	42	70	90	103	120
ABSOLUTE DIFFERENCE																	
11	7	3	3	0	5	4	3	3	3	3	3	2	2	2	1	1	1
18	3	1	1	0	1	0	0	0	0	0	0	0	1	1	1	1	1
103	3	1	1	0	0	1	2	2	2	2	2	2	2	2	2	2	2
211	1	5	6	0	2	3	3	4	4	4	5	5	7	9	11	13	14
240	5	9	9	0	4	3	3	2	2	2	2	1	1	1	1	1	1
41	9	5	4	0	7	6	5	5	5	5	4	4	3	2	1	1	0
69	3	2	2	0	2	1	1	1	1	1	1	1	1	1	1	1	1
76	2	0	0	0	0	1	1	1	1	1	1	2	2	2	2	2	2
80	0	2	2	0	0	0	0	0	0	1	1	1	1	2	2	2	2
sum	**33**	**28**	**29**	**0**	**22**	**19**	**19**	**18**	**19**	**19**	**19**	**19**	**20**	**21**	**22**	**23**	**24**

11	43
18	11
103	4
211	19
240	38

1	21.89041	27.77778	32.88889
1.5	18.9936	27.77778	32.88889
1.7	18.58015	27.77778	32.88889
1.8	18.47109	27.77778	32.88889
1.9	18.51493	27.77778	32.88889
2	18.56726	27.77778	32.88889
2.2	18.70584	27.77778	32.88889
2.5	19.00419	27.77778	32.88889
3	19.68112	27.77778	32.88889
4	21.18563	27.77778	32.88889
5	22.36177	27.77778	32.88889
6	23.09536	27.77778	32.88889
10	23.89935	27.77778	32.88889



Appendix E. Interpolation code

```
program interpolation

          implicit none
          real knoflook(3), ui(4), distance, x1, y1, x2, y2, p, w, wcum
          integer a, b, n
          real,dimension(:,:),allocatable :: inputpoints, allpoints
          !knoflook: to create allpoints matrix
          !ui: to create inputpoints matrix
          !distance: distance between the measured site and the estimation site (m)
          !x1, y1, x2, y2: coordinates of estimation site (1) and measured site (2)
          !p: parameter which sets dependency of weighting factor on distance.  High value means values of
near sites are relatively important
          !w: weighting factor
          !wcum: cumulative weighting factor
          !a, b: counters
          !n number of measured sites
          !inputpoints: matrix with number, coordinates and measured conductivity of measured points
          !allpoints: matrix with number, coordinates and measured/estimated conductivity of all points

          print*, "p=?"
          read(*,*)p
          n=42
          allocate(inputpoints(n,4),allpoints(283,4))

!--------------INPUT inputpoints---------------!
          open(unit=10, file="inputpoints.txt")
          do a=1,n
                    read(10,*)ui
                    inputpoints(a,1)=ui(1)
                    inputpoints(a,2)=ui(2)
                    inputpoints(a,3)=ui(3)
                    inputpoints(a,4)=ui(4)
                    print*, a, ui(4)
          enddo
          close(10)

!------------- INPUT allpoints----------------!
          open(unit=11, file="allpoints.txt")
          do a=1,283
                    read(11,*)knoflook
                    allpoints(a,1)=knoflook(1)
                    allpoints(a,2)=knoflook(2)
                    allpoints(a,3)=knoflook(3)
          enddo
          close(11)
!-------------CREATE OUTPUT---------------------------------!
                    do a=1,n
                    allpoints(INT(inputpoints(a,1)),4)=inputpoints(a,4)
                    enddo

          do a=1,283
```

```
        wcum=0
        if(allpoints(a,4).eq.0)then
            !calculate value
            do b=1,n
                !calculate distance between points output(a,*) and inputpoints(b,*)
                x1=allpoints(a,2)
                y1=allpoints(a,3)
                x2=inputpoints(b, 2)
                y2=inputpoints(b, 3)
                distance=((x1-x2)**2.+(y1-y2)**2.)**(1./2.)
                !determine weighting factor
                w=1/(distance**p)
                if(distance.eq.0)then
                    w=0
                endif
                wcum=wcum+w
                allpoints(a,4)=allpoints(a,4)+w*inputpoints(b,4)
            enddo
        endif
        if(allpoints(a,4).lt.6)then
            allpoints(a,4)=allpoints(a,4)/wcum
        endif
    enddo

!---WRITE OUTPUT------------------------------------------------!
    open(unit=12, file="output.txt")
    write(12,*) allpoints

    end program
```

Appendix F. Literature

Introduction

Literature

In this sheet you will find important titles for studying artificial recharge, especially in the Oum Zessar watershed (South Tunisia)
Some of the publications have already been read and summarized in the sheet 'horizontal summary'.
The paper publications which are available at the IRA are given in the sheet 'Available at IRA'.
Also, multiple models have been studied and compared in the last three sheets.

Stan van den Bosch dec-13
Alterra, Wageningen, the Netherlands
Institut des Régions Arides, Médenine, Tunisia

Vertical

Author	Year	Type	Remarks	Title		
Bouwer	1986			Intake rate: cylinder infiltrometer		
Mansouri	1992			Impact de l'exploitation sur l'évolution des caractérisiques hydrodynamiques et hydrochimiques du réservoir carbonaté de Zeuss-Koutine		
Osterkamp et al.	1995	article		Techniques of ground-water recharge estimates in arid/semi-arid areas, with examples from Abu Dhabi		
Sorman et al.	1997	articlle		Groundwater recharge estimation from ephemeral streams. case study, wadi Tabalah, Saudi Arabia		
Von Hofe and Helweg	1997	article		Modelling well dynamics		
Al-Qinna and Abu-Awwad	1998			Infiltration rate measurements in arid soils with surface crust		
Williams et al.	1998	EPA document		Estimation of infiltration in vadose zone: application of selected mathematical models		
Shentsis et al.	1999			Assessment of transmission losses and groundwater recharge from runoff events in a wadi under shortage of data on lateral inflow, Negev, Israel		
Nabil	2000	Report		Etude hydrologique d'un bassin versant du sud Tunisien, cas de bassin Oum Zassar		
Bouwer	2002			Artificial groundwater recharge: hydrogeology and engineering		
De Graaff & Ouessar	2002	book (in	Contains Oues	Water harvesting in medditerranean zones: an impact assessment and economic evaluation		
Ouessar et al.	2002		Can be found i	Water harvesting in southeastern Tunisia: state of knowledge and challenges		
Schiettecatte et al.	2002		Can be found i	Impacts of water harvesting techniques on soil and water conservation at field and sub-catchment scale in the Oued Oum Zessar watershed		
Yahyaoui, Chaieb, Ouessar	2002		Can be found i	Impact des travaux de conservation des eaux et des sols sur la recharge de la nappe de Zeuss-Koutine		
De Graaff et al.	2002		Can be found i	Tools for decision-making on water harvesting techniques in arid zones		
Sghaier et al.	2002		Can be found i	Economic assessment of water harvesting techniques: case of the Oued Oum Zessar watershed		
Ouessar et al.	2003	book		La désertification: ressources en eau et sols et evaluation des techniques actuelles de lutte contre la désertification		
Temmerman	2004	scriptie		Evaluation of the efficiency of recharge wells on the water supply to the water table in South-Tunisia		
Bacquaert	2004	scriptie		Influence of gabions on water use efficiency in the wadi Oum Zessar (Tunisia)		
Ouessar et al.	2004			An integrated approach for impact assessment of water harvesting techniques in dry areas: the case of Oued Oum Zessar watershed (Tunisia)		
Fleskens et al.	2005			Evaluation of the on-site impact of water harvesting in southern Tunisia		
Schiettecatte et al.	2005			Impact of water harvesting techniques on soil and water conservation: a case study on a micro catchment in southeastern Tunisia		
Hilkert	2005			Design of a recharge well in the dry regions of Tunisia		
Niswonger et al.	2006	book, MODFLOW		Documentation of the unsaturated-zone flow (UZF1) package for modeling unsaturated flow between the land surface and teh water table with MODFLOW-2005		
Ouessar and Yahyaoui	2006	book	parts available	Les ressources en eau		
Ouessar and Yahyaoui	2006			Les ressources en eau		
Ouessar	2007	PhD thesis		PhD thesis		
Ouessar	2007	PhD thesis chapter		Chapter 1 Overview of water harvesting systems in the dry areas of Tunisia		
Ouessar	2007	PhD thesis chapter		Chapter 2 Physical and socio-economic characteristics of the study watershed		
Ouessar	2007	PhD thesis chapter		Chapter 3 Onsite hydrological effects of WHT		
Ouessar	2007	PhD thesis chapter		Chapter 4 Evaluation and adaptation of the GIS-based watershed model SWAT		
Ouessar	2007	PhD thesis chapter		Chapter 5 Use of SWAT-WH model for assessing the hydrological effects of land use changes		
Ouessar	2007	PhD conclusions		Chapter 6 Summary, conclusions and prospects		
Rosales et al.	2007	article		Estimating groundwater recharge induced by engineering systems in semiarid area (southern Spain)		
Pulido-Bosch et al.	2008	presentation		Technique for increasing aquifer recharge in semiarid regions		
RYM HADDAD NOUIRI	2008	MSc thesis		Actualisation du modèle hydrogéologique de la nappe de Zeuss-Koutine et évaluation des aménagements de CES sur sa recharge		
Ouessar et al.	2009			Modelling water-harvesting systems in the arid south of Tunisia using SWAT		
D'Oria et al.	2008		IAHR symposiu	Artificial groundwater recharge and water storage from a riperian pit		
D'Oria et al.	2009		IAHR symposiu	Artificial river ponds storing flood water as a resource for agriculture and groundwater recharge		
Chung et al.	2010			Assessing distributed groundwater recharge rate using integrate surface water-groundwater modelling: application to Mihocheon watershed, South Korea		
Al-Assa'd	2010			Artifical groundwater recharge to a semi-arid basin, case study of Mujib aquifer, Jordan		
Chenini et al.	2010			Groundwater recharge zone mapping using GIS-based multi-criteria analysis: a case study in central Tunisia (Maknassy Basin)		
Kacimov et al.	2010			Green-Ampt one-dimensional infiltration from a ponded surface into a heterogeneous soil		
Arlai et al.	2010			Numerical investigation of combined flood mitigation and groundwater recharge in the Chao Phraya river basin		
Kettata et al.	2011		wrong study area			
De Graaff et al.	2012			The development of water and soil conservation policies and practices in five selected countries from 1960 to 2010		
Hessel & Van den Elsen	2012	WAHARA report		WAHARA report 02 - D7.1 - WAHARA Website		
Ouessar et al.	2012	WAHARA report		WAHARA report 03 - D1.1 - Study Site Database		
Ouessar et al.	2012			Laboratory simulation of the efficiency of groundwater recharge well filters		
Hamed et al.	2012		possibly intere	Groundwater recharge areas of the Continental Intercalaire aquifer-hydrogeochemical and environmental analysis, southern Tunisia and Algeria		
Liang et al.	2012		mathematical	An new analytical method for groundwater recharge and discharge estimation		
Dong et al.	2012			An areal recharge and discharge simulating method for MODFLOW	for areal recharge/di	
Xu et al.	2013	article		Assessing the hydrological effect of the check dams in the loess plateau, China, by model simulations		
Mohtar	?		presentation			
Renganayaki and Elango	2013			A review on managed aquifer recharge by check dams: a case study near Chennai, India		
Papers on transmission losses						
Osterkamp et al. 1995						
Shentsis 1999	transmission losses					
Shentsis 2003	floodevent recharge					
Shentsis 2003	transmission losses					
Sorman 1997	recharge channel					
Von Hofe 1997	modelling flow dynamics					

