Multiphysics Modelling of Standing Column Well and Implementation of Heat Pumps Off-Loading Sequence

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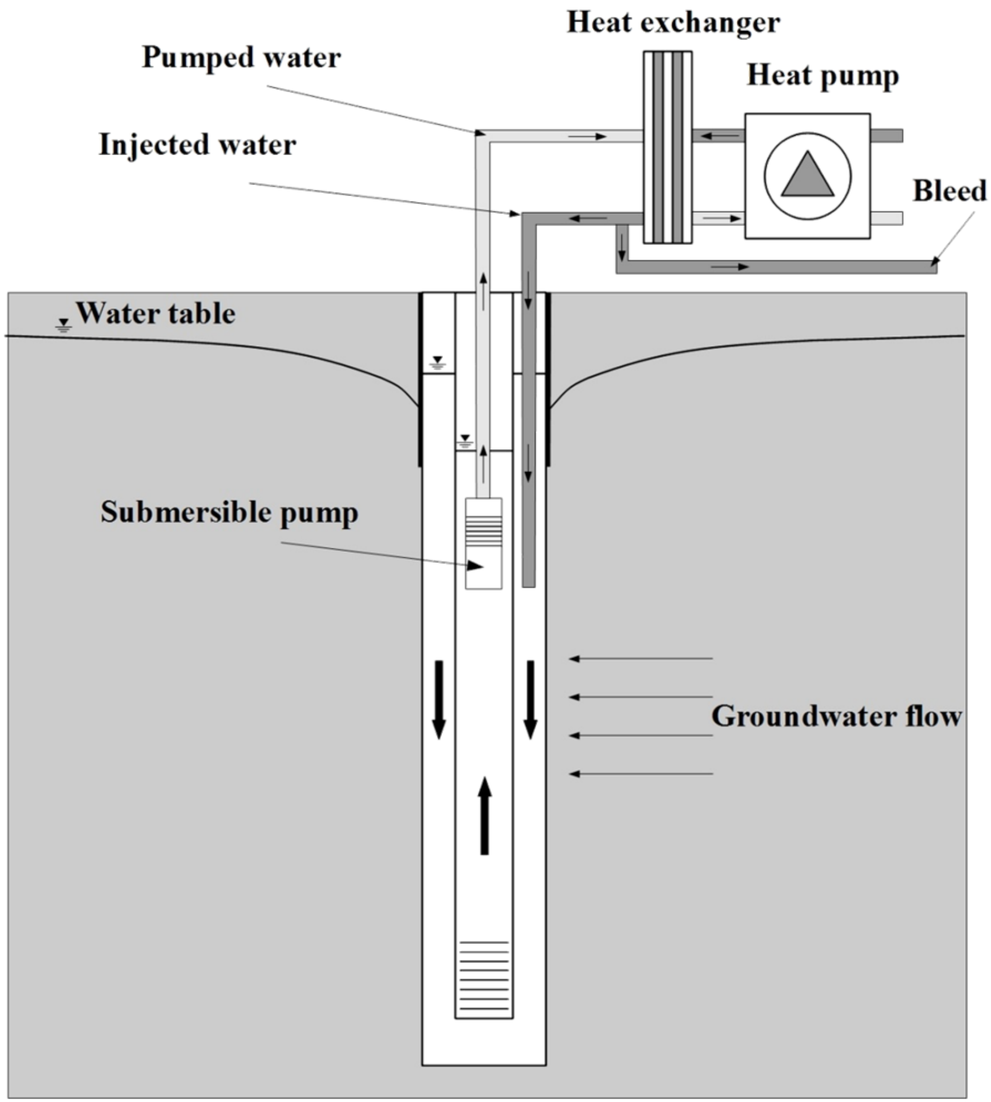
Ground-Coupled Heat Pump Systems (GCHPS)



During winter, heat is extracted out of SCW and the water gets colder.

Bleed
Help maintain the water temperature within the heat pump's operating range

Off-Loading Sequence
Sequentially shut down the heat pumps

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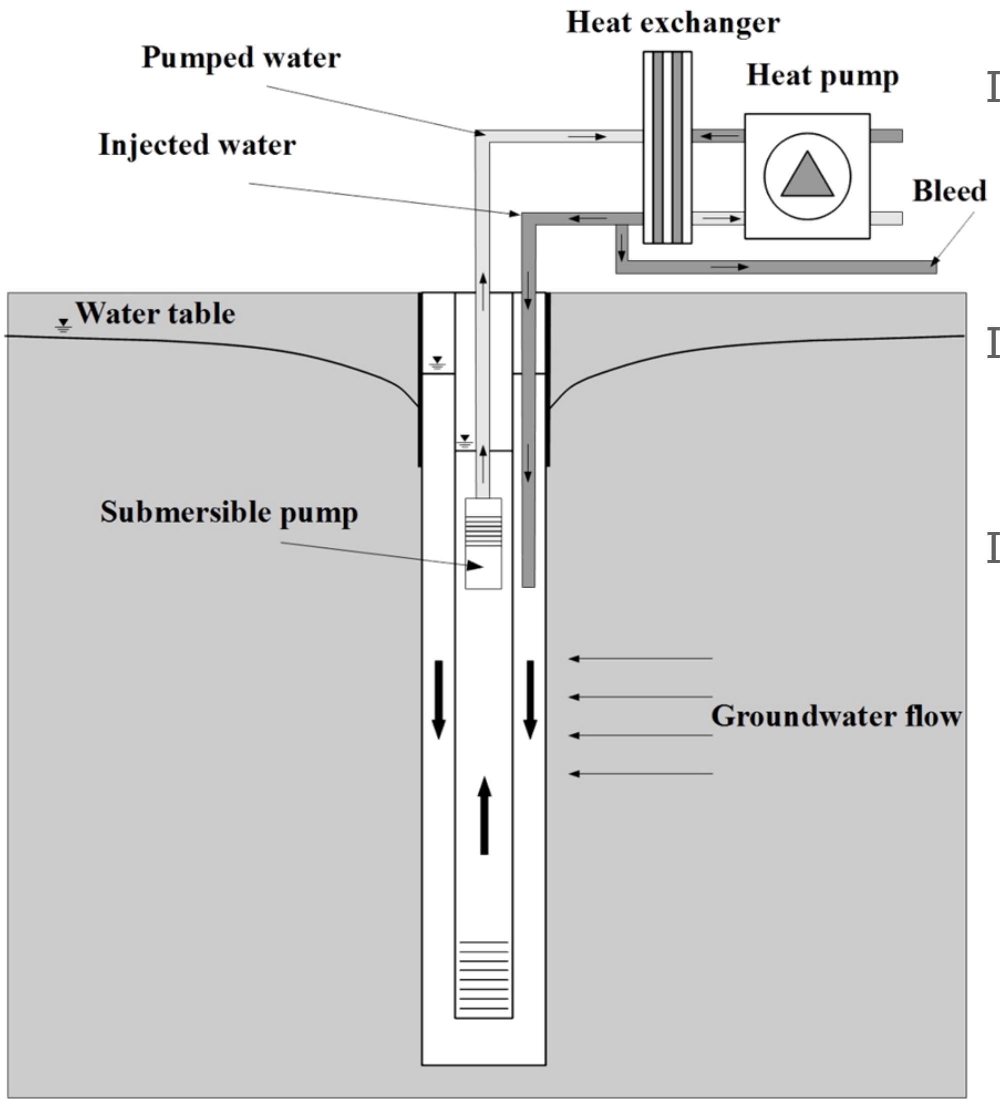
COMSOL MULTIPHYSICS 4.2a



