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International Water Resources Association
IWRA

Kingdom of Morocco
Ministry of Equipment and Water

XIX WORLD WATER CONGRESS
International Water Resources Association (IWRA)
Marrakech, Morocco | 1-5 December 2025

Optimization of the Evaluation of Water Cycle Components in Desert Environments where the Context Lacks Hydroclimatic Measurements

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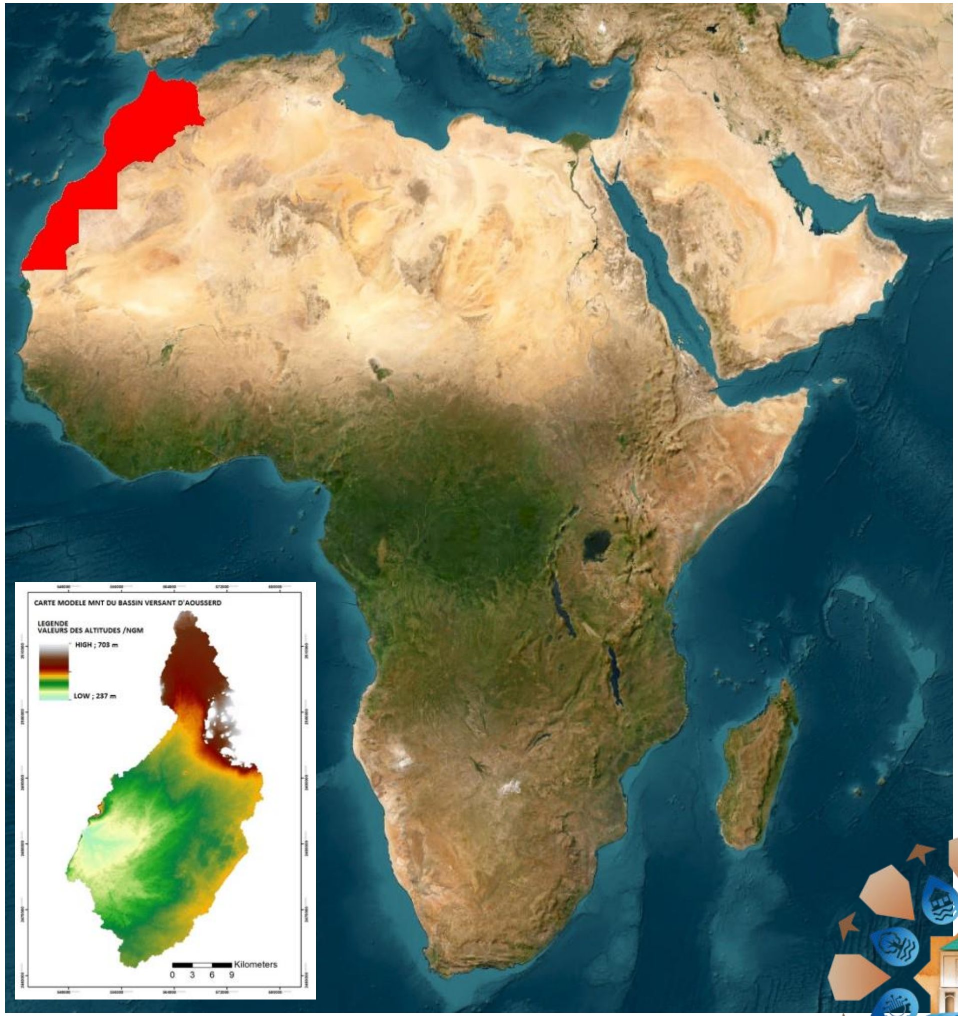
Marrakech 5th , December , 2025

Introduction

Stady Area : Desert Locality of Aousserd

situated in south of marroco.
Coordinates: 21° 55' 11" N, 15° 1' 14" W .



Problem statement :

Southern Morocco is part of the vast arid belt of Africa (35%), where water is fundamental to the survival of local populations and their daily lives.

However, hydrological data in this area are almost entirely lacking. This scarcity of information makes it very difficult to accurately estimate surface runoff, groundwater recharge, and available water resources, or to design secure drinking-water systems and sustainable development plans.

Objectives of Work

- Overall Aim :

**The characterization of a desert basin, Downscaling of precipitations,
Hydrological modelling with Horton with HEC-HMS, And finally Assessment of the water cycle components**.

- Main Objectives
  - **To characterize the hydrological cycle** of the Awserd desert watershed and quantify its renewable components (surface runoff and groundwater recharge).
  - **To Fill data gaps** through the development and deployment of an **experimental hydrological measurement system.**
  - **To calibrate and apply Horton-based infiltration modelling and HEC-HMS simulations** using downscaled daily precipitation and flood surveys.
  - **To assess the potential of surface and groundwater water resources** in order to secure the potable water supply and support local socio-economic development.

Methodological Approach

1. Classical approach

- *Precipitation data*
    - *https://power.larc.nasa.gov/data-access-viewer/utm_source*
    - *https://giovanni.gsfc.nasa.gov/giovanni/*
- *Runoff*
  The values are calculated from experimental average infiltration rates obtained using field infiltration monitoring devices installed in the different soil types.
- *ΔS – Change in groundwater storage*

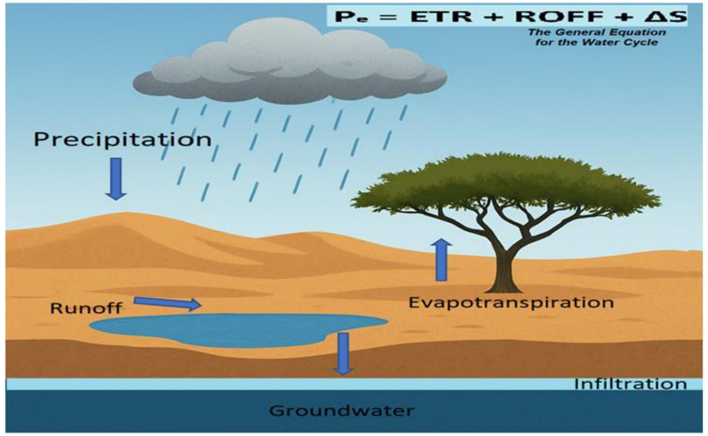
  The variation in groundwater storage is estimated from piezometric control measurements collected over a long period.
- *evapotranspiration (ETR)*

  ETR = Rainfall – Surface Runoff – Change in water storage.