Horizontal summary

red: contains fig/descr.

green: contains ref.

blue: possible (research) q.

Huisman and Olsthoorn
1983
Artifical groundwater recharge

When direct recharge is practiced by spreading water over pervious soils in basins, the amount of water entering the aquifer depends on: 1) infiltration rate 2) percolation rate 3) capacity for horizontal water movement

Bouwer
1986
Intake rate of infiltrometer

Ahmed Mamou
1990
Caractéristiques et évaluation des ressources en eau du sud Tunisien
Tunisie du sud

Contains: carte detaillée des isohyetes (1986)

du point de vue quantitatif, les eaux de surface apparaissent d'une importance secondair, dans le Sud tunisien. Leur irrégularité ainsi que l'aspect orageux des pluies font que leur mobilisation est dans tous les cas, relativement coûteuse

Les relief positifs comme le Dahar et la chaine de Gafsa introduisent une augmentation locale de la pluviométrie'/ Het lijkt erop (isohyet kaart) dat Oum Zessar meer regen in het zuiden ontvangt.

Il suffit, pendant deux à trois ans de suite, que les pluies soient plus rares et espacées pour que le bioclimat de la zone côtière passe de l'étage aride inférieur à l'étage saharien

déficit hydrique du sol est marqué durent, au moins dix mois par an, ce qui confère une importance capitale à l'eau souterraine. 'Sa préservation contre 'évaporation intense et continue, nécessite un enfouissement profond sous la surface du sol ce que n'est pas toujours le cas des nappe phréatiques.'

coefficient de ruissellement (Kr) à Oum Zessar: 7.3%: mais basé sur trop peu de données

P moyenne: 180 mm sur Oum Zessar

Oum Zessar: 278km2, compacité 1,34, indice de pente 15,1, profil en long est voisin de 31 km

1/3 de la superficie du bv oum zessar se situe dans la partie montagneuse

Castany (1967): seule une parte de l'eau infiltrée dite "infiltration efficace"contribue à la reconstitution des réserves des nappes

Zouari (1985): a conclue que l'eau infiltrée est susceptible d'être reprise par l'évaporation jusqu'à une profondeur de 7m (étude isotopique)

Aranyossy (1978): Même si la quantité de pluie efficace pénétrant dans le sol était important, le franchissement de la croûte gypseuse située entre 85 à 90 cm n'a pas été possible

Zouari (1985)? Coefficient d'infiltration efficace est égale à 2,8% (5,1/180). Ne dépasse 1/7 de la valeur de l'évaporation

Autres valeurs pour le coefficient d'infiltration efficace, basées sur la comparaison de quantité de pluie et augmentation du débit de sources: 3.2, et des valeurs oscillant entre 0.9 et 3.5 %.

Valeur pour le coefficient d'infiltration efficace, basée sur la comparaison entre la quantité de pluie et fluctuation piézométriques: 11%. (nappe phréatique)

"Les analyses isotopiques de (Zouari, 1988) permettent de conlcure à la parfaite coincidence entre le dernier interglaciaire et la dernière grande phase humide du Pleisocène au Sahara. On y dégage duex phases humides majeures, reconnues un peu partout dans le Sud tunisien qui se placent à -150 ka et à -85 ka. Il semble que ce sont ces deux phases humides qui sont responsables de la constitution de la majeure partie des réserves en eau des principales nappes du Sud tunisien." Une autre phaseL pendant l'Halocène inférieur et moyen (-11ka et -8 ka) a été moins important et a surtout joué sur les nappes profondes libres et phréatiques

contains: lithography at djeffara de Médenine until present p. 288

Mansouri
1992
Impact de l'exploitation sur l'évolution des caractérisiques hydrodynamiques et hydrochimiques du réservoir carbonaté de Zeuss-Koutine
Zeuss-Koutine

les resources en eau de la nappe de Zeuss-Koutine sont évaluées à 350 l/s B. Ben Baccar, 1981

Nappe de Zeuss-Koutine: contains Oueds Zigzaou, oum Zessar and Zeuss

Cette exploitation qui était de 102 l/s en 1974, est passée en 1979 à 207,5 l/s pour atteindre en 1985, 299 l/s puis 357 l/s en 1990 (nappe de Zeuss-Koutine

Le volume total d'eau de surface mobilisé lors des crues par ces traitements a été évalué à 4,617 Mm^/an (soit l'équivalent de 147 1/s f.c).

Between ~1975, 1988 and 1992, subsidence of water level has increased in oued Oum Zessar and Zeuss, but decreased in Zigzaou.

Between ~1975, 1988 and 1992, salinity increase became more pronounced in oued Oum Zessar and Zeuss, but less pronounced in Zigzaou

au bassin versant de oued zeuss, malgré l'importance des travaux de CES (52% de la surface totale est traité), la baisse piezométrique s'est accentuée depuis 1988 (achèvement du premier travail de CES). Ceci témoigne de l'effet faible des travaux de CES et de l'importance de l'exploitation. The increase in salinity also became stronger

Au bassin versant de oued Oum Zessar, la baisse des niveaux statiques au forages s'est aussi accentuée.

Many WHT do not contribute to recharge of deep layers: 42% of surface is affected by WHT, but only 10% of surface contributes to recharge of deep aquifers.

Travel time (of water or of pressure wave) to deep aquifer?

