Experimental and Numerical Modelling of Constructed Channels in the Desert Sand Dunes for MAR Applications

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Can A Desert Turn Into A Forest?

Overview

- Introduction
- Conceptual Model of Surface Flow
- Field Experiments
- Numerical Model
- Coupling Surface-Subsurface Flow
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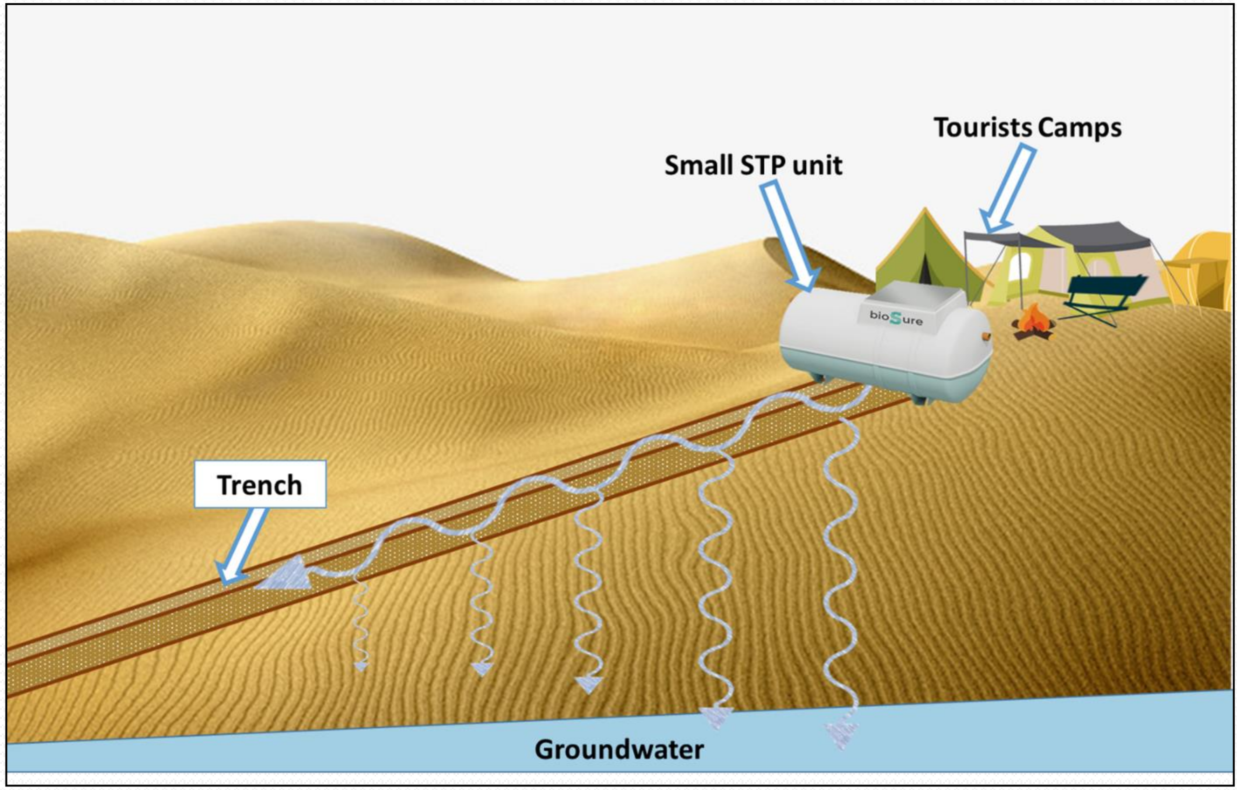
Introduction

