
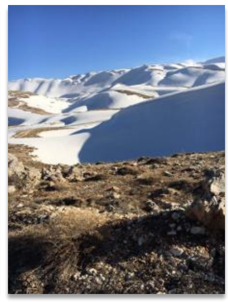


SUBSURFACE CHARACTERIZATION AND CONCEPTUALIZATION OF GROUNDWATER FLOW

Joanna J. Doummar* **, Jihad Othman, Mohamed El Ali**, Assaad, H. Kassem, Reda ElGhawi

*Dr. J. Doummar. American University of Beirut- Geology Department- P.O. Box 11-0236- Riad El-Solh, Beirut 1107 2020, E-mail: jd31@aub.edu.lb; 00961-1-35000, Ext 4165

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Challenges and Threats

1. Groundwater is currently facing tremendous stress due to climate change and climate variability in addition to the increase of water needs and demands (Kløve et al., 2014);
2. Water management measures are needed to overcome projected water scarcity, outline alternatives resources, and remedy water quality degradation (Iglesias et al., 2007);
3. This challenge is immense in snow governed, Mediterranean semi-arid regions (Lebanon) under projected climate change conditions;
4. There is a greater need to understand how groundwater systems work and the responses of water resources to input such as climate or contamination;
5. Water in Lebanon is mostly supplied from karst aquifers, which reveal to be much more challenging.

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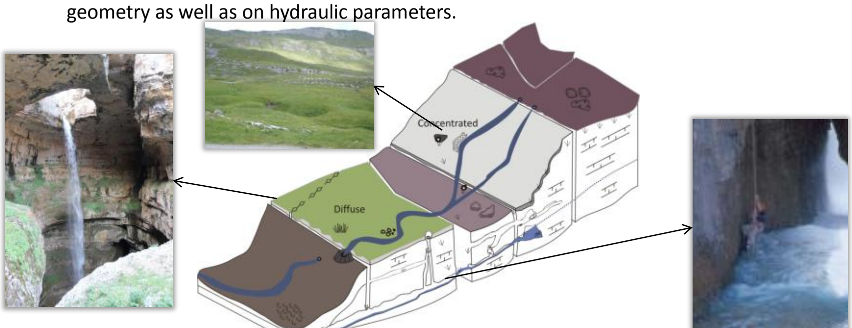
Main research questions of practical and social implications

1. What is the quantity of water that infiltrates to the subsurface?
2. What is the role played by geology (soil, faults and types of rocks) in the infiltration?
3. What is the extent of the contributing area (catchment)?
4. How is the flow of water occurring in the subsurface?
5. What is the implication of flow on water quality?
6. What are the expected flow rates if climatic conditions changed?

Challenges and Threats

1. Karst Systems are heterogeneous and are characterized by a duality of flow and infiltration
2. Transit times (residence time of water in a system) are highly variable) as flow velocity can be very high (100 m/h) in well developed conduits or very low in fissures or in the matrix
3. Karst systems are highly vulnerable to contamination and variation of input (climate variability and variation) → their responses depend on the input, on their subsurface geometry as well as on hydraulic parameters.



Karst systems are highly vulnerable to contamination and variation of input (climate variability and variation) → high implications on the availability of water for supply (seasonality: high flow and low flow, climate stress: wet and dry years) .

Afqa Spring

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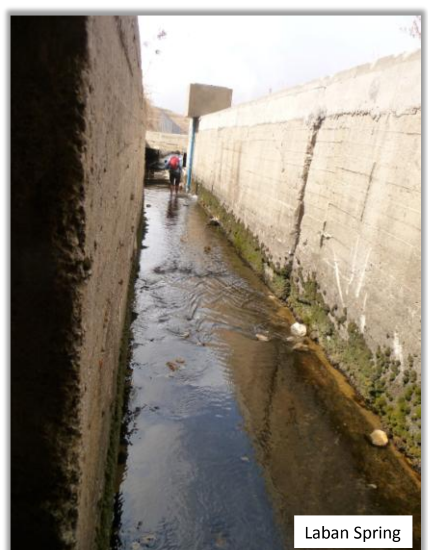