Osterkamp, Lane, Menges
1995
Techniques of groundwater-recharge estimates in arid/semi-arid areas, with examples from Abu Dhabi
Abu Dhabi, Oman

Uses approach similar to Lane 1983

event-based (5-yr flood)

method 1 channel morphology-discharge relations (assumes that channel geometry adapts to streamflow)

method 2: drainage basin/discharge relations. Use data from similar basins

CREAMS model was used. Calculates sequentially daily runoff, evapotranspiration, soil moisture, and deep percolation (recharge) below the vegetation zone. Requires records of daily precipitation, and estimates of monthly mean temperature, monthly mean radiation, rooting depth, soil properties, LAI

Uses approach similar to Lane 1982

Infiltration rates in wadis were are between 46 to 285 mm/hr and average 91 mm/hr

90% percent of recharge is through transmission loss of ephemeral stream beds, 10% by inter-wadi infiltration of soil water following sustained, infrequent precipitation events

uses curve numbers

groundwater recharge about 7% of precipitation

Sorman, Abdulrazzak, Morel-Seytoux
1997
Groundwater recharge estimation from ephemeral streams. case study, wadi Tabalah, Saudi Arabia
Tabalah, Saudi Arabia

vertical conductivity of riverbed 13.68 m/day

Al-Qinna and Abbu-Awwad
1998
Infiltration rate measurements in arid soils with surface crust
Al-Muwaqqar village, Jordan

Uses single ring infiltrometers, and double ring infiltrometers of 20/30cm

Soil surface sealing is a common feature on most soils in arid and semiarid regions, and is considered to be the major cause of low infiltration rates.

"The presence of only 0.1 mm of a thick crust may reduce the infiltration rate from 800 cm/day to 70 cm/day (McIntyre 1958a)"

"Investigations have indicated that the infiltration rate is less for prewetted surfaces than for dry surfaces due to the full development of the surface seal caused by the breakdown that occurred earlier during prewetting (Le Bissonais and Singer 1992)"

"Previous investigations at Al-Muwaqqar indicated that the infiltration rate measured by the double-ring infiltrometer was much higher than the average rainfall intensity, and yet significant runoff occurred even with low rainfall intensity. This indicated that measurements with the double-ring infiltrometer may be incorrect and lead to a false estimate of the infiltration rate (Shatanawi and Abu-Awwad 1994)."

Conversely, the correction factor F in the double-ring infiltrometer treatment was closer to 1 than that in the single-ring infiltrometer treatment. The average correction factors were 0.67 and 0.91 using single-and double-ring infiltrometers, respectively.

Double ring infiltrometer (20/30cm) driven 15cm into the ground, water depth of 72mm/hr applied (what does that mean??). Total infiltration in the order of 25mm.

Williams, Ouyang and Chen
1998
Estimating infiltration rate in vadose zone: application of selected models

Green Ampt model not valid for small time because it takes some time for piston-like flow to take place.

Shentsis, Meirovich, Ben-Zvi and Rosenthal
1999
Assessment of transmission losses and groundwater recharge from runoff events in a wadi under shortage of data on lateral inflow, Negev, Israel
Negev, Israel

water balance based: needs at least some streamflow data

assumes transmission losses are uniquely related to the total inflow of the reach

divides transmission losses in channel moistening, which evaporates, and deep percolation, which recharges groundwater

for large runoff events, transmission losses were substantially larger than the evaporation. Evaporation was about 1-2% of total transmission loss. For small runoff events, the evaporation was equal to transmission loss

uses recurrence intervals to infer streamflow at ungauged wadis

Schwartz and Schlick concluded that transmission losses were closely related to volume of vacant voids in the riverbed alluvium, and as such is correlated to the time elapsed to the last rainfall event.

evaporation is assumed to decline exponentially, proportional to potential evaporation and ratio of soil surface layer moisture to porosity, and initial moisture is assumed to be field capacity

Bouwer
2002
Artificial groundwater recharge: hydrogeology and engineering

-

Recharge wells should be pumped periodically to backwash clogging layers

Recharge wells can inject directly into the aquifer, or into the unsaturated zone where it percolates to the water table

contains: figure recharge wells

Bouwer (1989, 200c and references therein) and Tyler et al. (1996): natural recharge is about 0-2% of precipitation in dry areas, whereas it is about 10-20% in medditeranean type climates and 30-50% in temperate humid climates.

Tyler et al. 1996: Water ages in deep aquifers in dry climates can be over tens of thousands of years

Enhanced recharge can be done by replacing deep-rooted vegetation with shallow-rooted vegetation or bare soil; or by changing to vegetation that intercept less precipitation with their foliage.

In dry areas, crops are irrigated with more water than needed for ET. This is to prevent salt accumulation, but the leached water has a higher salinity than the water used for irrigation. This, along with agricultural and other chemicals degrades the groundwater quality (Bouwer et al. 1999a, Bouwer 2000b)

Urbanization can increase recharge, because roofs can have lower evaporation than plants.

Disadvantage dam: evaporation can be 2m/yr in warm, dry climate

Clogging of infiltration surfaces (so not necessarily in wells) can happen due to deposition and accumulation of suspended solids (algae, sediments and sludge), formation of biofilms and biomass on and in the soil, precipitation of calcium carbonates and other salts on and in the soil, and formation of gases that stay trapped in the soil where they block pores and reduce hydraulic conductivity.

Clogging is the bane of all artificial recharge systems (Baveye et al. 1998, Bouwer et al. 2001, Bouwer and Rice 2001).

Bouwer and Rice (2001) observed clogging by microbiological growth in the lab using high-quality drinking water in a dark environment

Free-falling water should be avoided in recharge wells in order to prevent air entrainment and entrapment in the soil.

In one project, where extensive pretreatment is used and the recharge wells are backpumped three times a day for 30 minutes, no clogging occurred in three years of operation

Another type of artificial recharge is where a gravel backfill is placed where an aquitard is present. This will drain the perched water table

De Graaff & Ouessar
2002
Water harvesting in medditerranean zones: an impact assessment and economic evaluation

Yahyaoui, Chaieb, Ouessar
2002
Impact des travaux de conservation des eaux et des sols sur la recharge de la nappe de Zeuss-Koutine

Can be found in De Graaff & Ouessar (2002)

Zeuss-Koutine aquifer is a multi-aquifer system with a surface of 785km2, average rainfall 190mm/yr

potential resources of the aquifer is estimated at 320 l/s

overexploitation has led to a decline of mean piezometric level of 11.3 m

abstraction rate in 1996: 420 l/s

Stan's calculation: 190mm/yr means 472 l/s average precipitation

pumping of the aquifer led to a vertical homogenization of chemical properties groundwater: deep groundwater becomes less saline, shallow groundwater increased salinity. Groundwater recharge is expected to decrease this effect

le coefficient de ruissellement anuel moyen a été évalué à 7% de la pluviométrie anuelle moyenne

map of aquifers belonging to Zeuss-Koutine aquifer system and their recharge

subdivise l'aquifère de Zeuss-Koutine en 725 mailles carrés régulières de 1km de côté (Derouiche, 1997)

1975 le débit d'alimentation de la nappe à partir d'infiltration des eaux de ruisselement a été estimé à 283 l/s

1975 la contribution des eaux pluviales dans l'infiltration directe a été estimé à 4 l/s au niveau des reliefs de Matmata et prâtiquement nulle sur le reste du domaine

1975 le débit transitant de la nappe de grès Triassique vers la nappe de Zeuss-Koutine a été estimé a 36 l/s

utilise 64 phases de calcul pour la période de 1975/2000

le débit d'infiltration à partir du réseau hydrographique a augmenté de 283 l/s en 1975 à 488 l/s en 2000: due au travaux C.E.S (conservation des eaux et des sols)

carte des rabattements piézométrique de la nappe par rapport à l'année de référence

Schiettecatte, Ouessar, Gabriels, Abdelli
2002
Impacts of water harvesting techniques on soil and water conservation on field and sub-catchment scale in the Oued Oum Zessar watershed

Ouessar, Zerrim, Boufelgha, Chniter **2002** **Water harvesting in southeastern Tunisia: state of knowledge and challenges**
Can be found in De Graaff & Ouessar (2002)
Topographic, geologic, pedologic description of South-Eastern Tunisia
Boers and Ben-Asher 1982: WHT traits: 1) applied in arid and semi-arid regions 2) depend on local water 3) operable on relatively small scale
Ennabli (1993) and Mechli and Ouessar (2002) published a compilation of WHTs applied in Northern Africa and particularly Tunisia
Division of WHTs in three categories
Jessour: first described around 1100
Jessours also control floods, ensure water table recharge and prevent wind erosion
Jessours are being abandoned due to emigration and a shift to non-agricultural activities
Recharge wells very effective in areas with low bedrock permeability, usefull for improving water level and salinity (Yahyaoui 1997, Yahyaoui and Ouessar 2000)
Terraces were used, but are currently totally abandoned as WHT. Currently used in small-scale afforestation works.
contains table with info on aquifers