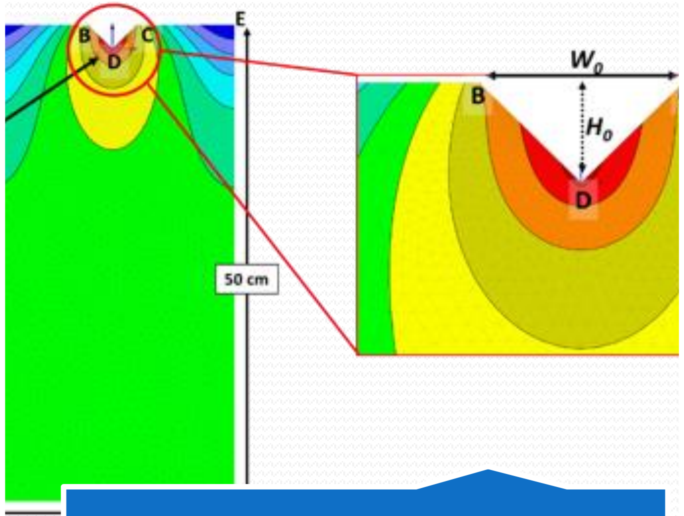
- Large areas of desert dunes across arid regions can be explored for MAR
- Mini sewage treatment plants (STPs of touristic camps and remote villages) can use small-scale infiltration channels.

- The key design question is:
  - What should be the length of the channel to infiltrate all water discharged?

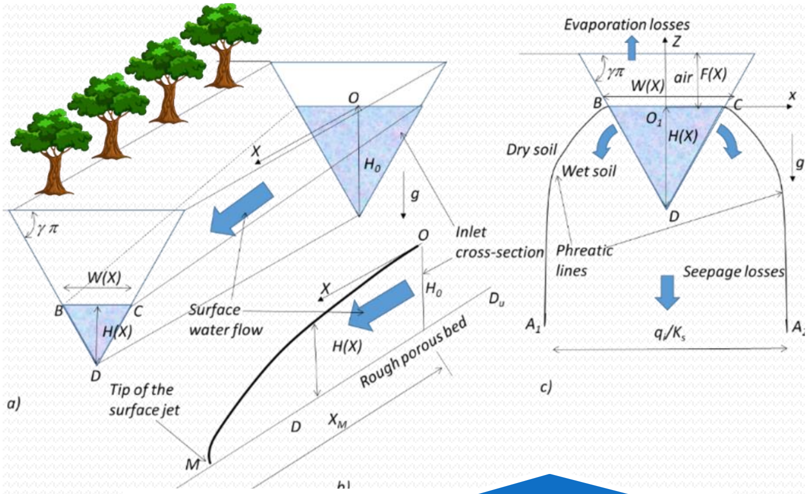
  (given a certain topographic slope, roughness of the bed, hydraulic conductivity of the sand, and a specific amount of TTW to be infiltrated)