I. Involves heat transfer and groundwater flow within and around a SCW

II. Integrates a three-level bleed control

III. Integrates a heat-pump off-loading sequence via Livelink with MATLAB.

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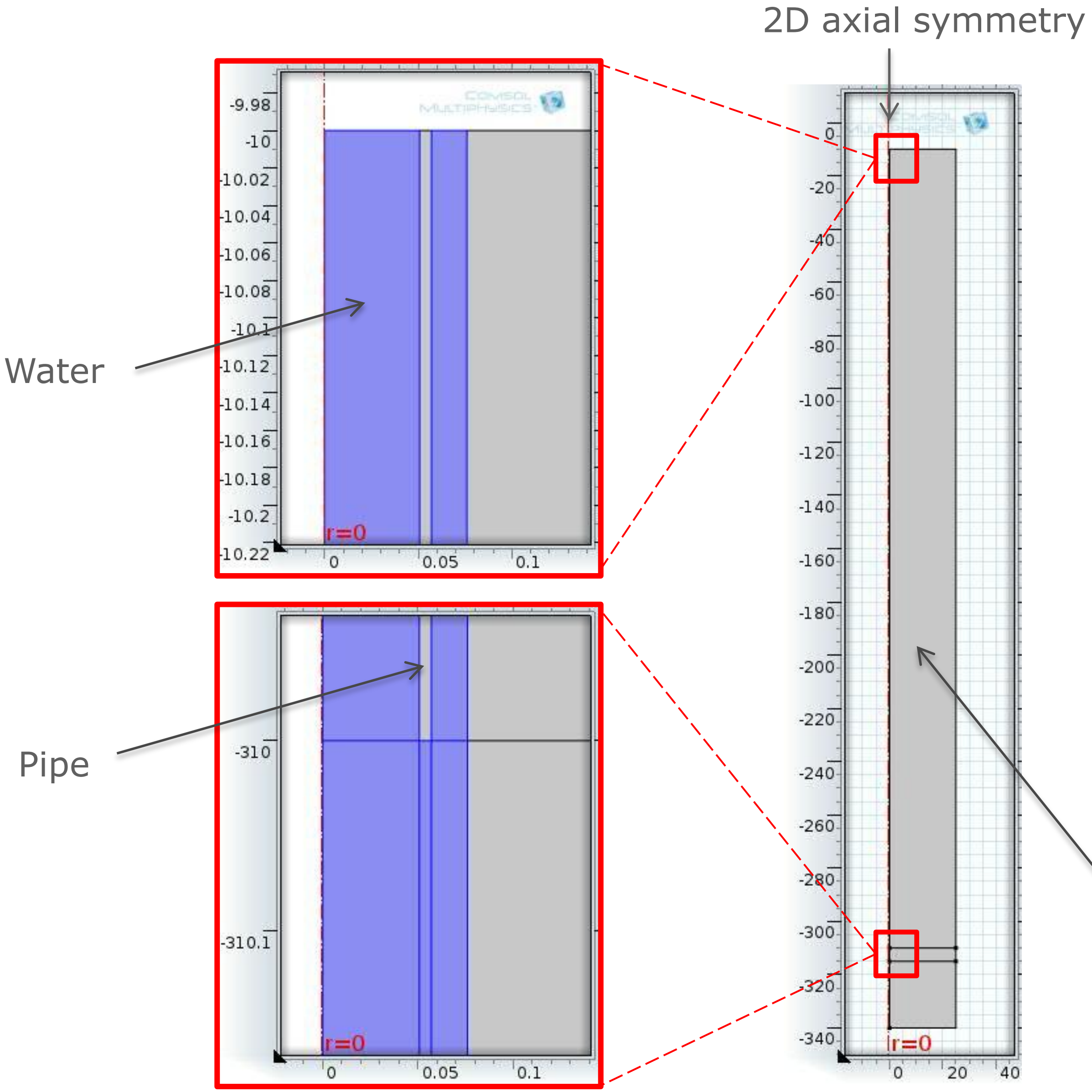
2. MODEL – GEOMETRY



Parameter	Value (m)
Domain radius	25
Domain depth	330
Inner pipe radius	0.051
Outer pipe radius	0.057
Pipe length	300
Borehole radius	0.076
Borehole length	305

Meshing	Value
Element type	Quadrilateral
Number of elements	37630
Discretization	Quadratic
Degrees of freedom	303446

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2. MODEL – GOVERNING EQUATIONS