De Graaff, Sghaier, Ouessar, Gabriels **2002** **Tools for decision-making on water harvesting techniques in arid zones**
Can be found in De Graaff & Ouessar (2002)

Sghaier, Mahdhi, De Graaff, Ouessar
2002
Economic assessment of water harvesting techniques: case of the Oued Oum Zessar watershed

Can be found in De Graaff & Ouessar (2002)

Ouessar et al.
2003
La désertification: ressources en eau et sols et evaluation des techniques actuelles de lutte contre la désertification

déscription des bassins versants de tunisie

déscription des nappes d'eau de Tunisie

déscription des sols de Tunisie

Ouessar, Sghaier, Mahdhi, Adelli, De Graaff, Chaieb, Yahyaoui, Gabriels
2004
An integrated approach for impact assessment of water harvesting techniques in dry areas: the case of Oued Oum Zessar watershed (Tunisia)

rainfall is characterized by its scarcity, variability, torrential nature and poor distribution

in dry parts of Tunisia, real ET/potential ET is generally very low and does not exceed 0,3 which indicates a deficit in the water balance (Hénia 1993)

Ennabli (1993) Ben Mechlia and Ouessar (2002), how ancient civilizations coped with the aridness

the oued Oum Zessar has three main tributaries: oued Negueb, oued Mogar and oued Hallouf

Fleskens, Stroosnijder, Ouessar, De Graaff
2005
Evaluation of the on-site impact of water harvesting in southern Tunisia

Amrich jessr, Boughara (near Sfax, no WHT)

according to Ouessar (2002), Jessour cover an estimated 400,000 ha in southern Tunisia

Temmerman
2004
Evaluation of the efficiency of recharge wells on the water supply to the water table in South-Tunisia
Laboratory/oum zessar
Since 1990 several gabions have been constructed (Bacquaert, 2004). In eight of them, a recharge well was additionally installed at their downstream end
schematisch study area map
question: variation coefficients in %: how does it work
rivers flow in valleys of old rivers now partially filled with sediment, which were formed during a more humid period.
Rain may fail to appear for a whole year (Heirman, 2002)
After heavy rainfall, water will flow with great power through the river valleys and eventually deposit silt and clay, thereby greatly increasing fertility in the inundated areas.
Watershed Oum Zessar consists of the following rivers: Oum Zessar, Nague, Hallouf, Koutine, Moggor, Nkim, Moussa, Lahimar, Halg, Jemel, Amid
In the whole southeast region of the Matmatas, the total annual runoff is estimated at 10^8m3, of which only 25% is conserved by WHT
Contains: geologic description
Geologic description is based on the work of Maati (2001)
There are two major discordances in the study area
Aquifer of Zeuss-Koutine is the source of all good quality water in the area.
Recharge wells are mostly installed in slightly developed soils of colluvial and alluvial genesis. These are relatively deep soils functioning as water conducting layers and can be located at river beds, irrigation zones (canalisations) and behind Jessour.
question colluvial/alluvial
There are two main aquifers in Southern Tunisia: the Complexe Terminal (under the Dahar and mainly stretching out in to Algeria) and the Continental Intercalary (under the grand erg oriental/occidental)
Jeffara aquifer is fed by the continental intercalary and by infiltration in the mountains of Matmata. Is overexploited, especially at the level of Zeuss-Koutine
Contains: quantities of extraction and replenishment of different aquifers.
Contains: hydrogeologic map of aquifers
Phreatic/surface aquifers are mostly generated by the subsurface underflow of the main rivers
Horizon A and horizon B of the inferior Senonian limestone constitute a hydrogeological continuity, called the aquifer of Zeuss-Koutine (Mtimet, 1994)
Since 1986 there has been overexploitation, which in 1996 reached 120% (an amount equal to 120% of the average yearly replenishment was used), but declined to 84% in 2000 (no overexplotation) SOURCE?
Contains: info on flow direction in aquifers
Flow in Grès de Trias is towards North-East
Recharge of the water table is influenced by: supply zone, water quantities (runoff, conductivity, etc.), type of recharge work and the site of the work
(Mansouri 1997) and this paper contain table with amount of pumped water and amount of precipitation
Water pumped out of Zeuss-Koutine aquifer is lower in 1996 than before because of appropriate water management
The region of what is today Algeria, Tunisia and Libya was once the granary of the Roman Empire.
Contains figure of Meskat
CCR values of meskat have decreased due to increased population pressure
Alluvium layer of jessour can reach a depth of 5m
Contains figure of jessr
gabion is name of cage only, or of entire structure
gabion can be permeable or impermeable, depending on the goal of the gabion
gabion is flexible, can follow the changing shape of the land (useful if there is strong erosion).
Recharge wells consist of a short outer and a long inner casting tube.
Recharge well project was started on personal arrangement of Houcine Yahyaoui in 1995 (ministry of agriculture)
Contains: table w/ characteristics of Oum Zessar recharge wells
Idea: place filter with radius =4 m around well, easy to clean and reduces water velocity (so less sediment in water bc less turbulence)
Constant head method: For filters with different gravel dimensions, the initial effluent concentration was similar
Constant head method: high concentrations are relatively better filtered than low sediment concentrations
Constant head method: geotextile increases filtration capacity
Constant head: hydraulic conductivity decreases significantly, especially in first three minutes if the influent water contains sediment. If not, there is no decrease
Constant head: for the filter with small gravel dimensions, the conductivity decreases at the highest rate
The inner tube of recharge wells is generally connected with cracks in the impermeable underlying bedrock. The sediment in the injected water can fill up these cracks.
Sediment particles can form aggregates when accumulating in the pores of gravel filter bc they are pushed together
The aggregates attain greater dimensions when the influent concentration is high
The sediment size distribution may be an important factor determining the rate and severity of clogging
What is the correlation between filtration capacity and K decrease?
Falling head method: the amount of sediment in the gravel filter increases with increasing experiment number.
Question: how many kgs are trapped in the gravel filter?
To prevent sediment from reaching the well, a larger tube without filtration openings could be installed around the recharge well with little height.

Bacquaert
2004
Influence of gabions on water use efficiency in the wadi Oum Zessar (Tunisia)

Oum Zessar

texture samples taken by Ouessar (2002)

infiltrometer used: outer ring 53 cm, inner ring 28 cm

Schiettecatte, Ouessar, Gabriels, Tanghe, Heirman, Abdelli
2005
Impact of water harvesting techniques on soil and water conservation: a case study on a micro catchment in southeastern Tunisia

Wadi Oum Zessar watershed; jessr (impluvium) of Amrich (upstream of Wadi Nagab), rainfall measurements at Chouamekh and El Bhayra

terrace and impluvium of jessr of Amrich have areas of respectively 2750 and 80 000 m2

Very similar to Schiettecatte (2002): same study

Detailed description of WHT: El Amami (1984), Ennabli (1993), Ouessar et al. (2002)

Bourges et al. (1974) observed sediment losses (due to erosion) of 4000 kg/ha/yr. Stan's calculation: assuming density of 2000kg/m3 this amounts to a layer of .2mm being removed.

According to Ennabli (1993), the average sediment load in runoff waters in central and Southern Tunisia is close to 100g/l

Wadi Oum Zessar watershed is located between Gabès and Médenine and has an area of 367 km2

crop coefficient kc: from Lelivelt (2001)

actual evapotranspiration: Rijtema and Aboukhaled (1975)

Time compression approximation was used(Ibrahim and Brutsaert 1968)

For laboratory rainfall simulations, samples were subjected to a wetting and a drying cycle to obtain a sealed surface, simulating field conditions

rainfall simulation measurements deemed more accurate than small infiltration experiments: because (undesired) breaking of the sealed surface has a larger effect if the measurement area is small (as in the small inflitration experiments)

For estimating amount of runoff, rainfall intensity is important. Daily rainfall data is not sufficient. Therefore, rainfall measurements at Béni Khedache were not used

height of spillway at jessour is limited to ensure stability of the dike

spillway at Amrich jessr is 200mm high

optimal CCR values vary because runoff coefficients vary and average annual precipitation varies.