2. New approach: integrated experimental dispositif

Based on a suitable experimental setup designed and implemented to directly determine all components of the water cycle:

1. *surface runoff,*
2. *total soil infiltration,*
3. *aquifer (groundwater) recharge,*
4. *Evapotranspiration ETR.*



Runoff, Evapotranspiration & Groundwater Recharge

1. Basin, Soil and Aquifer Characterization
- Delineation of the watershed and geomorphological analysis
- Mapping of soil types and homogeneous hydrological units
- Definition of aquifer system, recharge/discharge zones and boundary conditions
- Integration of hydraulic properties (S, T) and effective porosity into a conceptual model

2. Soil Hydro-Physical Properties & Limiting Infiltration Rate
- Mass measurements (wet/dry soil), field capacity, porosity and densities
- Experimental determination of limiting infiltration intensity (Ilim)
- Soil water retention and ETR estimation

3. Rainfall Analysis (PJmax – IDF – Chicago Storm)
- Extraction of annual maximum daily rainfall (PJmax)
- Statistical fitting (Gumbel, Montana…)
- Development of IDF curves and construction of the Chicago design storm

4. Surface Runoff Estimation
- Application of Ilim to each rainfall time step (Chicago storm)
- Rainfall–runoff separation (Norton method)
- Computation of runoff depth, peak flow (Qp) and runoff volume (Vp)
- Hydrological modelling with HEC-HMS (loss model, routing, CN calibration)

5. Piezometric Analysis
- Daily monitoring of water-table fluctuations
- Extraction of high-water & low-water depths
- Calculation of saturated thickness and conversion of ΔZ into equivalent water thickness

6. Rainfall–Recharge Relationship
- Establishing correlation between PJmax and saturated-thickness variation (ΔZ)
- Derivation of regression curves for recharge estimation
- Estimation of annual groundwater recharge (R)

7. Recharge & Real Evapotranspiration (ETR)
- Calculation of recharge from piezometric rise
- Determination of real evapotranspiration

Final Outputs
- **Runoff depth & volume (Qp, Vp) for return period T**
- **Groundwater recharge depth and total recharge volume**
- **Evapotranspiration (ETR)**

Materials and methods (statistical analysis & hyetographs)

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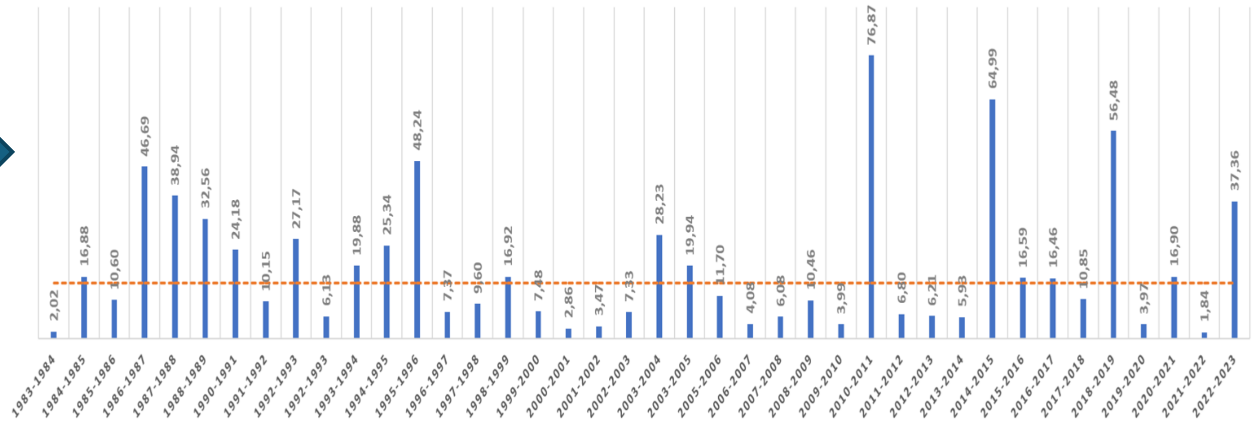
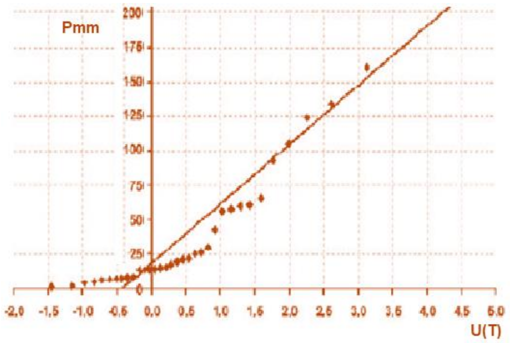
1. **The daily dataset obtained by downscaling from meteorological models.**

2. **Analysis of maximum rolling/moving precipitations based on the principle of summing daily rainfall depths over the year, which serves as the basis for establishing Intensity-Duration-Frequency (IDF) curves and hyetographs**

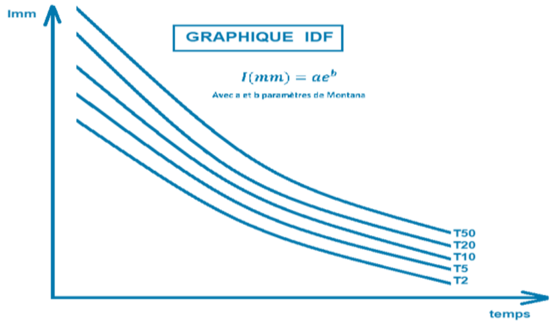
Annual Maximum Daily Rainfall at Aousserd " HTTPS://POWER.LARC.NASA.GOV/DATA-ACCESS-VIEWER/



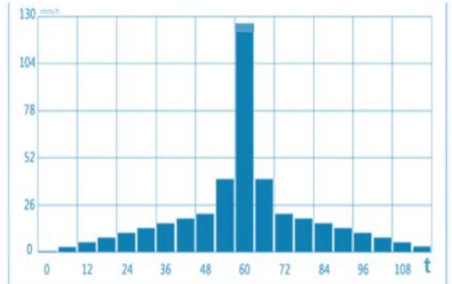
1. **The analyses allow for the extraction of data from the maximum daily rainfall (Pjmax)..**



2. to Fit the maximum daily rainfall PJmax to the Gumbel distribution: PJmax = f(U(T)), T2…..