Strongly Coupled Physics Problem

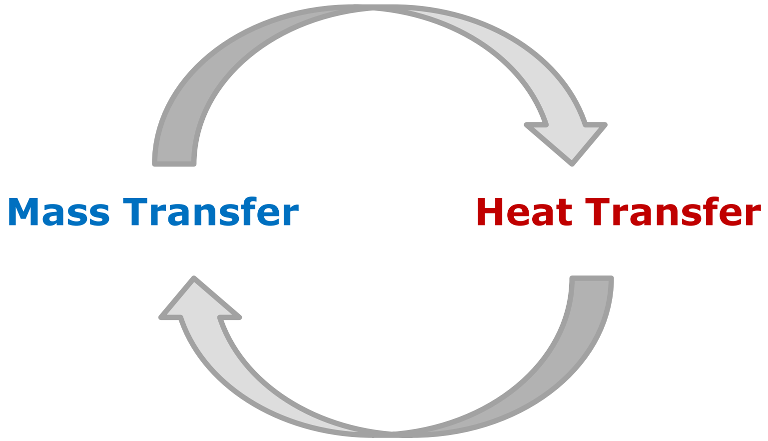
Subsurface Flow – Darcy's Law

$$\rho S \frac{\partial p}{\partial t} + \nabla \cdot (\rho u) = 0$$

$$u = -K \frac{\nabla p}{\rho g}$$

Heat Transfer in Porous media

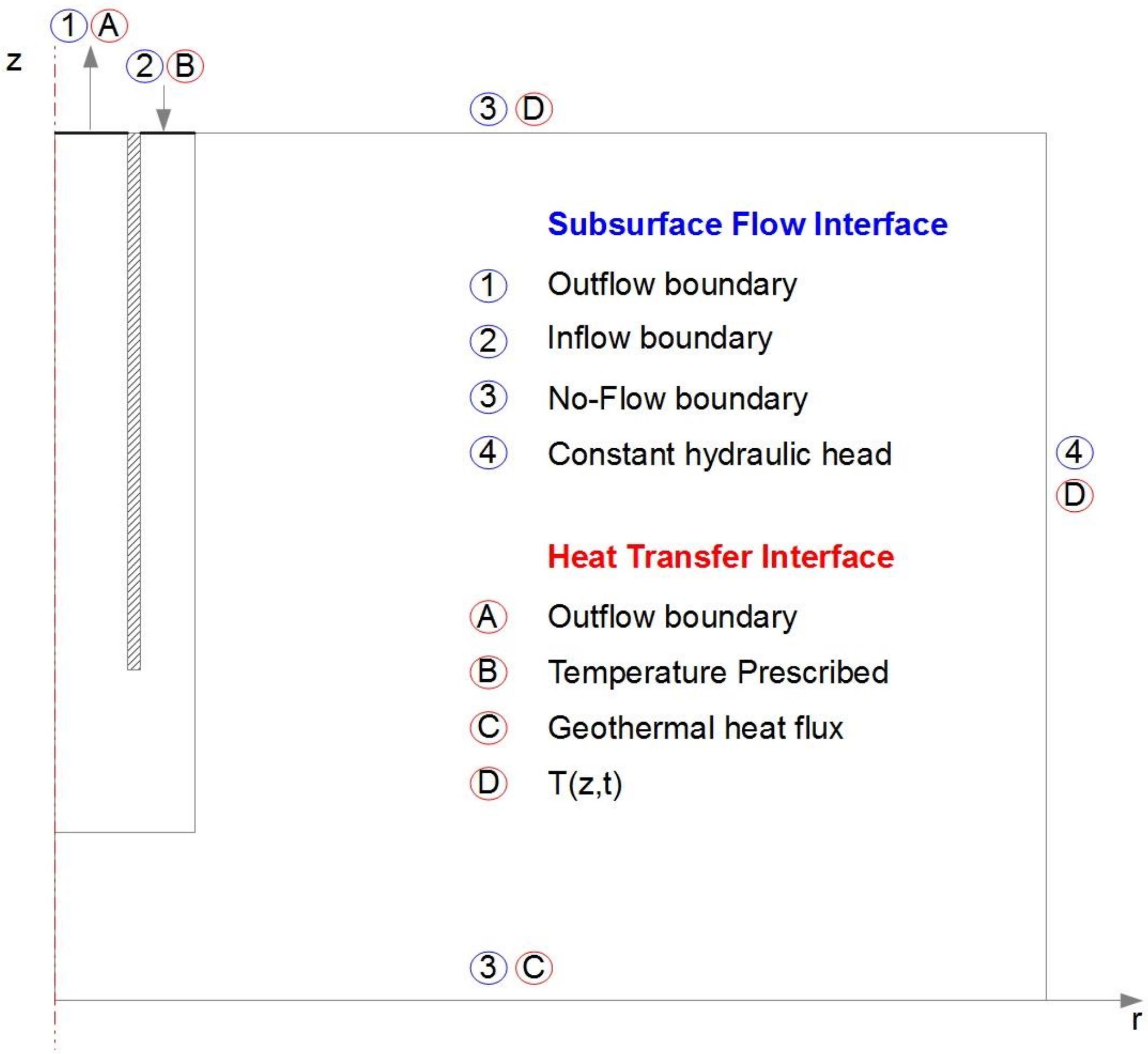
$$(\rho C_p)_{eq} \frac{\partial T}{\partial t} + \rho C_p u \cdot \nabla T = \nabla \cdot (k_{eq} \nabla T)$$

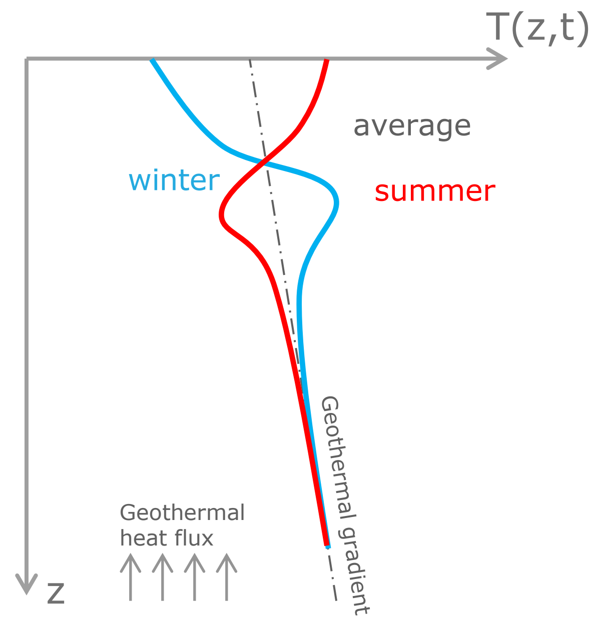


Time dependent

0 → **t**

2. MODEL – BOUNDARY CONDITIONS





Lunardini V.J. (1981)