Ouessar and Yahyaoui **2006** **Les ressources en eau**	
?	
Parts can be found on internet	
Surface water discharge in wadis occurs only once every 4 or 5 years as a consequence of high precipitation storm events	
Bonvallet (1979) Precipitation is highest in steepest areas (when comparing hillslopes of Matmata with Dahar plateau)	
Estimation de la lame ruissellée	
Kallel (2001) a appliqué trois formules (Tixeront, Turc, Fersi) pour les Oueds de la Jeffara tunisienne. Il en a conclu que la formule de Fersi (Fersi, 1979) donne les valeurs les plus probables du ruissellement interannuel	
Ouessar **2007** **Chapter 1 PhD thesis: Overview of water harvesting systems in the dry areas of Tunisia**	
Wadi Oum Zessar	
West Asia and North Africa (WANA) is by far the driest region on earth (Stan: excepting Antarctica?)	
Off-site and onsite effects on watershed by WHT is assessed in Gabriels et al. (2005) and Ouessar et al. (2006a)	
In the 1970s, an attempt to prevent water runoff on farmlands by constructing barriers made of earth and vegetation was not very succesful due to disinterest of, and hence poor maintenance by farmers.	
description and figure of Tunisia's climate and agricultural regions	
WHT presented in Ennabli (1993), Ben Mechlia and Ouessar (2004), Ouessar (2006)	
figure mescat	
300 mm in one day recorded maximum in central region of Tunisia	
in some areas, decline of piezometric levels are an increasing concern (Yahyaoui and Ouessar, 2000 and Abaab et al. 1994)	
Average gabion height varies from 1 to 3 m and width is a function of wadi width (Royet, 1992)	
Recharge wells relatively effective for improving water level and salinity (Yayhaoui 1997, Yahyaoui and Ouessar 2000, Yahyaoui et al. 2002)	
recharge wells started in Zeuss-Koutine aquifer, then extended to other areas such as Jerba	
the recharge wells in south-eastern tunisia are still under experience for the direct replenishment of aquifers using fresh runoff water	

Ouessar
2007
PhD chapter 2: Physical and socio-economic characteristics of the study watershed

Wadi Oum Zessar
Wadi Oum Zessar representative of the arid south-east of Tunisia (ecologically, hydrologically and socio-economically); Chahbani 1984; Mzabi 1988; Talbi 1993;Khatelli 1996, Derouiche 1997, De Graaff and Ouessar 2002)
Study site stretches from Matmata mountain to Jeffara plains, saline depression (Sebkha) of Oum Zessar and ends in the mediterranean sea (gulf of Gabès). It is bordered on the north by the watershed of wadi Zeuss
Location map of wad Oum Zessar watershed
main wadis are: Nagab, Hallouf, Moggar, Nkim, Koutine. They become wadi Oum Zessar which flows into Sebaka Oum Zessar before flowing into the Gulf of Gabès
Fersi (1995) estimated the mean annual runoff of the study watershed at 4,7 million m3
outline map of Oum Zessar, Zeuss, Zigzaou and El Morra watersheds
Geology described by Mzabi (1988), Yahyaoui (2001a), and Gaubi (1988)
According to the ministry of agriculture regulation, shallow refers to a watertable depth of less than 50 m bgl.
Salt content of the shallow Oum Zessar watershed aquifer increases in downstream direction and varies between 2 and 5 g/l
Sidi Makhlouf (wadi El Morra) watershed is exploited by 112 wells (37 exploited by pumps), salt content also increases in downstream direction (2 to 5 g/l), but mostly exceeds 5 g/l when approaching the salt depression
Average withdrawal of shallow Oum Zessar aquifer: 3.3 l/s (Yahyaoui 1997, 1998, 2001a; Labiadh 2003; Ouessar and Yahyaoui 2006
Soil map
hydraulic history of the study watershed is ancient (Carton 1888)
Recharge wells in place near Koutine and Alamet

Ouessar
2007
Chapter 3 PhD thesis: Onsite hydrological effects of WHT
Watershed of Oum Zessar, jessr: Amrich; tabia: Astout, located upstream of wadi Hallouf and wadi Nagab.
Preferential recharge areas are piedmont areas and wadis in the Triassic Sandstone area (Gaubi 1995)
Natural recharge of aquifers can occur through various mechanisms: direct infiltration in rocky areas in the mountains, infiltration from the beds of ephemeral rivers (Moench and Kisiel 1970; Besbes et al. 1978; Sorman and Abdulrazzak 1993), subsurface drainage in mountainous areas through alluvial material of valley beds (Khazaei 1999) and direct infiltration into alluvial material in lower plains (Dincer et al. 1974)
Watershed contains ephemeral wadis that abstract runoff. This abstraction is called transmission loss, and it is assumed that this eventually leads to replenishment of the deep aquifers through percolation through soil and faults. (Gaubi 1988, Derouiche 1997, Yahyaoui and Ouessar 2000, Yahyaoui et al. 2002)
Recharge wells: Yahyaoui and Ouessar 2002, Ben Mechlia and Ouessar 2004
Main problem with recharge wells: clogging due to physical, chemical and biological processes (Bouwer 2002)
sediment depth times area of site gave retention capacity loss (assuming uniform depth of the sediment)
For gabion check dam structure analyses only surface layer was considered because it controls surface infiltration (Schwab et al. 1992)
Contains table with saturated conductivity values for various gabion check dam (and recharge well) sites in the Oum Zessar watershed (page 69)
Lane (1993) estimated that dry wadi river beds have a hydraulic conductivity of 25 to 75 mm/hr and from 50 to 127 mm/hr for sand and gravel mixed with clay and for gravel and clean sand respectively.
Martin-Rosales et al. 2007 found that in southern spain, check dams overlying highly permeable strata (limestones and dolomites) the recharge induced is about 2 to 4 times the volume of the reservoir itself. For check dams overlying poorly permeable strata (calcoschists) this ratio is 1. Silting not taken into account!
Storage capacity of gabion check dam structures is severely reduced (88%) in the upstream areas, and slightly reduced (5%) in downstream areas by silting
Characteristics of the recharge wells in the wadi Oum Zessar watershed
Recharge wells recently used on the island of Jerba, for drainage of the impoundment water in depressions (garaa)
Recharge wells in wadi Oum Zessar watershed have a depth of up to 40m
Ambast et al. (2006) found that in India, recharge wells could work with vertical shafts conducting water directly from the ground to the aquifer after it has passed through a sand-gravel filter. The capacity was almost equal to a shallow cavity/filter well yield (11l/s)
After 3 runs with water containing sediment in laboratory, Ktr was reduced by 56%.
Cleaning and/or renewal of filters are necessary to ensure optimum performance of recharge wells.
Fersi 1985: on average, 3 runoff event annually in study site
Hilkert (2005) conducted experimental study on improved well design.
Temmerman (2004) showed that geotextile could improve the performance of a gravel filter
Ouessar et al. (2006a) proposed alternative recharge wells
cost-benefit analysis of various recharge well designs is needed Brouwer 2002
Comprehensive hydrological studies are needed to assess the relation between surface water and (deep) groundwater systems, especially the identification of processes and dynamic which control the exchange of water between these systems
Attention to silting up of wells is required.

Ouessar
2007
PhD thesis chapter 4: Evaluation and Adaptation of the GIS based watershed model SWAT

Wadi Oum Zessar

Soil and water assessment tool (Arnold, 1998) was selected because it simulates all water balance components at various temporal scales, it has a GIS interface which allows easy representation of different spatial layers (topography, soil, land use), and a wide development and users' community

Much research has been done using SWAT in humid areas, whereas little research is done in dry areas using SWAT

Neitsch et al. (2002, 2005): theoretical documentation about soil and water assessment tool

Transmission losses (channel infiltration) represent an important mechanism for aquifer recharge (Gaubi, 1988; Yahyahoui and Ouessar 2000; Yahyahoui et al. 2002)

Question: why is transmission loss at jessour set to 0? Don't they actually increase infiltration?

Possible research questions: what is the exchange rate between shallow and deep aquifers? What recharge well design performs best? What is the effect on piezometric/groundwater level of recharge wells on the catchment/local scale? What is the infiltration rate of recharge wells?

Derouiche (1997) calculated the recharge to the deep aquifer in the Wadi Koutine watershed using annual or biannual groundwater measurements in 28 piezometers or drillings: about 301l/s groundwater recharge from the matmata mountains and wadis, assuming 30l/s recharge from the Grès de trias, and 4l/s from direct recharge from Matamata mountains

Land use map in Koutine watershed

AWC: available water capacity, determined by measuring field capacity and wilting point of a soil. %vol. Divmax: maximum diversion (mm), flowfr: flow fraction %.

The model overestimates runoff of precipitation events in mid-and downstream areas, and underestimates runoff of precipitation event in upstream areas.

A problem with this model is that the rainfall information is too limited spatially: the same shower will ellicit different runoff responses based on where it occurs.

Bouraoui et al. (2005) and Conan et al. (2003) stated that bad model predictions are primarily due to inadequate rainfall data.

Ouessar
2007
PhD thesis chapter 5 Use of SWAT-WH model for assessing the hydrological effects of land use changes

Ouessar et al. (2003) found that camel herders who graze their camels in saline depression express concern for the ecology of the wetlands. These depressions are located at the outlet of the watershed, and receive less water since WH works have been realized.