Laban Spring

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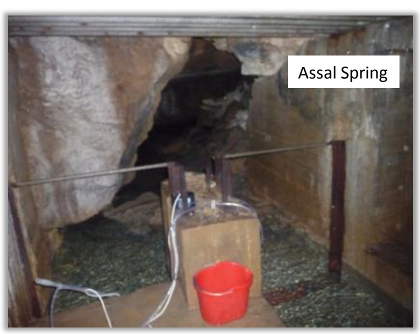
Field sites: EL Assal Spring

The annual discharge of Assal spring is estimated at 15-22 Mm^3 (based on ongoing high resolution monitoring since 2014). The spring provides downstream villages in the Kesrouane district with about 24,000 m^3 (0.28 m^3/s) of water daily for domestic use.



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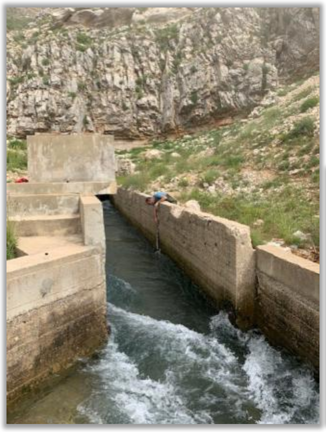
Field sites: Laban Spring

The annual discharge of the Laban spring is estimated at 15-20 Mm^3 (based on the latest studies, BGR, 2012). The spring feeds into the Chabrouh dam and is used locally for agricultural purposes



Previous work undertaken by the team and important results

Activities were undertaken on El Assal spring in the framework of a previous project funded by USAID(2014-2018) :

- **Monitoring** since 2014-ongoing of Water level and Discharge, Temperature, Turbidity, Electrical conductivity to understand spring behavior→ ongoing data collection
- **Multiple tracer experiments** to identify connections and delineate catchment, and estimate transport parameters→ v= 127-1500 m/d (1.5 and 15 days) depending on flow periods snow melt conditions (T) and injection conditions.
- **Characterization of parts of the catchment (Soil and Geology)**
- **Numerical model and use of the model for prediction purposes**
- **Application of the model in vulnerability studies**

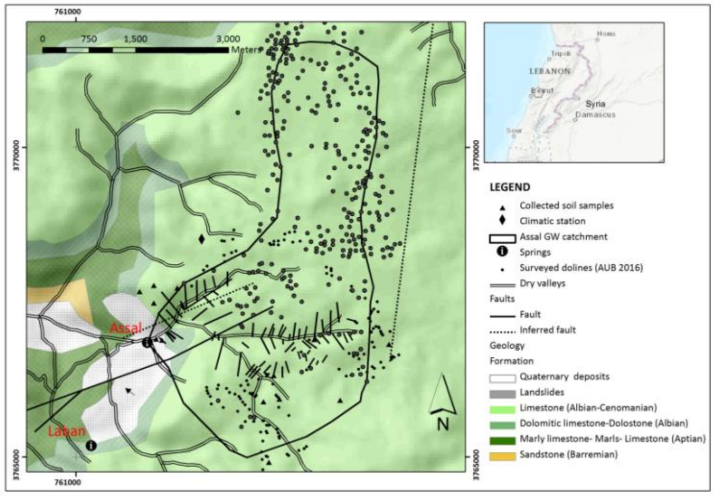
Preliminary surface Characterization (Geological mapping, karst mapping and soil analysis)

- Surface characterization

From Kassem et al. in submission

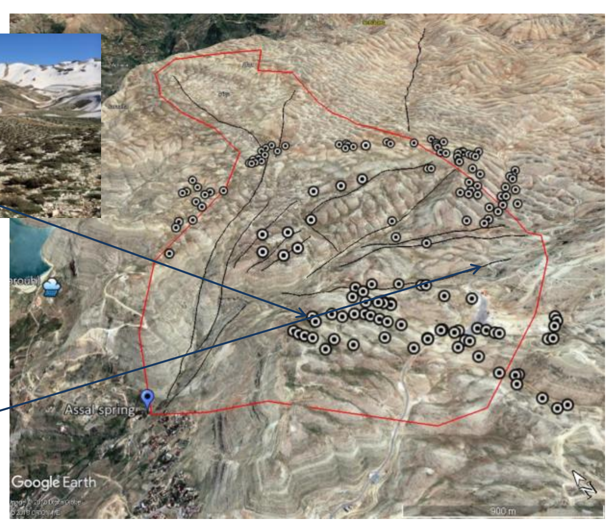
Marls and Marly limestone

Limestone



Surface Characterization (Geological mapping, karst mapping and soil analysis)