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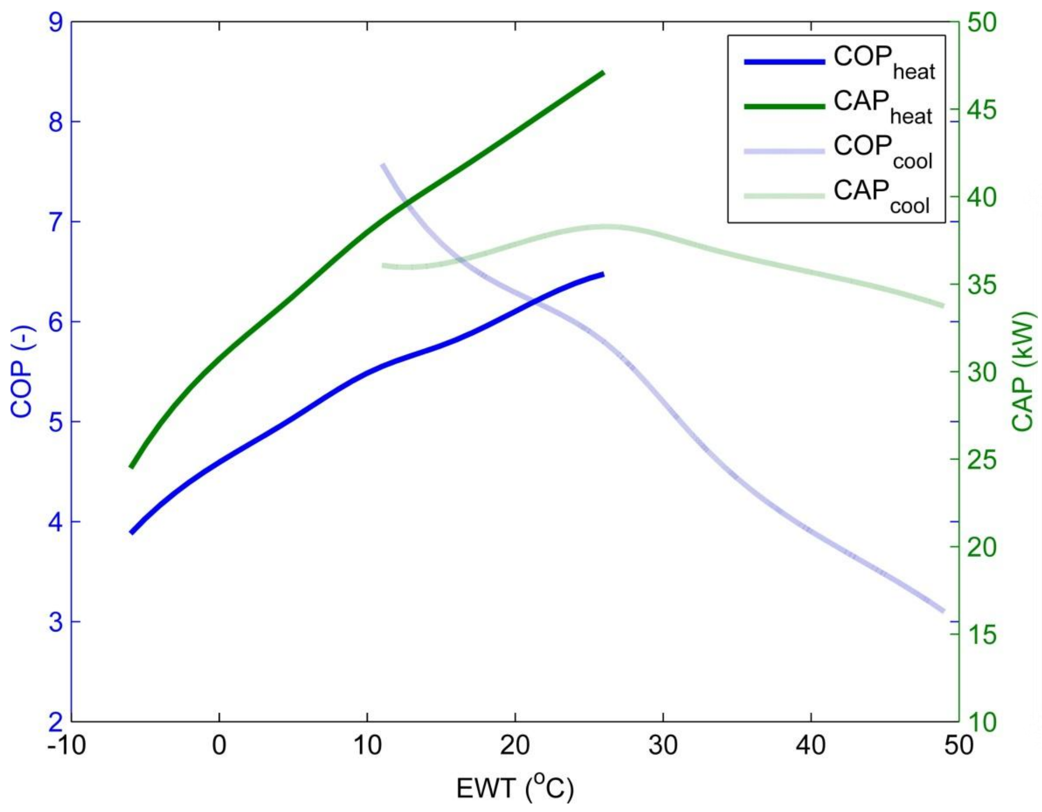
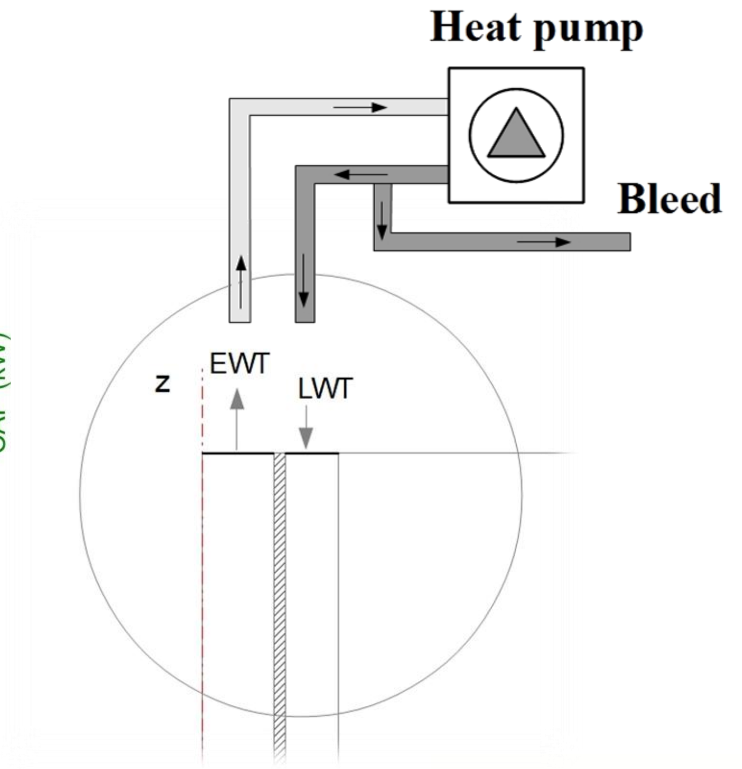
Heat Pumps

Coefficient of Performance (COP) & Capacity (CAP) as function of the heat pump's entering water temperature (EWT)





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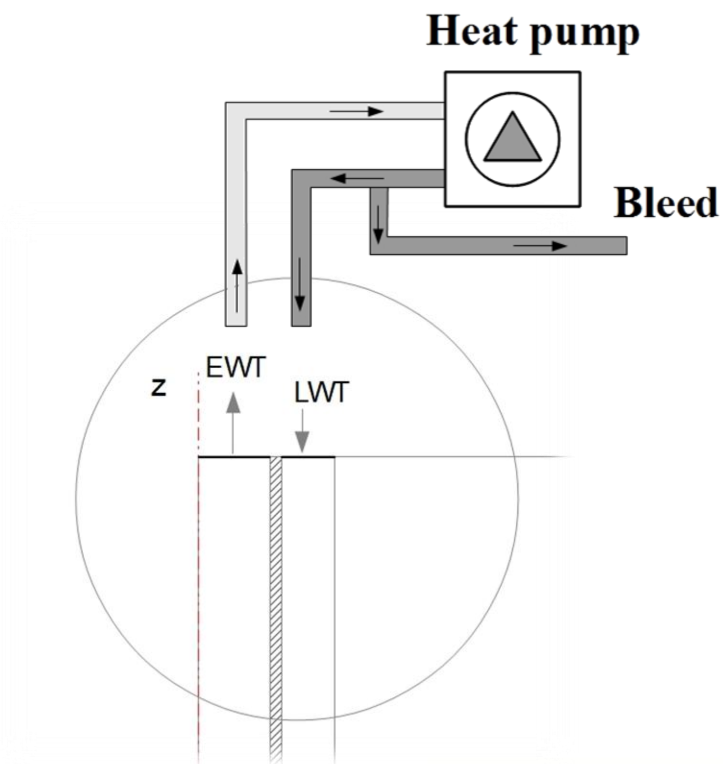
Leaving Water Temperature (LWT)