Water harvesting has a non-linear effect on total recharge. During very dry to wet years, recharge is reduced by WH works, whereas during very wet years, recharge is increased. Stan: very dry to wet: water would stay in watershed anyway, but ET is increased bc more vegetation. Very wet: runoff is reduced by WHT

While it is generally assumed that the main recharge in dry areas occurs through transmission losses in the wadi network (Renard et al. 1993), it was shown that the percolation of the soil can be of great importance, especially where WH works are present (up to 80% of total recharge)

Stan: percolation takes place in soils (tabias, jessour), whereas transmission losses occur in the channels.

Total recharge: percolation, transmission loss and seepage. Stan: volgens woordenlijst NHV; seepage=kwel=diffuus uittreden van grondwater

Question: how does seepage occur at the gabion check dams?

Ouessar
2007
PhD thesis chapter 6: Summary, conclusions and prospects

Wadi Oum Zessar

question: what is storage capacity reduction, or storage capacity, or capacity loss

storage capacity of jessour and tabias: is it desirable?

an option would be to combine SWAT with Modflow to include groundwater level evaluation in the modeling approach , as presented by Sophocleous et al. (1999)

Ouessar 2007 PhD thesis
Wadi Oum Zessar

Martìn-Rosales, Gisbert, Pulido-Bosch, Vallejos and Fernàndez-Cortèz
2007
Estimating groundwater recharge induced by engineering systems in a semiarid area (southeastern Spain)
Southeastern spain
Used curve number method
HEC-HMS code (USACE 2000)
direct runoff: unit hydrograph triangular method
flow routing method: Muskingum-Cunge
Gumbel distribution for precipitation data
Infiltration rate at dams is calculated in stages as in Martìn-Rosales (2002) and Pulido-Bosch et al. (2002)
20 double-ring infiltrometer tets were done in the beds of the water-courses. 4 infiltration tests more were done in a selected gravel pit, using the Haefeli method (González de Vallejo et al. 2002)
no records available in the stream-gauging stations nor measurements for basins with similar characteristics
infiltration rate in reservoirs described in Martín-Rosales (2002) and Pulido-Bosch et al. (2002)
predicted storm events were used
In the case of check dams overlying highly permeable strata (limestones and dolomites, 217mm/hr), recharge induced is between 2 and 4 times the volume of the reservoir itself. For low-permeability strata (calcoschist, 18mm/hr), this ratio is almost 1.
Water collected in gravel pits infiltrates within a day in all cases

Rym Haddad Nouiri
2008
Actualisation du modèle hydrogéologique de la nappe de Zeuss-Koutine et évaluation des aménagements CES sur sa recharge

Zeuss-Koutine aquifer

La recharge et le pompage sont variables en fonction du temps (Manglik et al., 2003)

Vu qu'il faut faire de nombreuses simplifications pour consitutuer un modele, la representation du modele ne peut etre unique (Tarhouni, 2007)

Anderson et Woessner (1992) contains the different stages of creating a hydrogeological model.

MODFLOW utilise une grille a blocks centres (et methode de differences finies)

en 3D, il existe des elements finies tetraedriques, hexaedres et prismes. Lineaire, quadratique, cubique et mixte a a faire avec le nombre de noeuds

periode de contrainte = periode de stress, divisées en pas de temps

december, janvier, février: + froid et humide, juillet, aout, septembre: +chaud et sèche

evaporation par mois 100-200mm, precipitation par an 100-200 mm? -> bilan hydrique est déficitaire

contains descripitions bassin versants zeuss, zesser, zigzaou, morra and makhlouf

oued zeuss traverse en amont du bassin des formations détritiques et carbonatées favorables à l'infiltration de l'eau

l'oued de Koutine-Oum Zessar est le plus important de la région en raison de la densité de son réseau et de l'importance de la surface de son b.v.

le relief dans le bv d'oum zessar est très fort

Djebel de Tebaga a une structure monoclinale tronquée au Nord par un accident Est-Ouest marqué par **une zone bréchique**. Stan: zone bréchique: high perm?

Dôme du Dahar: les Matmata consitue la partie nord, la partie orientale se trouve effondrée sous la plaine de Jeffara

Question: what age does the Dahar dome have?

The Djeffara plain is the result of the collapse of the eastern flanc of the Dahar monoclinal, buried under MPQ continental deposits. This flanc is affected by 2 types of faults. 1) Eocene until Pontian, NW to SE. Most important faults: Médenine, Mareth, Zarat. Mareth not in our study site. Médenine fault: displacement highest in south (1000m) 2) Quartenary, SW NE which caused the biggest wadis, among others Zigzaou.

Alimentation de la nappe de Zeuss Koutine: soit par les eaux de pluie, soit par l'infiltration des eaux des crues le long des lit des oueds

Nappe de Zeuss Koutine se situe dans des formations du Jurassique, de l'Albo-Aptien, du Turonien, et du Senonien inferieur. Les relais sont possibles soit par le biais des failles, soit par drainance verticale

Ou est la coupe EE'?

Hydrochimie de la nappe de Zeuss Koutine varie bcp d'un bv a l'autre.

Yahyaoui and Ouessar (1999): l'exploitation du reservoir engendre une homogenisation verticale des caracteristiques chimiques

Yahyaoui (1997): le suivi mensuel de la salinite de l'eau depuis 1984 a permis de constater une tendance franche d'homogenisation verticale de la salinite des eaux des differents niveaux aquiferes de Zeuss Koutine

Contains: déscription des forages en termes de profondeur de la nappe, sa profondeur et sa façon d'alimentation

Pour les forages Zeuss 3, 1 en 1bis, les fluctuations de salinité refletent le débit de pompages et des épisodes pluvieux

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La nappe du Jurassique calcaire est en contact avec: l'unité marno-gypseuse du Sénonien inférieur pour rejoindre l'unité calcaire du même ensemble; le Cénomanien Turonien au niveau d'Oued Zeuss; les sables du Miocène à l'Est de Médenine. La nappe de Zeuss Koutine peut alors être assimilé à un seul aquifère.

La nappe est considerée libre, la côte altimétrique de son toit est considerée représentée par la topographie du terrain et la profondeur du mur est variable entre 170 et 600 metres. La profondeur augmente en allant vers le nord-est

Ben Baccar (1982); Contains: piezometric map of ZK aquifer

Limites de la Nappe: Sud: grès de Trias, Ouest: affleurements argileux et dolomitique du Cénomanien inférieur à moyen au niveau des Matmatas, Sud-Est: faille de Médenine et une faille de direction nord, Nord: limite des bassins versants. Nord-Est: Sebkhat Oum Zessar (Chaieb et Derouiche, 1997)

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Gescand

among others, assumes a recharge of 2.42% of precipitation (Pallas et al. 2005) for the Jeffara plains, 35% for the Matmatas, and assumes that 50% of the surface flow infiltrates.

Pallas et al. (2005): transsmissivité de la jeffara tuniso-lybienne.

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REMARQUES:

Régime permanent: recharge of 2.42% of precipitation (Pallas et al. 2005) for the Jeffara plains, 35% for the Matmatas and 50% of surface flow. How is surface flow determined?

Steady state calibration: transmissivity and initial conditions.

Use steady state hydraulic head as starting point for transient model.

For transient model calibration, adapt storativity, if results are not satisfactory, go back to steady state modeling.

Exploitation: à partir de forages; quel est l'importance de forages non-enrégistrés?

First calibration (steady state): inflow from grès de trias and recharge in Matamatas judged too high: decrease transmissivity

storativity: following Ben Baccar (1982), coefficient d'emmagasinement de 14*10-4 for the entire study area. Value of 6.42E-4 found in the Hessi Abdelmakek2 drilling is ignored

Take into account the relation with other aquifers for calibration

Wadis responsible for 65% of surficial recharge, of which 45% is located in wadi zigzaou where precipitation is higher. *But this is based on initial assumptions!*

For final model, coefficient d'emmagasinement is 4.62E-4 which was determined by essai de pompage sur le forage 'Hessi Abdel Malek 2' in 2002

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volume d'eau ruisselée; Lame d'eau ruisselée= 16,39 *precipitation*slope^(1/2)

Evaporation?? Verdisconteerd in 2.24%

Ouessar et al.
2009
Modelling water-harvesting systems in the arid south of Tunisia using SWAT

Wadi Koutine (260 km2)

similar to PhD thesis chapter 4?

talweg=tributary

PET= reference evapotranspiration: NOT potential evapotranspiration

Wseep is the percolation from the soil profile

in SWAT-WH, first total water harvested is calculated. If it exceeds field capacity, percolation takes place. But what is the initial condition? Wilting point?

research question: determine curve numbers

SWAT WH does not allow ponding. There is a way to work around this, but detailed monitoring of water movement in the vadose zone would be needed.