Field Experiments

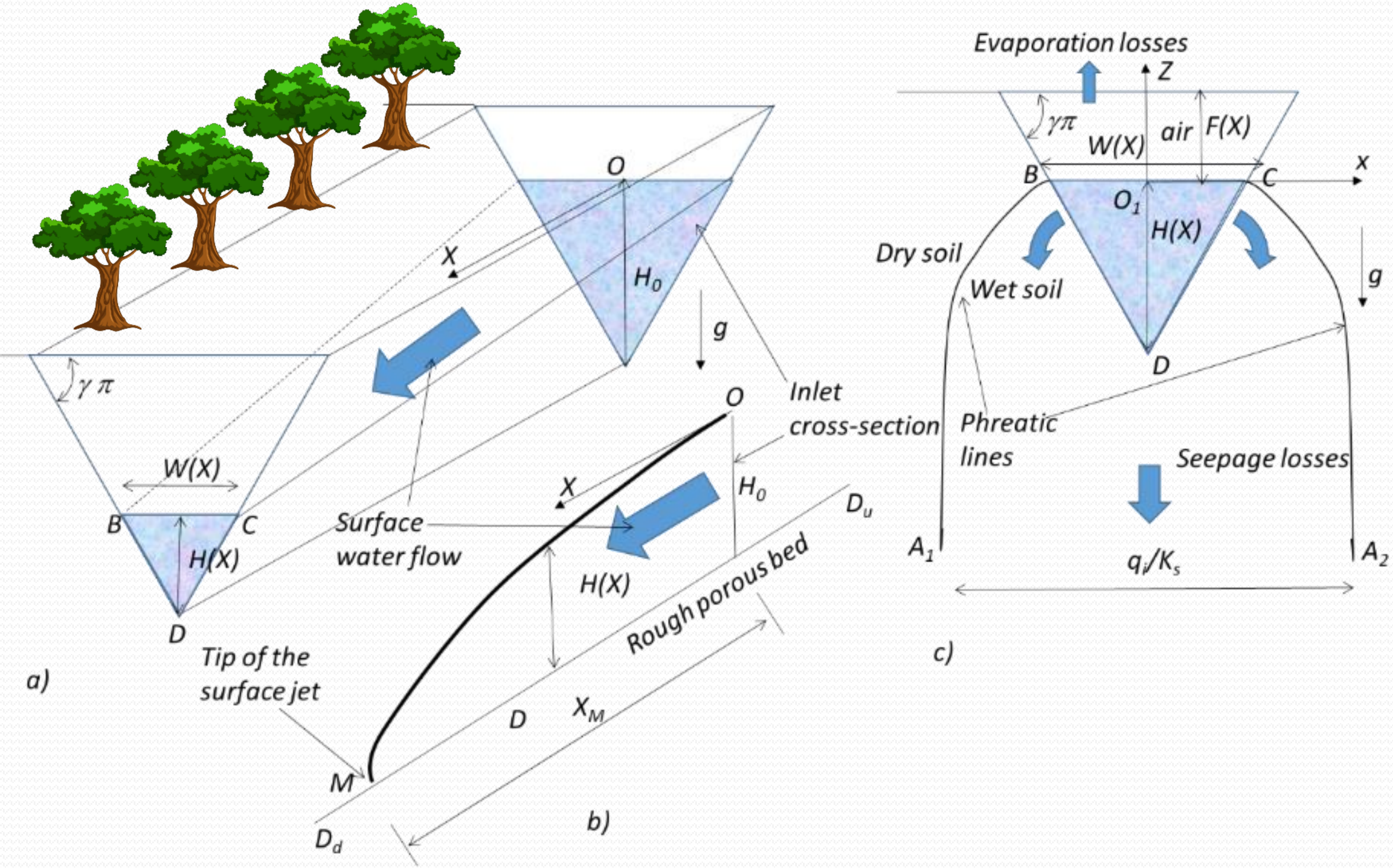


Numerical Modelling



Coupling of Surface & Subsurface Flows

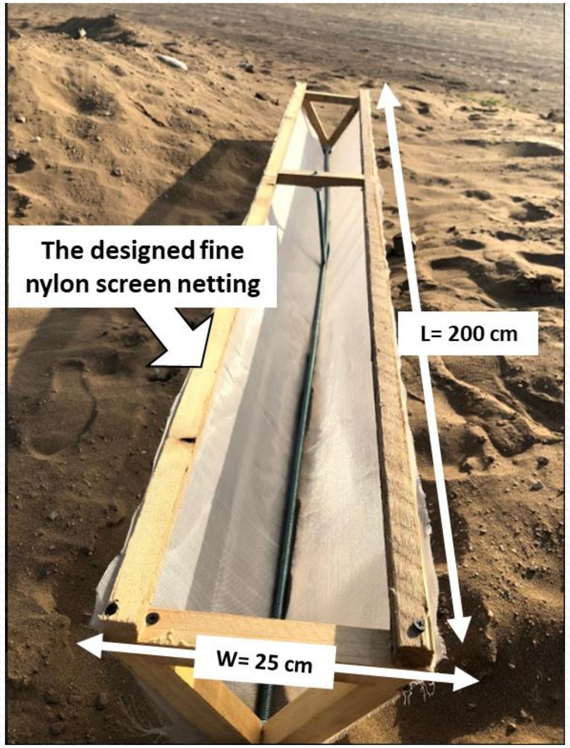
Conceptual Model of Surface Flow

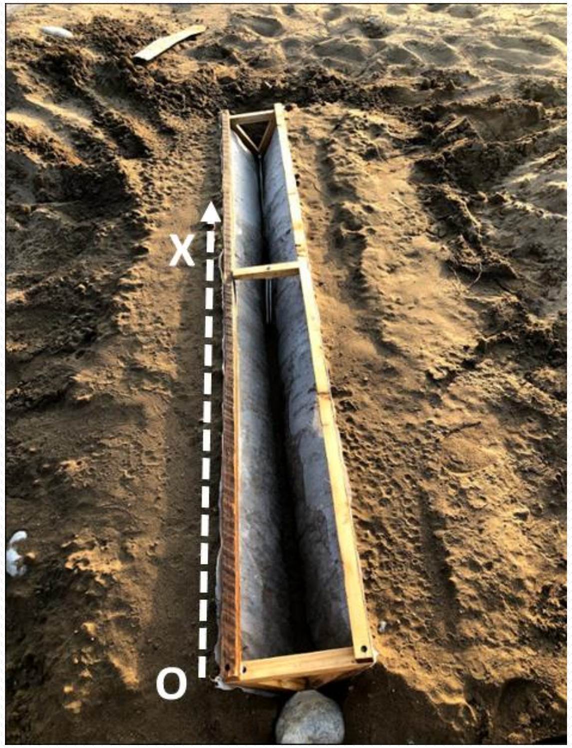


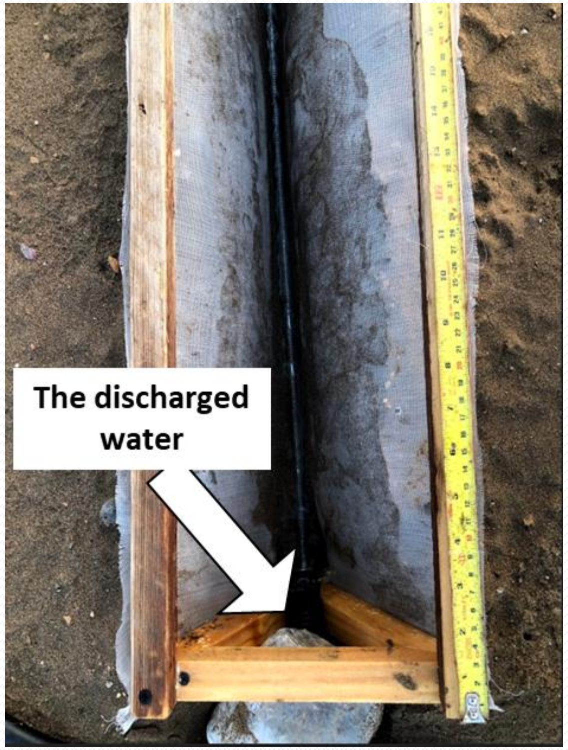
a) 3-D sketch of surface flow through a triangular channel,
b) "Free jet" of surface flow in a cross-section along the channel axis,