- Karst Mapping



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Set up of a monitoring network = climate and spring data

Installation of a climatic station (Close to Chabrouh Dam at 1600 m above sea level)

Full climatic station (Brand-Campbell) / Humidity, Precipitation (Rain and snow melt), Temperature, Radiation, etc.

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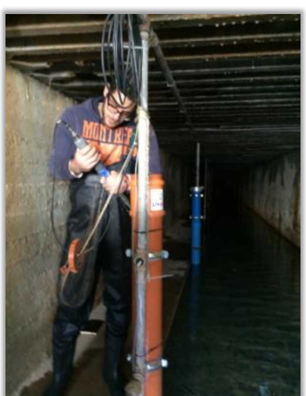
Set up of a monitoring network = climate and spring data

- Installation of a multi parameter probe



Multi Parameter probe (Brand-Insitu 9500 Prof.) / Water level, Temperature, Chloride, pH, and Electrical conductivity etc.

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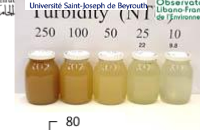
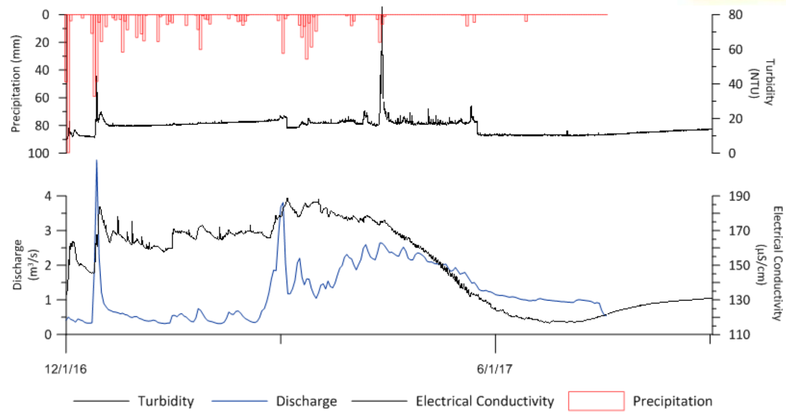
Set up of a monitoring network = climate and spring data

- Relationship between data (Example 2016-2017)





Multi Parameter probe (Brand-Insitu 9500 Prof.) / Water level, and Electrical conductivity etc.

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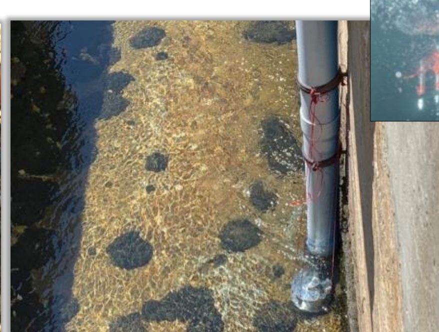
Tracer Experiments

- Tracer Experiments consist of injecting a non toxic dye on the surface and monitor it automatically with a field fluorometer at an outlet (Spring) for the below purposes:
  - Identify transport properties of a system (e.g., velocities)
  - Identify connections between point sources and spring s/water body and delination of a catchment area,
  - Identification of aquifer geometry and flow paths



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Tracer Experiments

- Dye tracers were injected in dolines on the Assal catchment (low flow periods)




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Tracer Experiments

- Tracer experiments were done in dolines on the Assal catchment (Snow melt; April 2015-2017)