Chenini, Nem Mammou, El May
2010
Groundwater recharge zone mapping using GIS-based multi-criteria analysis: a case study in Central Tunisia (Maknassy Basin)

Maknassy Basin, Central Tunisia

Approach: use maps with info about lithology, permeability, piezometry etc.. Then combine to see which are the best zones for artifical recharge.

limited number of studies has been undertaken mapping of potential artificial recharge zones. **Which are?**

Compressive phases: Miocene and Pleistocene (Tanfous et al. 2005)

conducted pumping tests to determine hydraulic conductivity

create a artificial recharge map using 8 thematic layers and then superimpose drainage network map and by taking into account outcrop lithology characteristics. These last two pieces of information are used to identify the type of artificial recharge structure.

the recharge structures consist of dams in serial diposition in the principle watercourse of the watershed

Is the watershed border the same for surface flow as for groundwater flow? Infiltrated water may flow out of the watershed.

drainage density: indicates average length of stream channels per surface area (km/km2)

lithology derived from published geology maps and field observations

permeability from pumping tests and common permeability value of sedimentary rock formation (Davis and De Wiest 1966)

fractured rocks have a high permeability and storage capacity and are therefore considered most suitable for artificial recharge

each polygon in each thematic map is classified with a number from 1 to 4 (1: excellent, 4: poor)

drainage density of an area indirectly indicates its permeability and porosity due to its relationship with surface run-off. Areas with high drainage density values indicate high surface run-off and higher permeability

hydrodynamic and surface water availibility are the major limitations for artificial recharge plans

Final product: map with artificial recharge zones (deep and undeep), binary (either a recharge zone or not)

The proximity of some fault which influences groundwater flow is considered as a limiting factor of artificial groundwater recharge.

De Graaff et al.
2012
The development of water and soil conservation policies and practices in five selected countries from 1960 to 2010

To reduce sedimentation in the big reservoirs, hill lakes were created in the 1980s.

stan: is soil conservation sustainable? At one point, (but maybe not in the near future), a mountain will level out. The jessour will continue to receive sediment, can they handle this? Do they get higher and higher? Until they are situated at the same height as the top of the mountain? Will they start eroding at that point? When will the hill lakes be filled with sediment?

Hessel & \	Ouessar et al
2012	2012
WAHARA	WAHARA rep

Ouessar, Gabriels, Yahyaoui, Temmerman
2012
Laboratory simulation of the efficiency of groundwater recharge well filters

Wadi of Oum Zessar

prepublication paper

Heirman 2002: Sediment concentrations in study area are 5-15 g/l.

Renganayaki, Elango
2013
A review on managed aquifer recharge by check dams: a case study near Chennai, India

REVIEW! See sheet 'Renganayaki Elango (2013)'

Recharge of groundwater increases due to check dams.

Check dams can function more efficiently by periodical silt removal or discharging the water at intermittent intervals so as to increase the recharge on the downstream side

Renganayaki Elango (2013)

Reference (alphabetical order)	Method	Location	Findings
Alderwish (2010)	water balance, Darcian method	Sana Basin, Yemen.	Increase in recharge by about 36%
Al-Muttair et al. (1994)	?	Malham, Al-Amalih Saudi Arabia.	Suggested to gradually release water in to downstream for improving recharge.
Ashraf et al. (2007)	Well monitoring	Pakistan.	Groundwater level was increased from 3 to 5 m.
Al-Turbak (1991)	Well monitoring	Al-Amalih, Saudi Arabia.	Sedimentation reduces the efficiency of the check dam.
Gale et al. (2006)	Well monitoring	Satlasana, India.	Recharge increased from 6% to 24%
Gale (2006)	Water budgeting	Gujrat, Tamil Nadu, Maharastra, India.	Considerable contribution to aquifer recharge
Mudrakartha (2003)	Well monitoring	Gujarat, India.	Suggested to increase number of wells near to the structure to get maximum benefit.
Muralidharan (2007)	Tritium technique	Andhra Pradesh, India.	Recharge increased from 27% to 40%.
Neumann et al. (2004)	Water balance (MODFLOW)	Tamil Nadu India.	33% of additional water could be extracted from the wells located nearer to the check dam.
Niranjan and Srinivasu (2012)	Well monitoring	Saurashtra, Gujarat,India.	Groundwater level near the check dam was increased about 2m.
Palanisami et al. (2006)	Well monitoring	Tamil Nadu, India.	Impact of check dam on water quantity was identified
Pandey et al. (2004)	Well monitoring	Rozam, Gujarat,India.	Well yield has increased from 0.64 litre per second to 1.50 litre per second after the intervention structure.
Saxena et al. (2010)	Well monitoring	New Delhi, India.	Rise of groundwater level up to 4m.

Available at IRA

Author	Year	Title
Mamou	1990	Caracteristiques et evaluation des ressources en eau du sud tunisien
Yahyaoui	1998	Fluctuations piezometries des principales nappes dans le gouvernorat de Médenine
Fersi	1985	Etude hydrologique de l'oued Oum Zessar à Koutine
Yahyaoui	1997	Note sur l'évolution verticale de l'hydrochimie de la nappe de Zeuss - Koutine
Gaubi	1995	Synthese hydrogéologique sur la nappe des gres du trias
Labiadh	2003	Les aménagements de conservation des eaux et sols (CES) et la mobilisation des ressources en eau dans la région de Zeuss-Koutine
Nabil	2000	Etude hydrologique d'un bassin verant du sud tunisien. Cas du bassin Oum Zessar

Not available at IRA

Author	Year	Title	Type
Ben Baccar	1982	Contribution à l'étude hydrogéologique de l'aquifère multicouche de Gabes Sud	thèse de doctorat, Paris Sud
Zammit	2002	Modélisation de l'hydrogéologie et de la salinité de la nappe de Zeuss Koutine	projet fin d'études, ENIT
Gaubi	1988	Evaluation de la piézométrie et de la géochimie de la nappe de Zeuss-Koutine	résultats de la compagne de forages, DRE
Gaubi	1995	Synthèse hydrologique sur la nappe des Grés du Trias (Gouvernorats de Médenine et Tataouine)	
Derouiche	1997		Contribution à l'étude par modèle numérique de l'impa
Yahyaoui	2001a	Nappes profondes de la Jeffara de Médenine	
Yahyaoui	2001b	Nappe des Grès du Trias du Sahel El Ababsa. Aspects hydrogéologiques et mobilisation des ressources	
Yahyaoui	1998	Fluctuations piézométries des principales nappes dans le Gouvernorat de Médenine	
Yahyaoui&Ouessar	1999	Withdrawal impacts on piezometric and chemical characteristics of groundwater in the arid regions of Tunisia: case of Zeuss Koutine water table	
Yahyaoui&Ouessar	2000		Abstraction and recharge impacts on the ground water i
Labiadh	2003	Les aménagements de conservation des eaux et des sols (CES) et la mobilisation des ressources en eaux dans la région de Zeuss-Koutine	
Khalili	1986	Nappe de grès du Trias de Médenine	
Hilkert	2005	Design of a recharge well in the dry areas of Tunisia	Design of a recharge well in the dry areas of Tunisia
Fersi	1985	Etude hydrologique d'oued Oum Zessar à Koutine	Etude hydrologique d'oued Oum Zessar à Koutine
Bouri, Makni, Ben Dhia	2008	A synthetic approach integrating surface and subsurface data for prospecting deep aquifers: the Southeast Tunisia	
		Journal of Hydrology, volume 356, issue 1-feb, July 2008, Pages jan-16	
Ouessar et al.	2006a	Aménagements et techniques de lutte contre la désertification: inventaire et bilan	
Azaza et al.	2012	Geochemical Characterization of Groundwater in a Miocene Aquifer, Southeastern Tunisia	
Abaab et al.	1994	Valorisation et gestion des eaux d'épandage de l'oued El Fakka à Sidi Bouzid (Tunisie)	technical report Wageningen
Van Ranst	1997	Tropical soils: geography, classification, properties and management.	lecture notes, Ghent
Schwab et al.	1992	Soil and water conservation engineering	book