c) Seepage flow in a vertical cross-section perpendicular to the channel axis.

Field Experiments

- The experiment was conducted at Sultan Qaboos University (SQU), Oman.
- Applying constant water discharge Q (L^3/T)





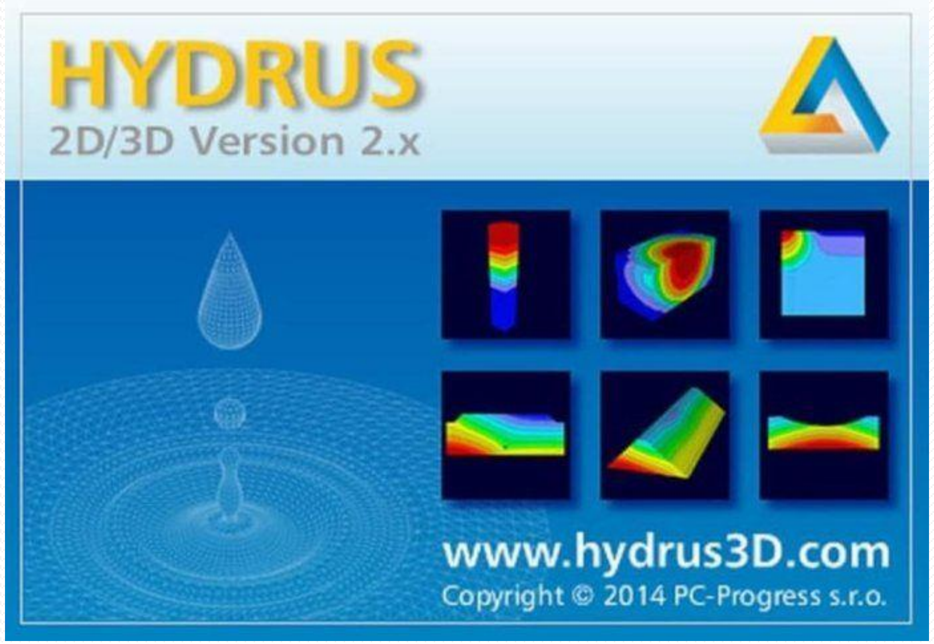


Numerical Model

- Richard's equation has been solved by **HYDRUS2D** (Šimůnek et al., 1999)