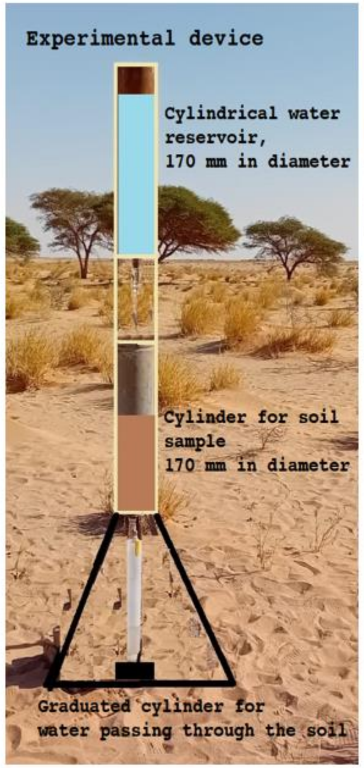


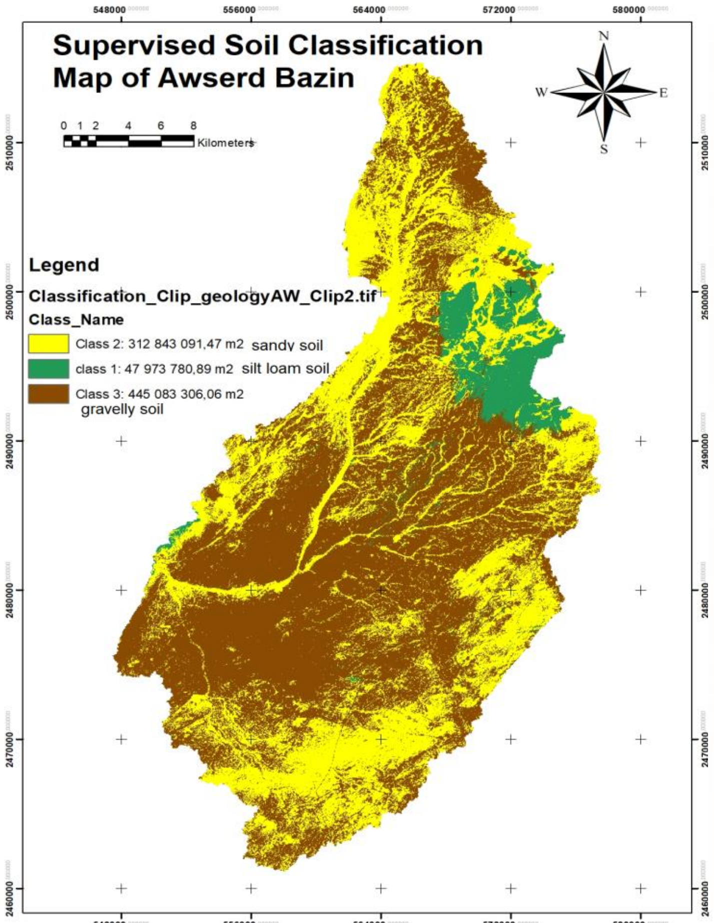
3. To Develop the IDF equations as a function of time and the return period T

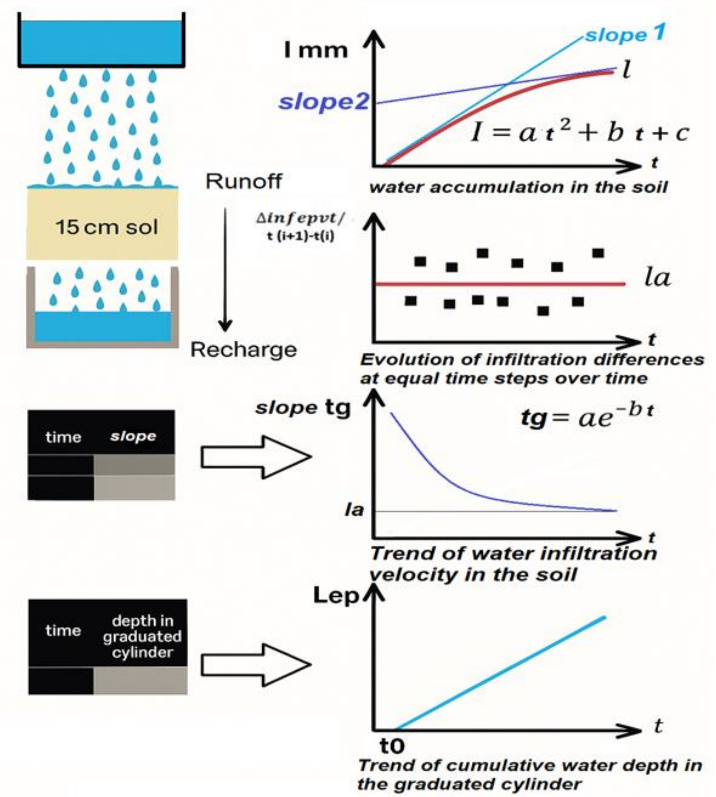


4. To built Chicago hyetographs for each return-period event(T2, T5, T10, T20, T50, T100))

Materials and methods (Horton method)