Models vertical

Author	Year	Title			
Dong et al.	2012	An areal recharge and discharge simulating method for MODFLOW		for areal recharge/discharge (discharge and recharge wells, precipitation, etc.), no special package needed ('make best use of existing equipment'),	
MODRET		infiltration from stormwater retention ponds using MODFLOW	http://www.scisoftware.com/products/modret_details/modret_details.html		
HYDRUS			http://www.pc-progress.com/e	richard's equation, package for modflow	
Kim et al.	2008	Development and application of the integrated SWAT-MODFLOW model		modflow has difficulty computing the distributed groundwater recharge	
Kim et al.	2004a&b	development of SWAT-MODFLOW model			
Guzman et al.	2012	An integrated hydrologic modeling fram	presentation		
Neitsche	2005	Theoretical background and user manual for SWAT			
Sophocleus et al.	1997, 1999	SWAT-MOD: interface between SWAT a	Several surface-subsurface interactive processes such as evapotranspiration and river-aquifer interaction can also be adequately simulated by MODFLOW (Kim, 2008 (Sophocleus et al. 1997)		
Sophocleus and Perkins	2000	Adapted SWAT-MOD			
Conan et al.	2003	Coupled SWAT and MODFLOW			
Menking et al.	2003, 2004	Studied combined SWAT results with previous estimates of groundwater flow			
Council	1999	MOD-LAK2 package			
Galbiati et al.	2006	Coupled SWAT and MODFLOW			
Inside mines		Presentation on MODFLOW	http://inside.mines.edu/~epoeter/583CSM/04_2011-MODFLOW-GettingStarted.pdf		
Modman		User manual for MODFLOW	http://www.geo.wvu.edu/~donovan/ftp/modman.pdf		
Hydrus homepage					
Hydrus forum			http://www.pc-progress.com/forum/viewtopic.php?f=3&t=900		
PCRaster			pcraster.geo.uu.nl		
MicroFEM		sheet fact, user manual	http://www.microfem.com/		
Niswonger et al.	2006	Documentation of the unsaturated-zone flow (UZF1) package for modeling unsaturated flow between the land surface and teh water table with MODFLOW-2005			
Chiang	2005	Processing Modflow PRO (version 7)	http://www.simcore.com/sites/default/files/pm/v7/pmwinpro.pdf		DOES NOT INCLUDE MODFLOW 2005. (Version 8 does)
US EPA					

Models horizontal

Model requirements	Kim, Chun, Won, Arnold 2008 Development and application of the integrated SWAT-MODFLOW model	Inside mines Presentation on modflow	Modman MODFLOW manual	NEITSCH et al. 2005b SWAT input/output documentation	PC Progress HYDRUS intro, description, manual
Evaporation	MODFLOW replaces groundwater part of SWAT	http://inside.mines.edu/~epoeter/583CSM/04_2011-MODFLOW-GettingStarted.pdf	www.google.tn/url?sa=t&rct=j&q=input modflow list&sour	Data on watershed, subbasin and HRU scale	http://www.pc-progress.com/en/Default.aspx?hydrus-3d#k1
Ponding	Major inputs used for the MODFLOW River package were: row&collumn of the river of cells for the river, river stage, conductance of the river bed and riverbed elevation	saturated, single phase flow	KIJKEN: evapotranspiration module		Model for water and solute movement in variably saturated media
Wells	SWAT requires following inputs: weather, land use and management, stream channels, topography, soils, shallow aquifers etc.	anisotropic (if aligned with grid)			Can be linked to modflow
Unsaturated zone	River stage for the River package of MODFLOW is imported from SWAT	BC include: Dirichlet, Cauchy, Neuman, and phreatic surface			Numerically solves Richards equation
	Calibration of model with: a soil evaporation compensation coefficient, AMC and CN2 (condition II curve number). Groundwater part: hydraulic conductivity, storativity and riverbed conductance	Stresses such as wells, recharge, evapotranspiration, rivers, drains etc.			Van Genuchten, Brooks&Corey, Durner, and Kosugi type analytical functions. Hysteresis is accounted for by the model introduced by Scott et al. (1983) or Lenhard (1991) or Lenhard and Parker (1992)
	Pumping module for MODFLOW was used	Springs, re-wetting, thin bariers to horizontal flow			Galerkin type linear finite element method applied to a network of triangular elements
	Well package for MODFLOW was used				Automatically generates mesh
					HYDRUS calculates and reports surface runoff, evaporation and infiltration fluxes for the athmospheric boundary

2002 Hydrus forum	PCRaster user manual	MicroFEM fact sheet	Niswonger, Prudic and Regan 2006 Documentation of the unsaturated-zone flow (UZF1) package for modeling unsaturated flow between the land surface and the water table with MODFLOW-2005	MicroFEM Help function ?
http://www.pc-progress.com/forum/v	2.5D: vertical interactio	Saturated single-density flow	Unsaturated flow can be calculated using Richard's equation. To do so, a fine grid is needed. However, USF1 uses a kinematic wave approximation which is solved by the method of characteristics (Smith 1983)	Evaporation depends on groundwater level, is linear, non-negative, and bounded by a maximum
Hydrus 2D/3D assumes surface water is instanteneously remov		Multiple aquifer systems and stratified aquifers	Diffusive forces are neglected: flow is assumed to take place due to gravity	Wadi: when groundwater level is below river bottom: infiltration is constant
In Hydrus 1D, ponding does occur (allows excess water to accu		Confined, leaky and unconfined conditions	Evaporation can cause soil water to move upward by drying out the soil at the land surface. Since diffusive forces are neglected, this cannot be modeled	
		Heterogeneous aquifers and aquitards	Evapotranspiration can be modeled during relatively wet conditions by assuming evaporation and uptake by roots can be grouped together as ET and that they occur as instantaneous loss of water over an interval equal to the root depth	
		Steady-state and transient flow	Supported in MODFLOW - 2005	
		Spatially varying anisotropic aquifers	When the UZF package is used, the RCH, EVT, and ETS packages should not normally be used because the UZF simulates recharge and evapotranspiration. However, MODFLOW does not prevent UZF being used in conjunction with the the RCH, EVT, and ETS packages. (http://water.usgs.gov/nrp/gwsoftware/modflow2000/MFDOC/index.html?uzf_unsaturated_zone_flow_pack.htm)	
		Spatially and temporally varying wells and boundary conditions		
		Precipitation, evaporation, drain, river and wadi top systems		
		Wadi recharge system' can be added as a 'top system': what does this mean?		
		Evaporation system' can be added as a 'top system'		

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Document on site

Several infiltration models have been developed, including those by Parlange et al. (1985) Haverkamp et al. (1990, 1994) and Salvuccie and Entekhabi (1994)

Models +-

	SWAT	PCRaster	MODFLOW	HYDRUS	MicroFEM	MODFLOW+SWAT	MODFLOW+HYDRUS
	Is a **soil water** model		Is a **groundwater** model		Saturated single-density flow		
			Can be downloaded for free on USGS website		Multiple aquifer systems and stratified aquifers		
	lumped (HRU's)		distributed (cells)		Confined, leaky and unconfined conditions		
	Groundwater component does not consider distributed fe		Can be extended by MODRET (650 dollar)		Heterogeneous aquifers and aquitards		
	Difficult to calculate head distribution and distributed pum		Modular 3D block -centered finite-difference code used in aquifer systems (I		Steady-state and transient flow		
	Physically based (Kim, 2008)		Physically based (combines Darcy's law with mass conservation)				
	Major components include weather, hydrology, soil tempe		Can represent confined, unconfined, leaky, delayed yield, and variably confined/unconfined conditions. (Kim, 2008)				
	Time step at least 1 day		Steady state&transient (Kim, 2008)				
			Several surface-subsurface interactive processes such as evapotranspiration and river-aquifer interaction can also be adequately simulated by MODFLOW (Kim, 2008 (Sophocleus et al. 1997)				
			Has a 'River' package (Kim, 2008)				
			Anisotropic (inside mines)				
Available surface water	**yes**	**yes**	**no**	**no**	**no**	**yes**	**no**
Groundwater accurate	**no**	**?**	**yes**	**yes**	**yes**	**yes**	**yes**
Evapotranspiration	**yes**	**yes**	**yes**	**yes**	**yes**	**yes**	
Ponding	**yes**	**?**	**MODRET**	**1D**	**wadi recharge**	**yes**	
Recharge well	**no**	**?**	**yes**	**yes (internal sink/source)**	**yes**	**yes**	
Distributed	**semi-distributed**	**yes**	**yes**	**yes**	**yes**	**yes**	
Help?	yes	yes	no	no	no	no	
+	Free?	Free	Free			Combines SWAT and MODF	Combines HYDRUS and MODFLOW strengths
			GUI	GUI			
	Strong for surface water	strng for surface flow	Strong for groundwater	Strong for unsaturated flow			
	I learn something new	direct exchange with ArcG	I have some experience	Can model complex irregular systems			
	Computationally efficient (HRU's)		Can model complex irregular systems				
-				Not free	Not free	Might take too long	Might take too long
	Weak for groundwater	weak for groundwater flov	Weak for surface water				
	I have no experience		Unsaturated flow?				
	Cannot model complex irregular systems (HRU's)						