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial x}\left[k_{un}(p)\left(\frac{\partial h}{\partial x}\right)\right] + \frac{\partial}{\partial z}\left[k_{un}(p)\left(\frac{\partial h}{\partial z}\right)\right]$$

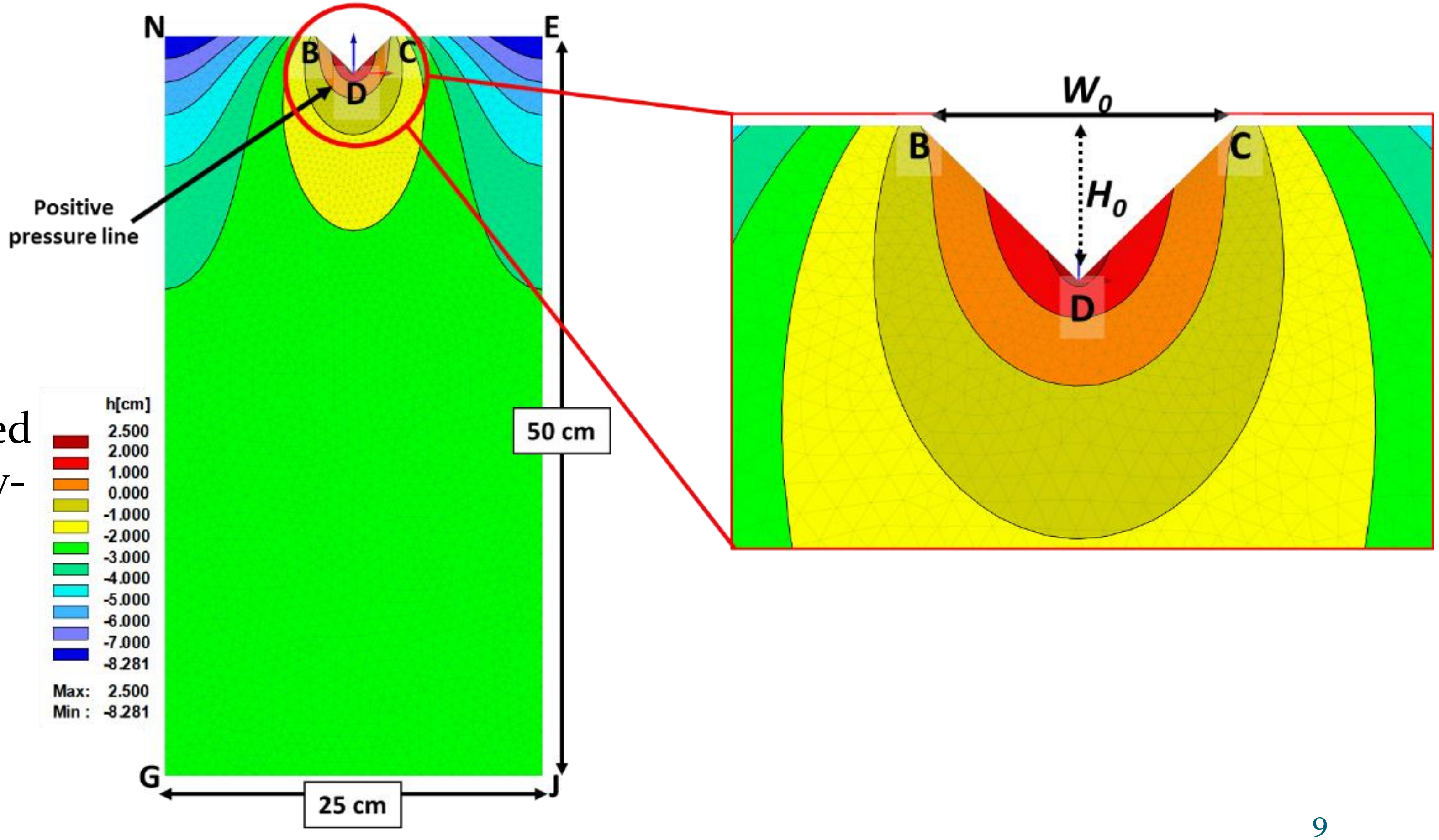
h → the total (piezometric) head [cm]
p → the pressure head [cm]
$\boldsymbol{\theta_v}$ → the volumetric moisture content [cm3/ cm3]
t → time [day]
x & z→ the horizontal & vertical Cartesian coordinate [cm]
$\boldsymbol{K_{un}}$ → the unsaturated hydraulic conductivity [cm*day^{-1}]