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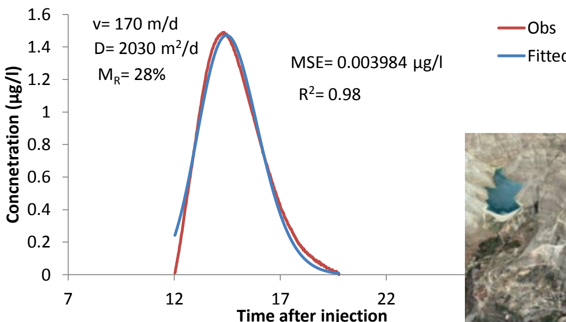
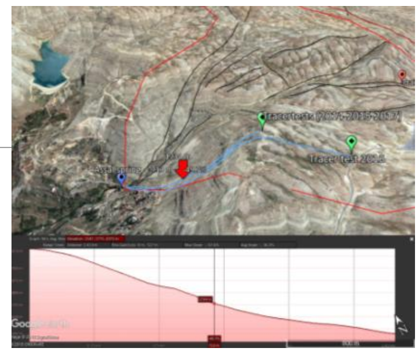
Tracer Experiments
June 2014





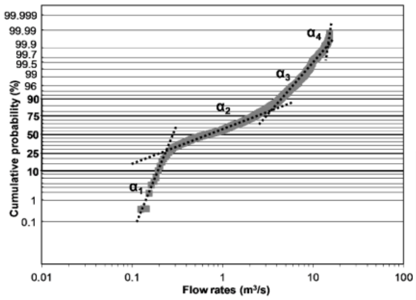
- Mean transit time of 12 days (over a distance of 1.5-2 km)



How can the data be used?

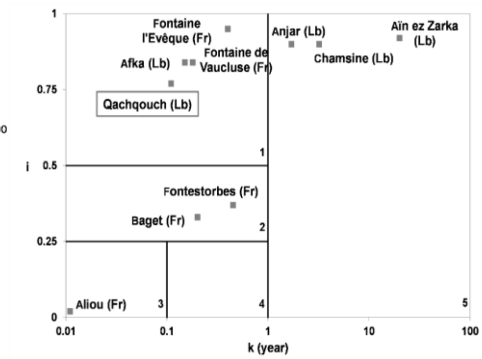


Classification of spring flowrates – Qualitative Karst Typology



- Flow rate frequency (Dörfliger *et al.,* 2010)

➔Spring discharge = single aquifer + slow and fast flow functions



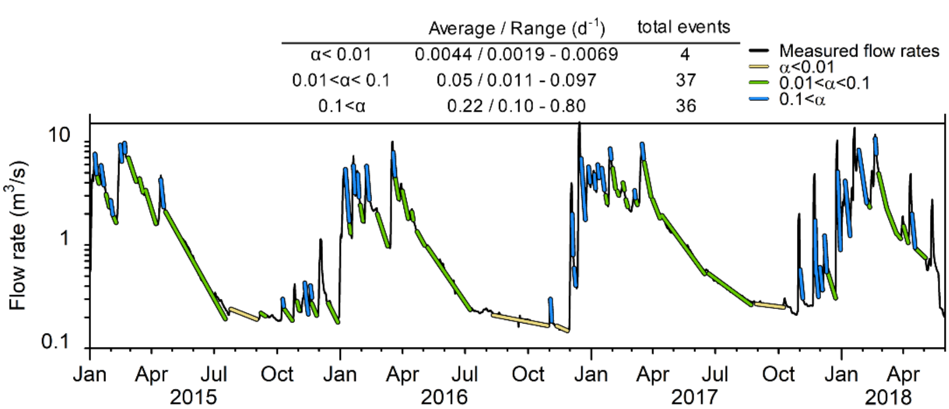
From Dubois et al. 2020

- Recession coefficient (El-Hakim and Bakalowicz, 2007)

➔Fast and slow infiltration processes and significant storage

Understanding the recessions over time➔ degree of aquifer depletion

	Average / Range (d^{-1})	total events
α< 0.01	0.0044 / 0.0019 - 0.0069	4
0.01<α< 0.1	0.05 / 0.011 - 0.097	37
0.1<α	0.22 / 0.10 - 0.80	36



From Dubois et al. 2020

Calibration of the recession coefficients for 77 depletions over the 2015-2018 period.