Model of graphs resulting from the experiments on the sol

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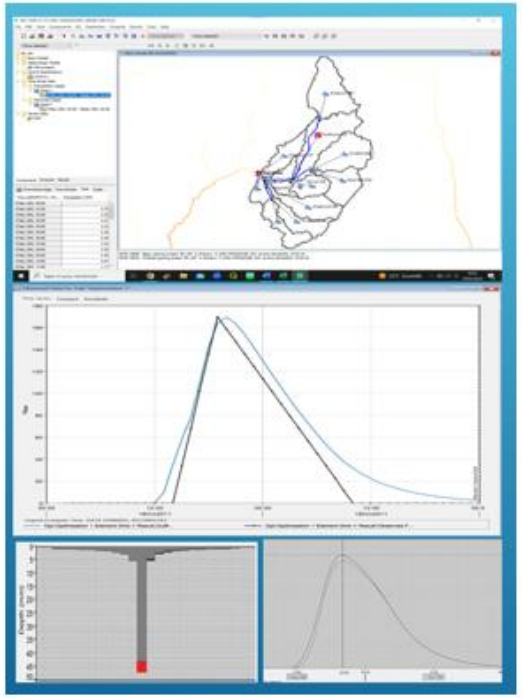
Materials and methods (Hec-hms calibration , pumping test & geophysics data analysis)

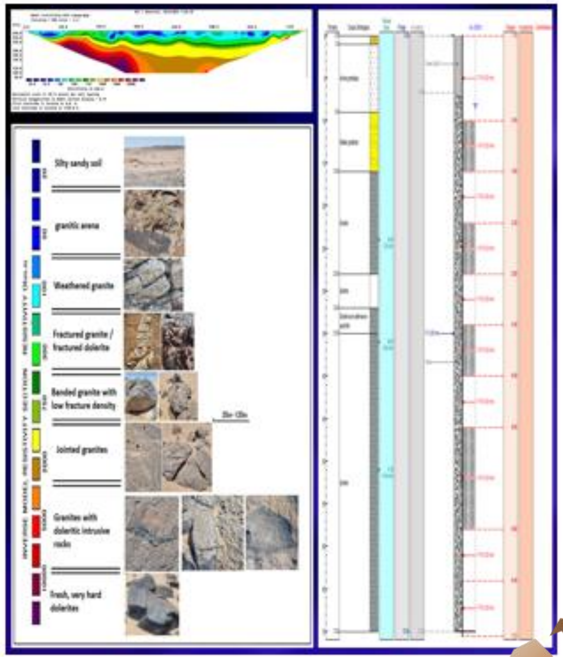
1. Analysis of historical record of water inflows, Topographic work & Sediments transport observations (

2.Characterization of the Awserd basin Calibration of HEC-HMS with the regenerated T100 event (Hydrog. Generation)

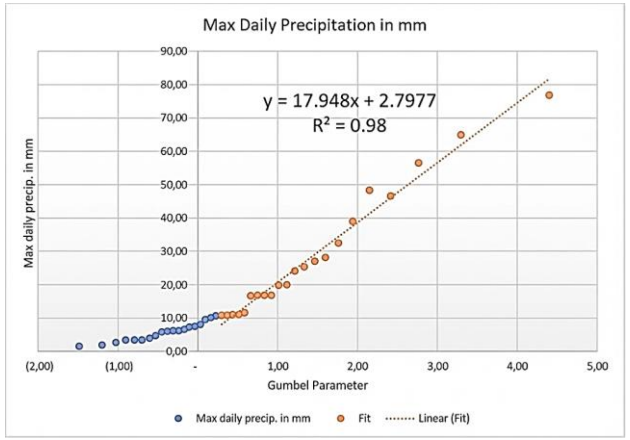


3. Analysis of Piezometric results and pumping test

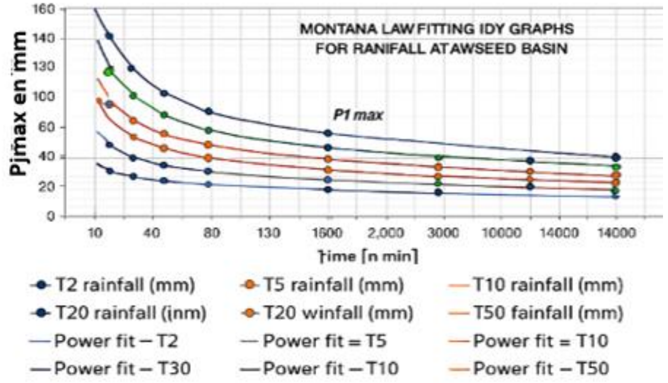
4; Geometry of the aquifer (geophysical results, surface, boundaries and drilling cuttings).



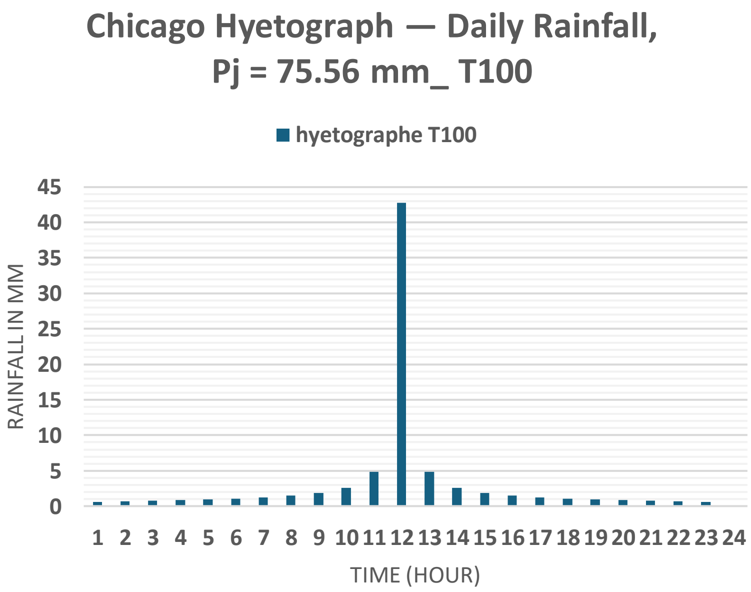
Return periods, Montana coefficient & hyetographs construction results