Coupling Surface-Subsurface Flow

- Channel's cross-section, a rectangle (x, z) = (25, 50) cm
- **The domains:** sand (K_s=*0.91 cm/min*)
- **Hydrostatic head** → wetted parameters
- **Free drainage** → lower boundaries
- **Impermeable** → other sides

- The bottom segment GJ outlet was selected to determine the infiltration rate at steady-state conditions.



HYDRUS-computed $q_i\ (H)$ values for various channel depths

H (cm)	$\mathbf{q_i}$ (cm²/min)
0.5	6.974
0.7	8.096
1.0	9.450
1.2	10.417
1.5	11.629
1.7	12.500
2.0	13.626
2.2	14.395
2.5	15.259

Interpolation function and interpolation polynomial qi [H] has been obtained by *Wolfram's Mathematica*:

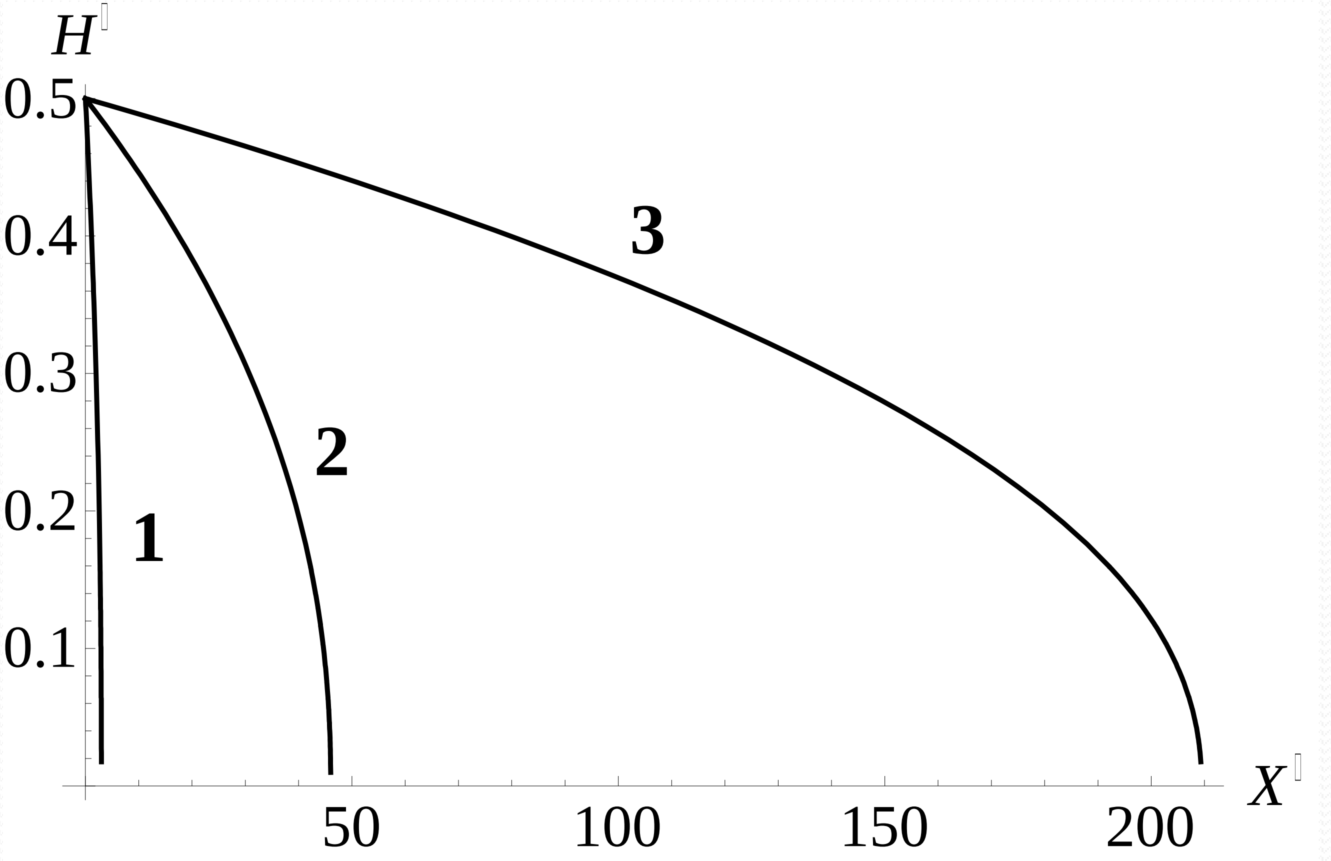
$$q_i[H] = -163871. + 202262.\ H - 96917.1\ H^2 + 23936.\ H^3 - 3192.48\ H^4 + 218.515\ H^5 - 6.01235\ H^6$$