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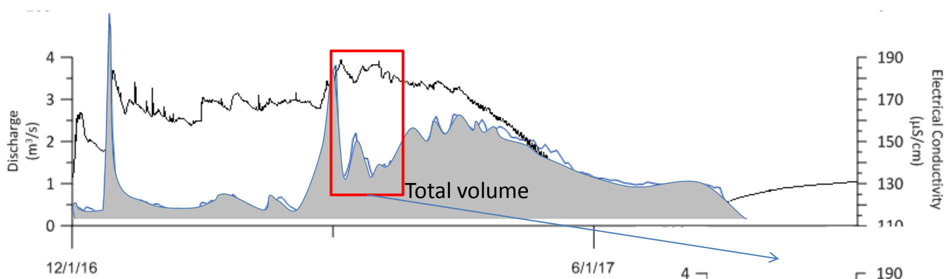
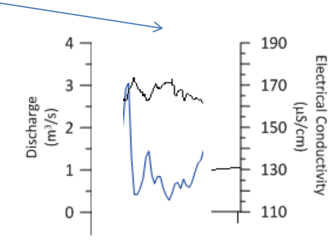
Calculation of exact water volumes for specific events and for the hydrogeological year



Relationship between electrical conductivity EC (ion content of water) and discharge→ differentiation of water from snow melt (low EC) and water from the aquifer (Higher EC)



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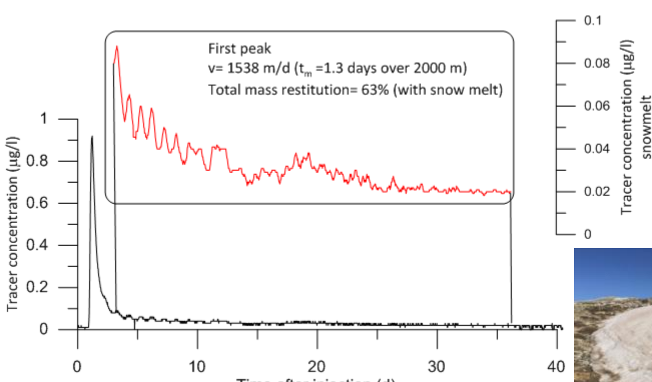
Examples of results: Tracer Experiments and snowmelt



- Mean transit time of 1.3 days (over a distance of 2 km)
- Restitution over more than 30 days

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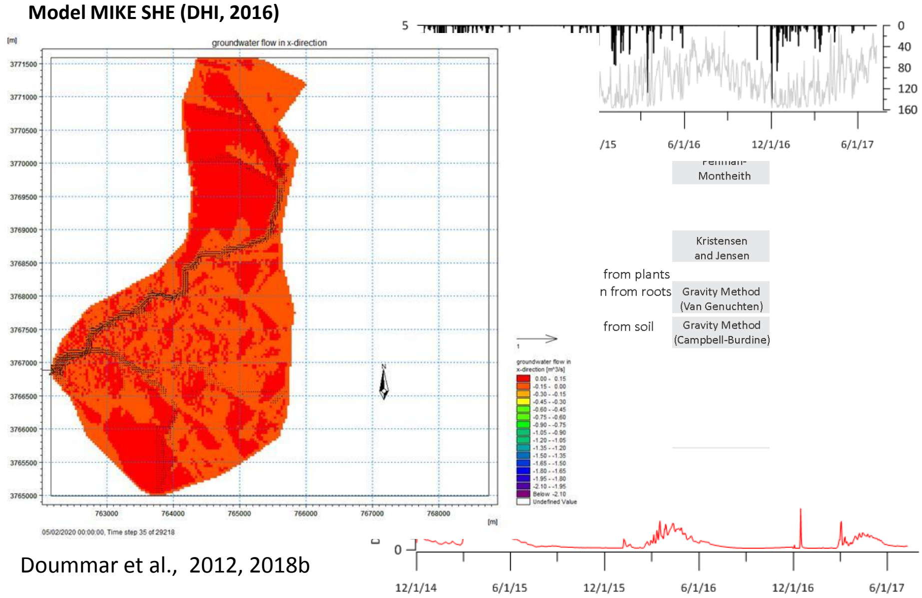
Implementation of data in a distributed integrated model to simulate flow
Model MIKE SHE (DHI, 2016)