Return period (years)	Gumbel variable U(T)	Annual maximum daily rainfall (mm)
2	0,37	8,94
5	1,50	29,22
10	2,76	55,66
30	3,37	55,80
100	5,60	84,46
500	5,00	84,66
100	6,00	64,24
500	6,80	92,72
1000	9,21	167,60
10000	9,21	167,60



Return period (years)	Coefficient a	Coefficient b	Equation I=f(T,t)
2	154,53	-0,746	I(2 years, t) = 154.53 * t^-0.746
5	447,54	-0,812	I(5 years, t) = 447.54 * t^-0.812
10	653,26	-0,800	I(10 years, t) = 653.26 * t^-0.800
20	853,75	-0,806	I(20 years, t) = 853.75 * t^-0.806
30	969,69	-0,809	I(30 years, t) = 969.69 * t^-0.809
50	1115,6	-0,812	I(50 years, t) = 1115.60 * t^-0.812
100	1312,9	-0,814	I(100 years, t) = 1312.90 * t^-0.814



infiltration limit assessment & soils characterization results

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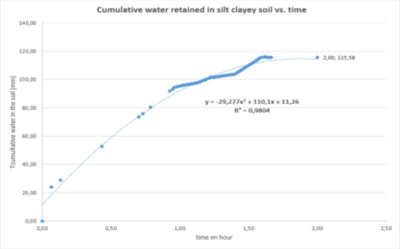
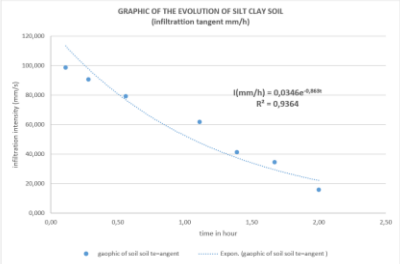
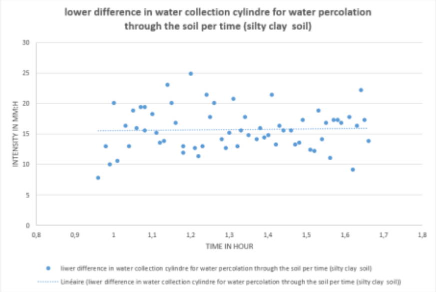
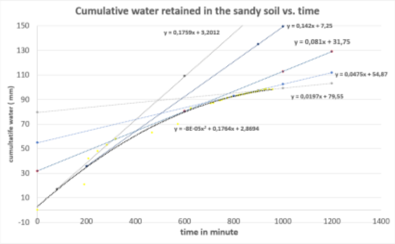
Soil N°1 silty clay soil

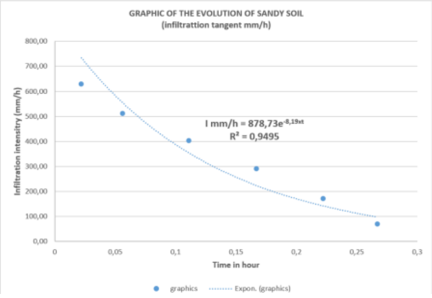


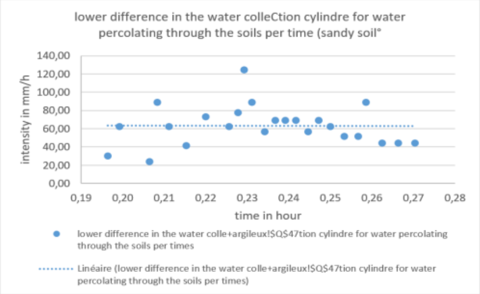




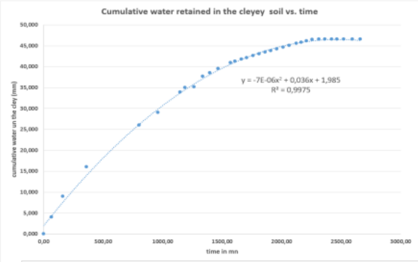
Soil N°2 sandy soil

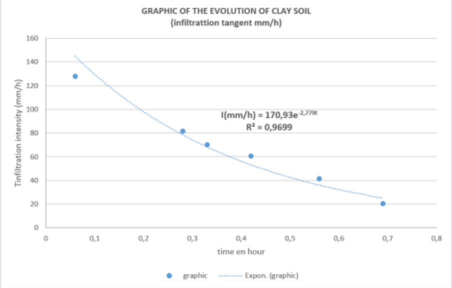


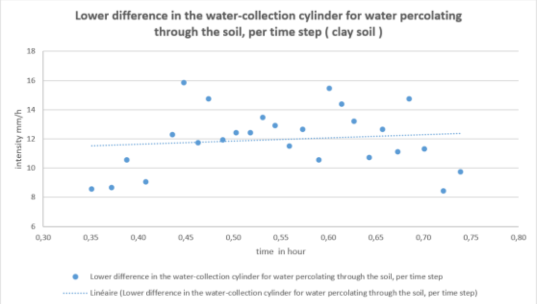




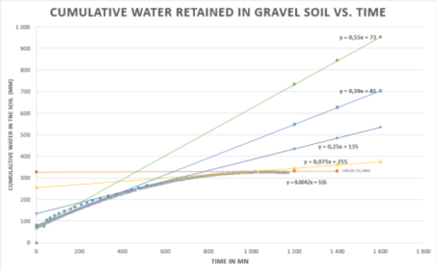
Soil N° 4 clayey soil

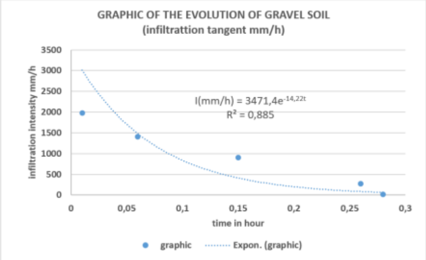






Soil N° 3 gravel soil





Limit infiltration rates (mm/h) for the soil categories are :