Results

- Dimensionless depths of the jets as functions of dimensionless longitudinal coordinate for:

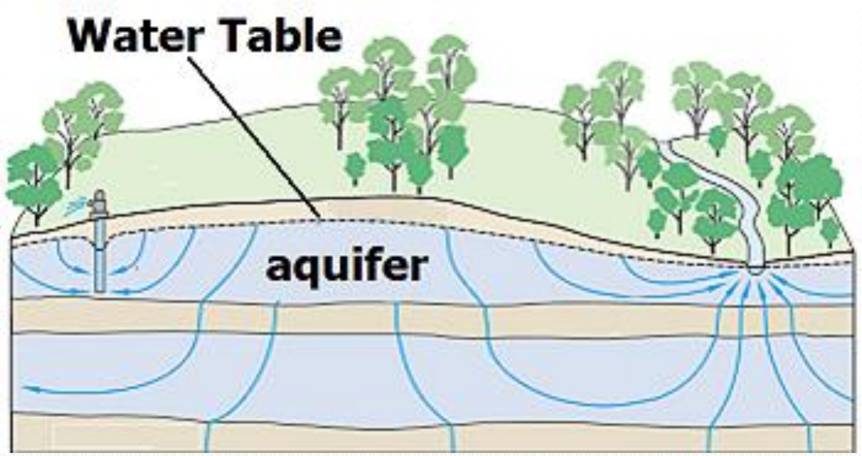
  W_0=0.05 m, H_0=0.025 m, n=0.02 s/m$^{1/3}$, topographic slope of 5°

- Curves 1-3 correspond to K_s = 1.4*10^{-2}, 8.9*10^{-4} and 2.0*10^{-4} m/s.