Doummar et al., 2012, 2018b

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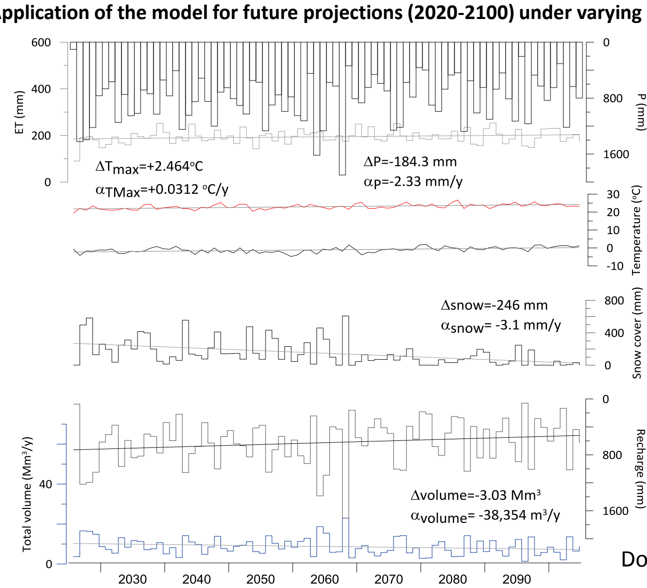
Application of the model for future projections (2020-2100) under varying climatic scenarios



Doummar et al., 2018b

Project: Conceptualization of flow in a snow-governed groundwater catchment in Lebanon:
A science- based approach for future guidelines for sustainable water management

ACTIVITIES

1. Complete the **monitoring network** on two springs in Kfadebbiane area (Laban and Aasal)
2. Characterize the **surface geology** (Geological mapping and doline characterization)
3. Obtain further **information about the catchment areas** of Laban and Aasal springs with tracer tests
4. Estimate **transport parameters** (example: fast velocity of flow) and flow patterns
5. Understand the **relationship between snow and flow**
6. Estimate the **water balance** and calculate yielded **water volumes**

OUTPUT

Technical Reports, Informative flyers and Presentations, Maps, and Data

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Activities undertaken to date

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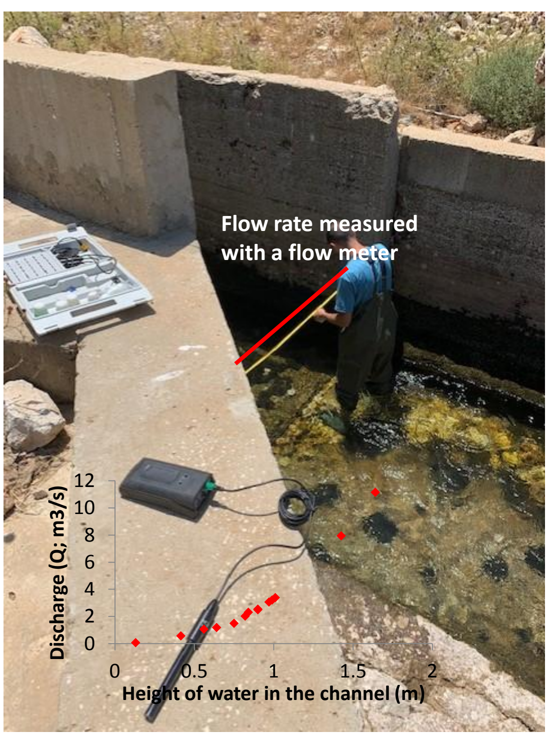
Installation of monitoring equipment on Laban Spring

- Installation of a monitoring station on Nabaa el Laban (Weir, Pressure transducer and multi parameter probe)




Thank you