- **Soil 1 (silty clay):** 15.86 mm/h
- **Soil 2 (sandy soil):** 63.11 mm/h
- **Soil 3 (gravel soil):** 15.12 mm/h
- **Soil 4 (clay soil) :** 12,54 mm/h

Gravel soil characterization results

1. Physical Properties

- Sample thickness: 0.17 m
- Cylinder cross-sectional area: 0.0193 m^2
- Dry sample mass: 3.808 kg
- Moistened sample mass: 5.174 kg
- Mass of water contained in the sample: 1.366 kg
- Sample volume: 0.00319 m^3
- Sample Soil density: 1.19 (g/cm^3 equivalent)
- Sample soil total porosity: 43%
- Soil Area : 55%

2.1. Hydraulic Characteristics Infiltration & Water Retention

- Injected water depth: 265 mm
- Water depth passing through the soil: 195 mm
- Water depth retained in the soil: 70 mm
- Volume of water retained: 0.00137 m^3
- Retained water depth in the sample:70 mm

2.2 Hydraulic Characteristics Hydrological Parameters

- Limit infiltration rate: 15.12 mm/h
- Field capacity (for 165 mm thickness): 70 mm
- Evapotranspiration during the test: 70 mm
- Hypodermic flow: 0 mm

3.Scientific Interpretation

- This gravelly soil is porous at (43%) but with low effective infiltration, meaning:
- Moderate water storage capacity (70 mm),
- Low limit infiltration rate (15.12 mm/h) typical of compacted or cemented gravelly soil.
- Most of the applied water passes through, but the final infiltration rate is still low, indicating a less permeable underlying layer, or a coarse but compacted structure.
- The relatively low density (1.19) confirms a light, non-compact soil, but the measured infiltration rate shows poor permeability

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Runoff depth

Rainfall event with a 100-year return period: daily maximum rainfall (Pjmax) = 75.56 mm,
Observed around the year 2010–2011

type	Area in m²	i en mm/h T100 (dia. Chicago)	Soil limit infiltration rate in mm/h	Runoff I in mm	Infiltrated I in mm	Runoff volume in m³	Evapotranspiration Volume in m³	Recharge volume in m³	Total volume per Soil
silt-Clay	47 073 380,00	46,86	15,86	**12,40**	34,46	583 709,91	1 622 148,67	0	2 205 858,59
Sandy	312 813 091,00	46,86	63,12	**0,00**	46,86	0	14 658 421,44	0	14 658 421,44
Clay	288 972,00	46,86	12,54	**13,73**	33,13	3 967,01	9 574,22	0	13 541,23
Gravel	445 083 306,00	46,86	15,12	**12,70**	34,16	5 652 557,99	14 950 283,44	253 762,29	20 856 603,72
	805 258 749,00				Ineffective Rainfall	0,00	23110926,10	0,00	23110926,10
					total Volume	**6240234,91**	**54351353,88**	**253762,29**	**60845351,07**
					Percentage	**10,26%**	**89,33%**	**0,42%**	**100,00%**

Tab : Distribution of water inputs/contributions from the Aousserd T100 event

Resaults of runoff for:

T50, Pe=40,15 mm

T30, Pe=35,33 mm

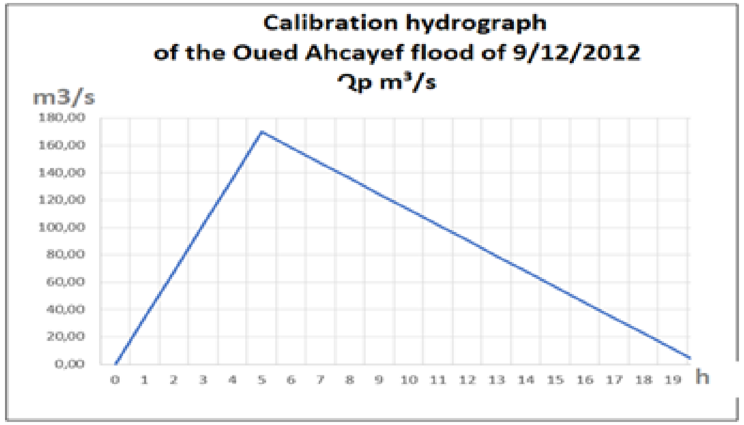
T20, Pe=31,49 mm

T10, Pe=24,69 mm

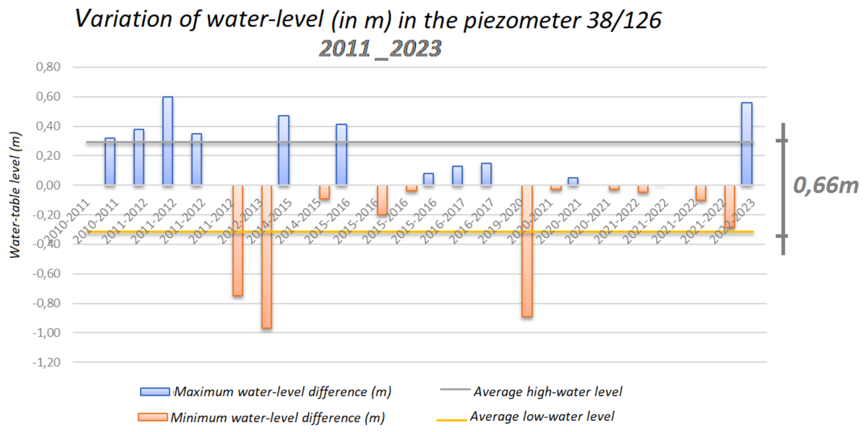
T5, Pe=16,11 mm

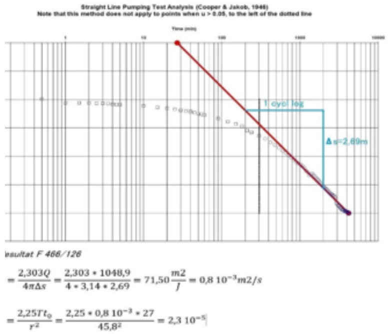
Soil type	Runoff depth (mm) T50	Runoff depth (mm) T30	Runoff depth (mm) T20	Runoff depth (mm) T10	Runoff depth (mm) T5
Silty-clayey soil	9,72	7,79	6,25	3,53	0,1
Sandy soil	0,00	0,00	0	0	0
Clayey soil	11,04	9,12	7,58	4,86	1,43
Gravelly soil	10,01	8,08	6,55	3,83	0,4