$$LWT = EWT + \Delta T(EWT)$$

$$\Delta T(EWT) = \frac{n_{hp} CAP(EWT)}{Q \rho C_p} \left(1 - \frac{1}{COP(EWT)} \right)$$



List of variables

EWT	Entering water temperature	[°C]
LWT	Leaving water temperature	[°C]
n_{hp}	Number of heat pumps	[-]
COP	Coefficient of performance	[-]
CAP	Capacity	[kW]
Q	Flow rate	[m^3/s]
ρ	Water density	[kg/m^3]
C_p	Water heat capacity	[J/kg/°C]

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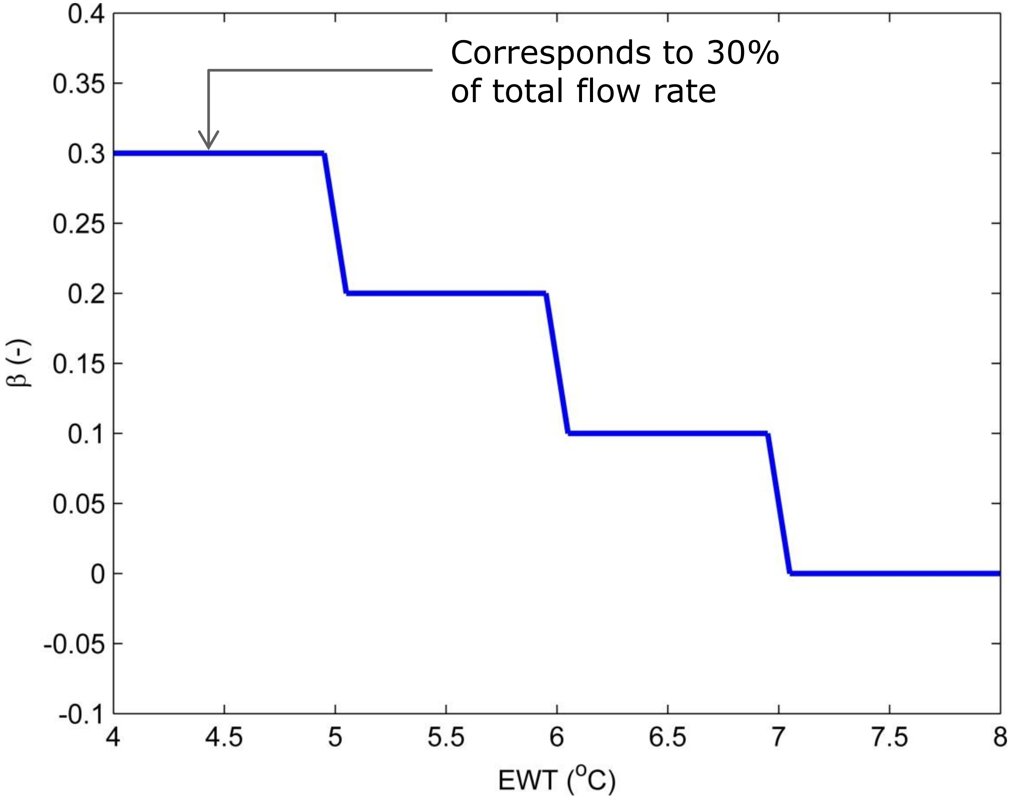
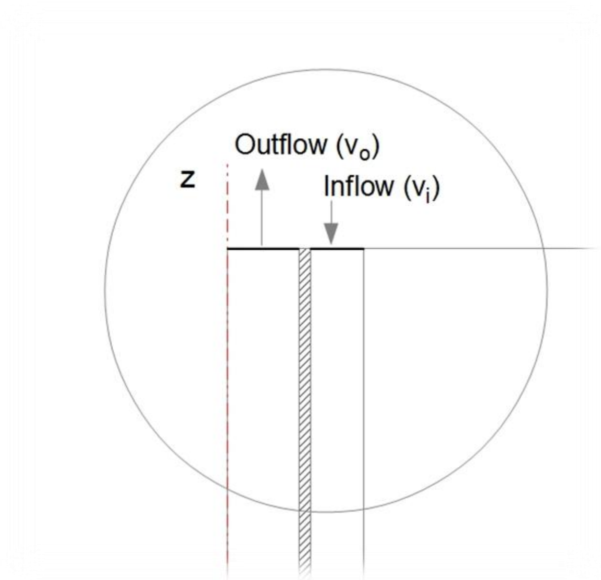
Three Level Bleed Control

Velocity at the **Outflow** and **Inflow** Boundary:

$$v_o = \frac{Q}{A_o}$$

$$v_i = \frac{Q(1-\beta)}{A_i}$$





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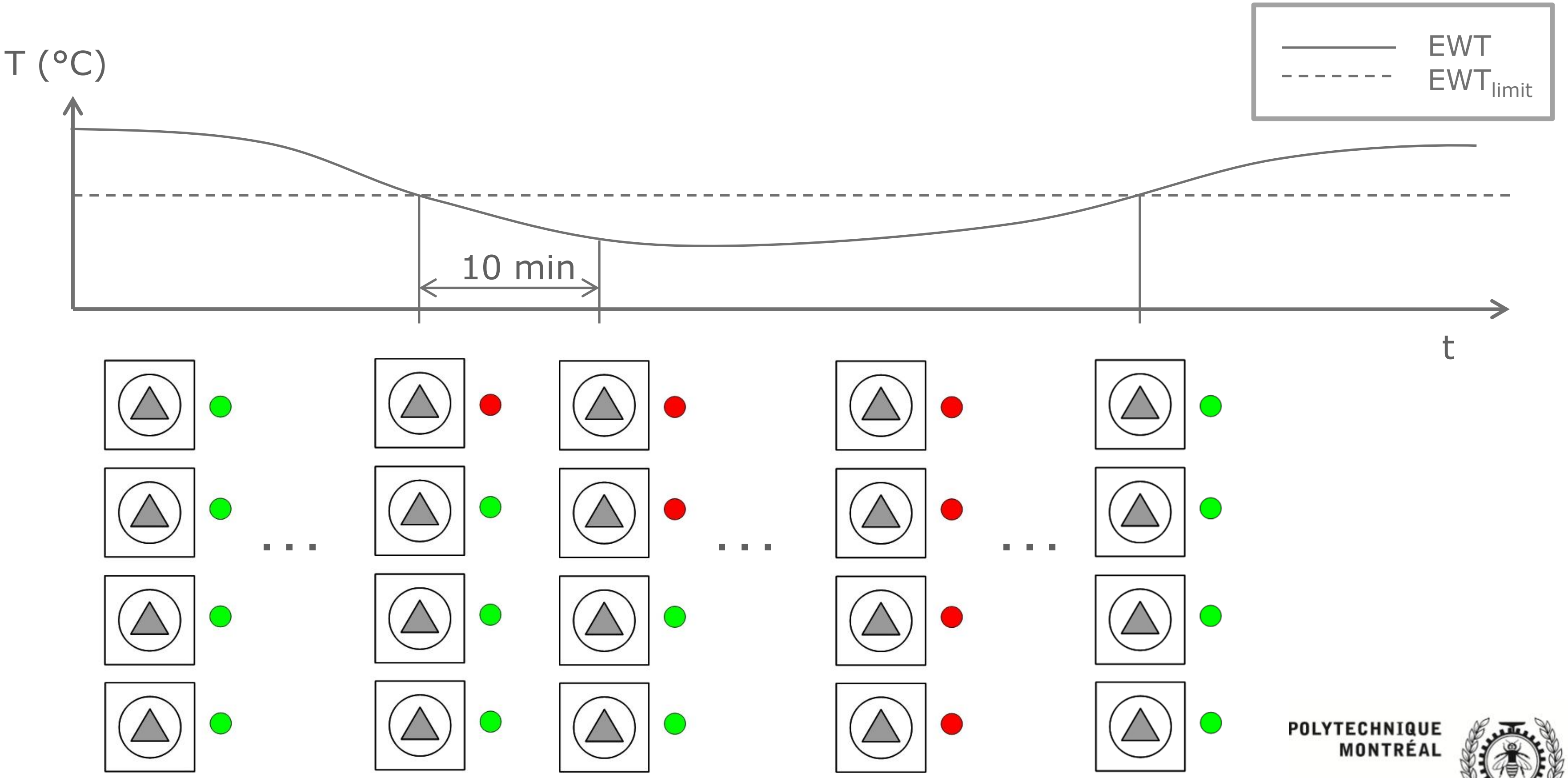
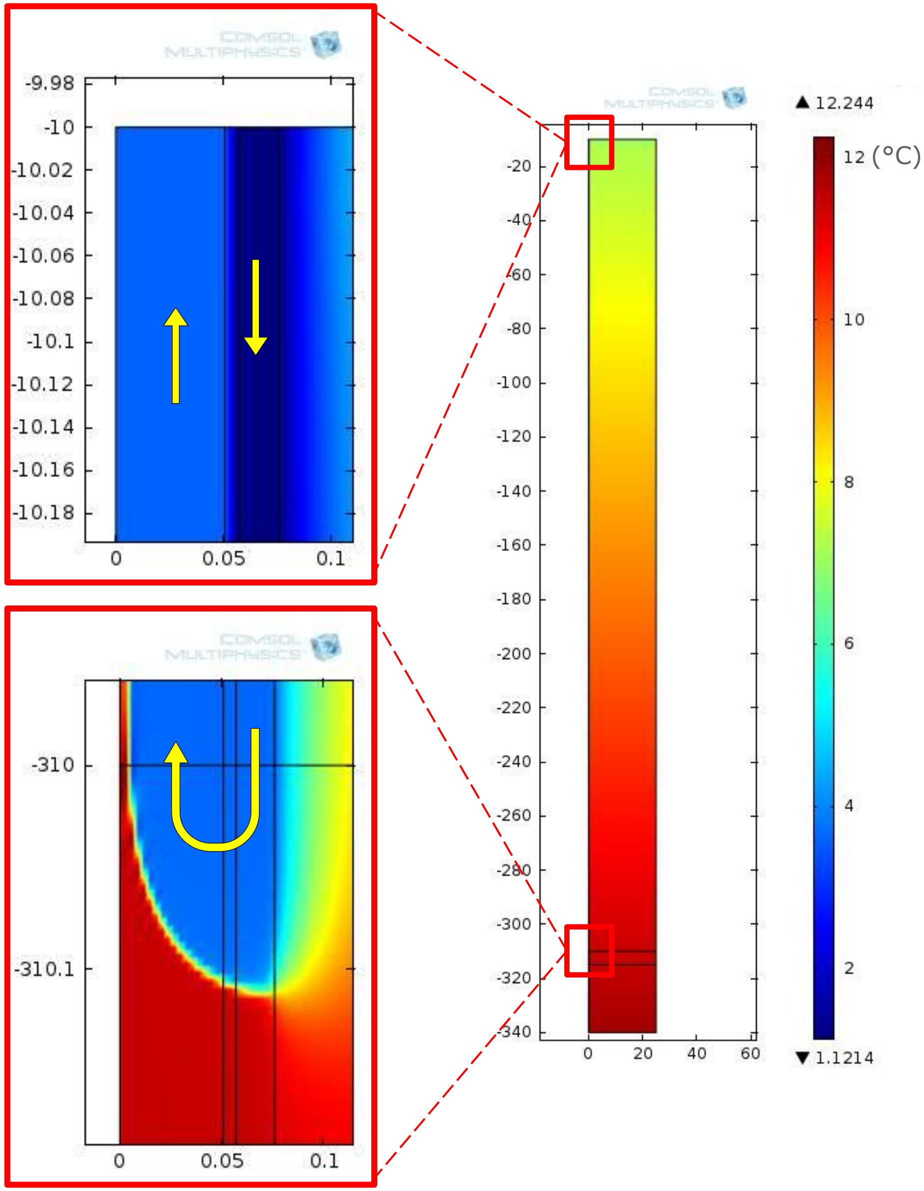
Off-Loading Sequence, Via MATLAB → n_{hp} = fct(t,EWT)