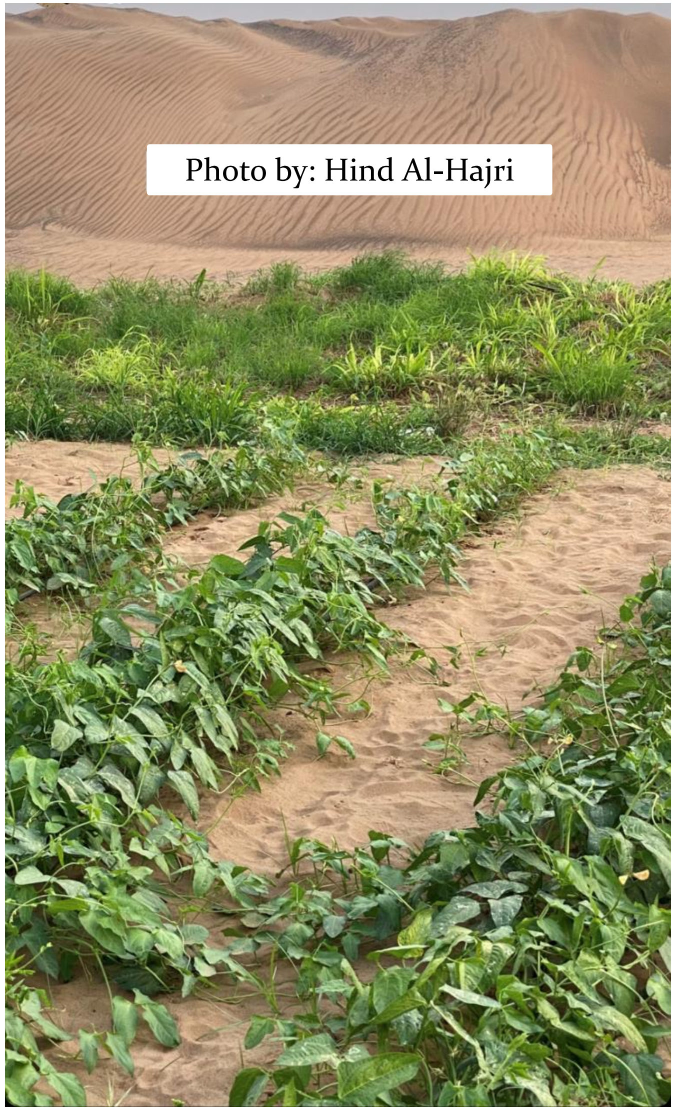
Conclusion and Recommendations

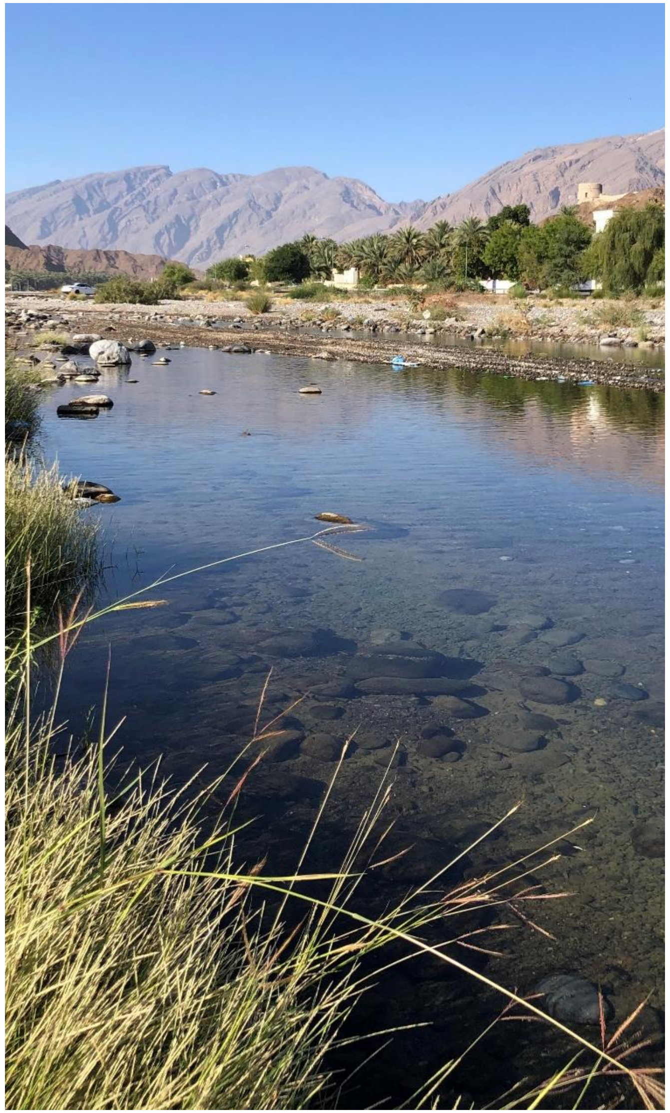
- Rural areas in arid regions, particularly sand dunes, are expanding and require sustainable and independent water supply for their desert agriculture and domestic consumption.
- Evaluate the length of propagation of a “free jet” downslope from the inlet where a given quantity of water in MAR is released.
- Solve optimal shape design problems with selection of the seepage losses and channel’s cross-sectional area (or volumetric flow rate) as benchmark.


Water Table
aquifer

Other Applications

- The results of this paper can be used not only for planning MAR operations but also for furrow irrigation in desert agriculture of arid lands.
- The results can be also used for evaluation of "transmission losses" from large-size wadi channels flowing after flash floods.





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Thank you

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