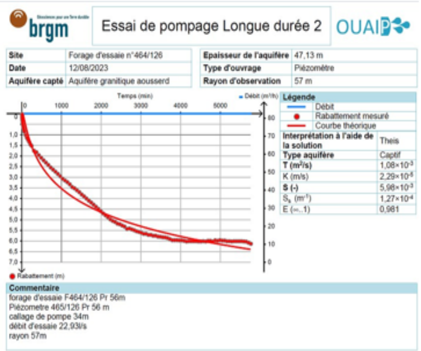
Characterisation of the 12/9/19	Values
Wetted area A (m²)	211,83
Wetted perimeter P (m)	313,53
Hydraulic radius A/P (m)	0,6756
Slope I	0,00148
Strickler Ks	27
Water velocity v (m/s)	v = 0,80 m/s
Concentration time (h)	13,89 h
Base time (h)	18,51 h
Lag time (h)	4,58 h
Peak discharge Qp (m³/s)	169,72 m³/s
Volume (m³)	6 221 087,60

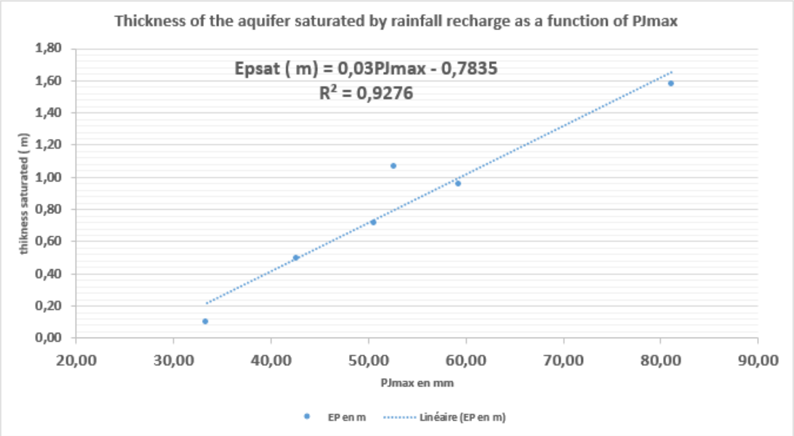


Recharge depth and aquifer volumes infiltered









ID No	UTM coordinate		Aquifer characteristics	
	X	Y	Transmissivity (m²/s)	Storativity S= porosity
223/126	557,85	2487,62	2,7.10-3	0,000400
462/126	550,43	2482,07	3,06 10-3	0,000214
464/126	550,34	2482,18	0,91 10-3	0,000126
467/125	568,13	2484,49	0,8 10-3	0,000023
483/126	551,2	2480,47	18 10-3	0,000330
			The average	0,000219

Return period T (years)	Recharge volume (m³)	Infiltrated depth (mm)
5	44,352.27	0.06
10	89,408.53	0.11
20	132,610.28	0.16
30	157,477.63	0.20
50	188,540.74	0.23
100	230,435.90	0.29

HEC_HMS modeling results /T)

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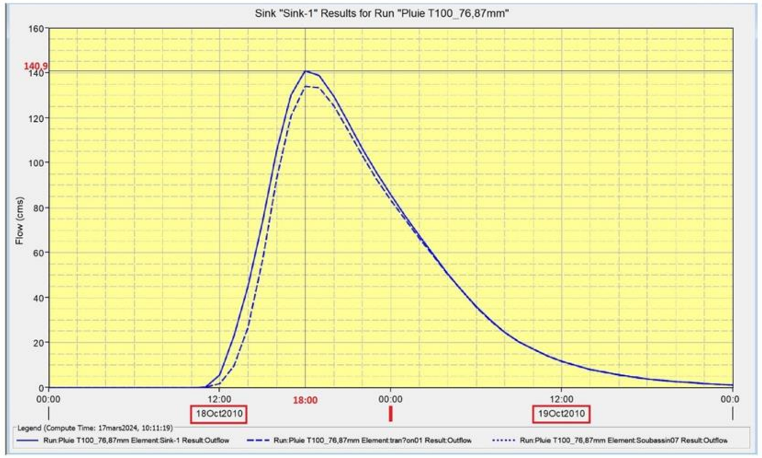