3. RESULTS – SURFACE TEMPERATURE FIELD



After 24 hours of heat extraction, the EWT dropped from 7 to 4 °C

Building load of 200 kW provided by a backup system and 4 heat pumps $n_{hp} = 4$

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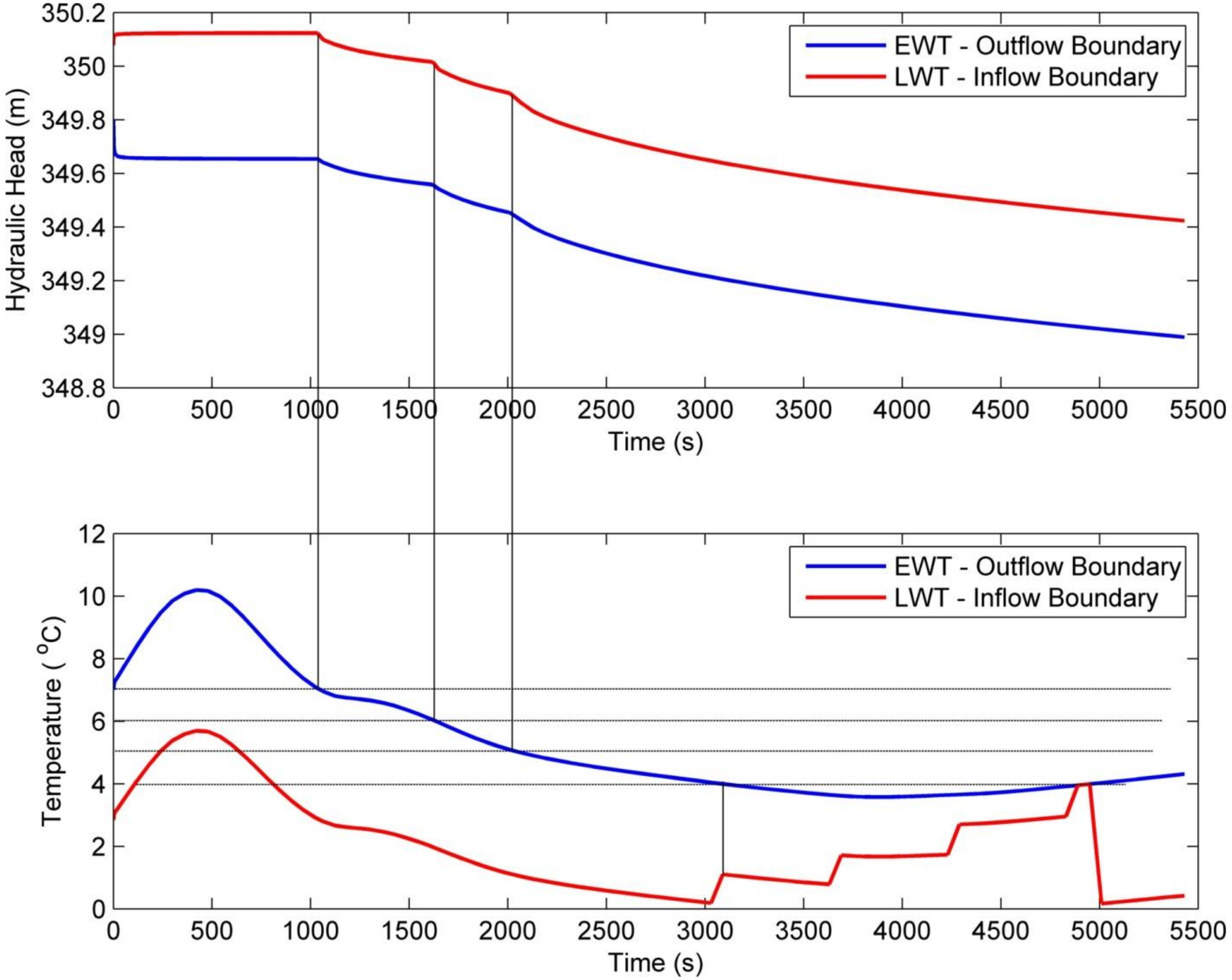
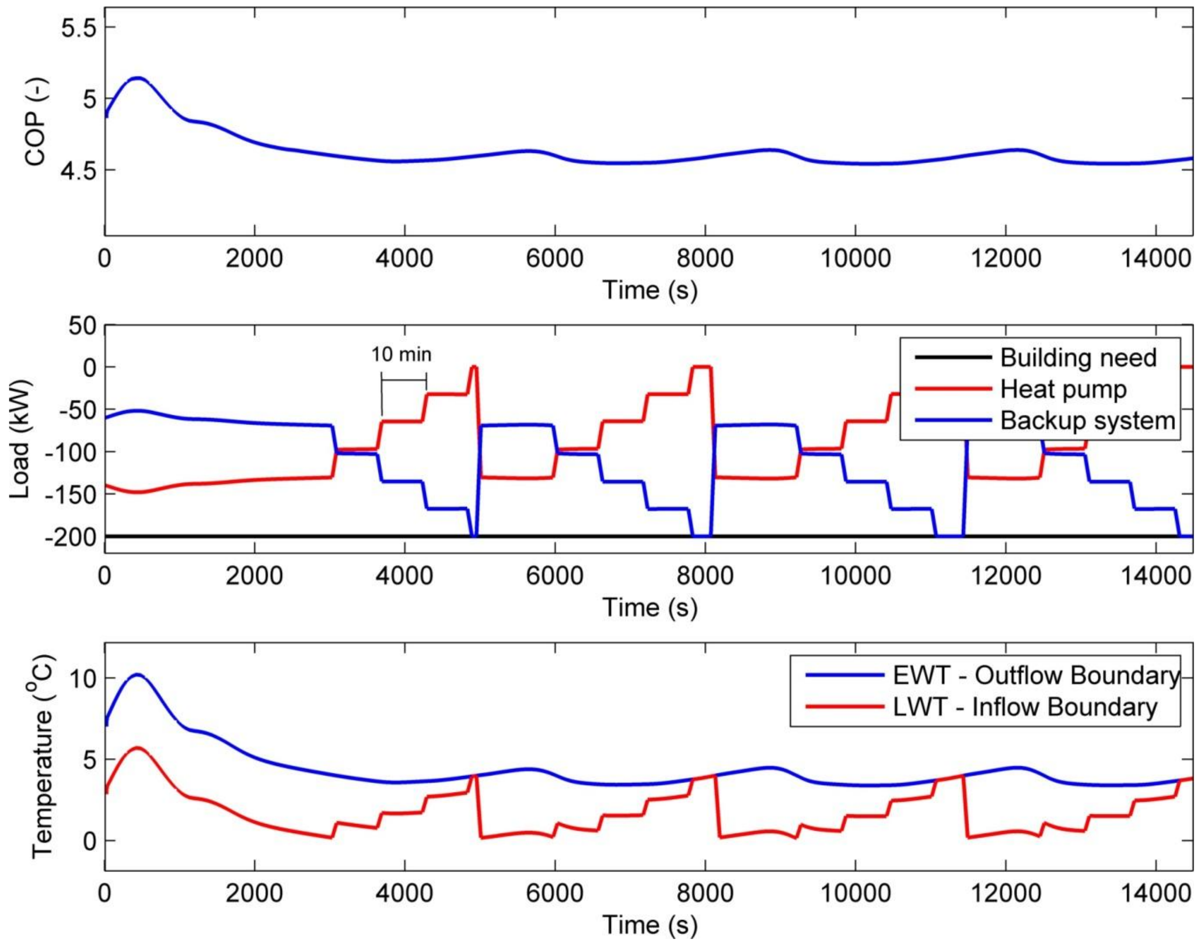
3. RESULTS – THREE LEVEL BLEED CONTROL