Figure: Flood hydrograph of Oued Achayef t100

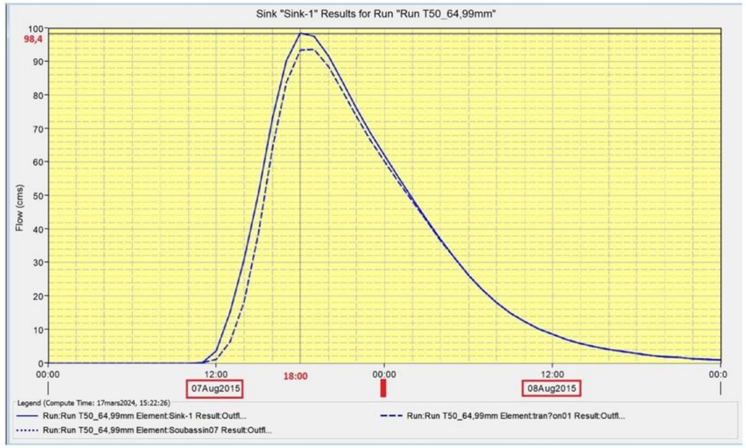

Figure: Flood hydrograph of Oued Achayef T50

Figure: Flood hydrograph of Oued Achayef T30

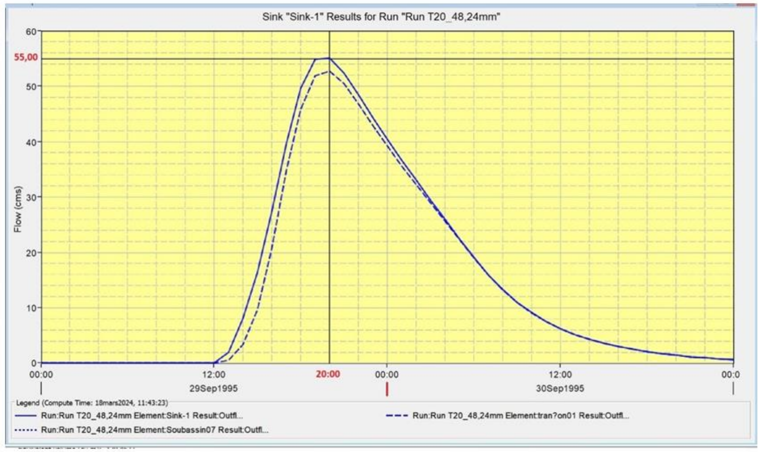

Figure: Flood hydrograph of Oued Achayef T20

Figure: Flood hydrograph of Oued Achayef T10

Return period (years)	Area (km²)	Qp (m³/s)	Volume off runoff (m³)
100,00	805,92	140,90	6 112 300,00
50,00	805,92	98,40	4 341 700,00
30,00	805,92	72,70	3 201 000,00
20,00	805,92	55,00	2 503 700,00
10,00	805,92	29,40	1 381 100,00
5,00	805,92	6,20	313 600,00
2,00	805,92	0,20	9 400,00

Analysis & Interpretation

❑ Water balance analysis using the Horton model over various periods

Return period (years)	Rainfall (mm)	Qp en m3 /s	Total volume (m³)	Runoff volume (m³)	Runoff percentage (%)	Evapotranspiration volume (m³)	Evapotranspiration percentage (%)	Groundwater recharge volume (m³)	Recharge percentage (%)
100	75,56	140,9	60 845 351,07	6 240 234,91	10,26%	54 351 353,88	89,33%	253 762,29	0,42%
50	64,99	98,4	52 333 766,10	4 916 730,43	9,39%	47 216 036,74	90,22%	200 998,93	0,38%
30	56,48	72,7	46 906 322,13	3 967 295,20	8,46%	42 777 149,33	91,20%	161 877,60	0,35%
20	48,24	55	42 155 295,51	3 210 898,67	7,62%	38 813 837,53	92,07%	130 559,31	0,31%
10	39,94	29,4	33 901 393,33	1 871 446,48	5,52%	31 953 796,45	94,26%	76 150,41	0,22%
5	31,42	6,2	25 293 177,31	181 372,98	0,72%	25 092 398,42	99,21%	19 405,91	0,08%
2	16,59	0,2	13 359 242,65	0,00	0,00%	13 359 242,65	100,00%	0,00	0,00%

Table: Water input balance as a function of return periods (limit infiltration method)

- The analysis shows that evapotranspiration is extremely high, representing **93.74%** of the total inflow, whereas runoff accounts for **5.6%**, and only **0.66%** contributes to groundwater infiltration.

❑ Water balance analysis using the HEC HMS model over various periods

Return period (years)	Rainfall (mm)	Qp en m3 /s	Total volume (m³)	Runoff volume (m³)	Runoff percentage (%)	Evapotranspiration volume (m³)	Evapotranspiration percentage (%)	Groundwater recharge volume (m³)	Recharge percentage (%)
100	75,56	140,9	60 845 351,07	6 112 300,00	10,05%	54 479 288,78	89,54%	253 762,29	0,42%
50	64,99	98,4	52 333 766,10	4 341 700,00	8,30%	47 791 067,17	91,32%	200 998,93	0,38%
30	56,48	72,7	46 906 322,13	3 201 000,00	6,82%	43 543 444,53	92,83%	161 877,60	0,35%
20	48,24	55	42 155 295,51	2 503 700,00	5,94%	39 521 036,20	93,75%	130 559,31	0,31%
10	39,94	29,4	33 901 393,33	1 381 100,00	4,07%	32 444 142,92	95,70%	76 150,41	0,22%
5	31,42	6,2	25 293 177,31	313 600,00	1,24%	24 960 171,40	98,68%	19 405,91	0,08%
2	16,59	0,2	13 359 242,65	9 400,00	0,07%	13 349 842,65	99,93%	0	0,00%

Table: Water input balance as a function of return periods (HEC HMS method)

- Evapotranspiration represents **93.74%** of inflow, compared to **5.6%** runoff and only **0.66%** groundwater infiltration.

Conclusion:

In the studied basin, evapotranspiration is extremely high (94%), due to sandy soils, strong soil heating, intense winds, and limited deep infiltration.

This removes most of the effective rainfall and leads to very low groundwater recharge (0.66%), making aquifers highly vulnerable to overexploitation.

In contrast, surface water is a key resource, but surface runoff is episodic and concentrated in intense runoff events, which calls for storage and regulation structures (**small dams, retention basins, managed aquifer recharge**) to capture and use these episodic flows.

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Thank you

Acknowledgment: *I express my scientific gratitude to Mr. Moulay Driss Hasnaoui for this new approach to evaluating hydrological components in a watershed in a context of a lack of hydro climatological data, and also for his assistance in designing and implementing the experimental setup that forms the basis of this research. He even conducted the field experiments with me.*

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