Hydraulic head drop at 7, 6 and 5 °C

3. RESULTS – OFF LOADING SEQUENCE



COP allows an evaluation of the energy consumption

Load provided by each subsystems

EWT maintained within the HP's operating range

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4. CONCLUSION

Developed a coupled model of SCW that

- Integrates a three level **Bleed** control
- Integrates an **Off-Loading Sequence**
- Successfully evaluate the EWT over time
- Allows an evaluation of the energy consumption by the HPs

It was found that

- Both **Bleed** and **Off-Loading Sequence** played a key role in maintaining the EWT within the heat pump's operational range.

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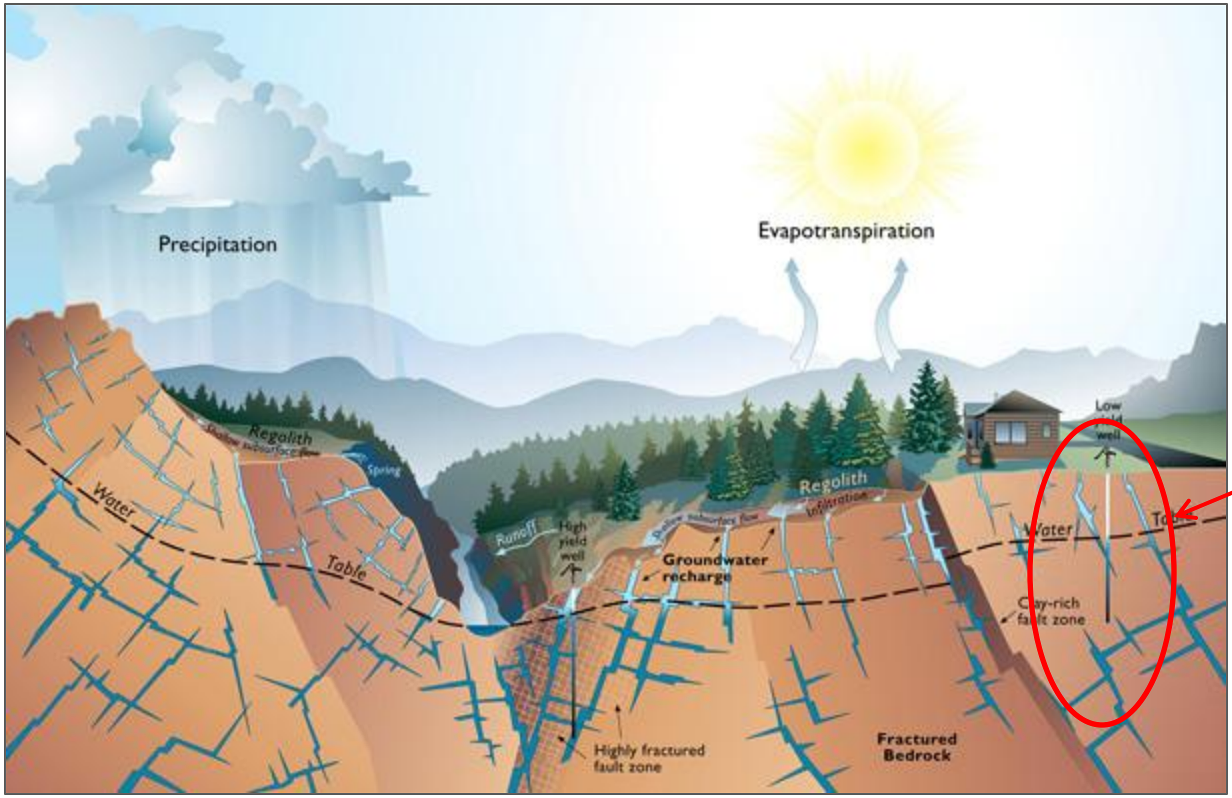
4. CONCLUSION – ONGOING RESEARCH

This current model can be extended to **fractured aquifers**



Potential SCW

Source:
http://geosurvey.state.co.us/apps/wateratlas/chapter7_5page2.asp

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5. QUESTIONS

Thank You! :)

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