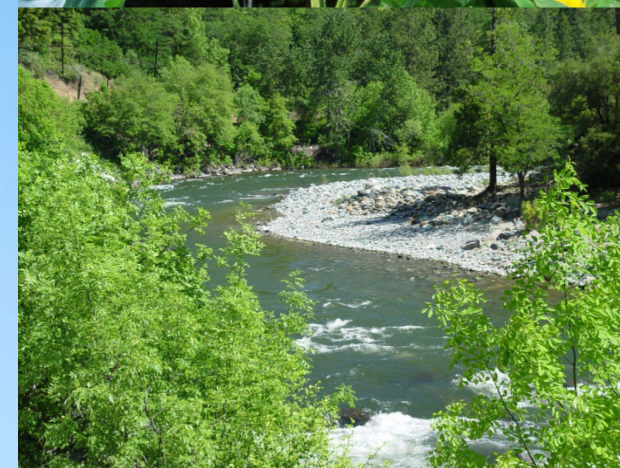
GROUNDWATER RESOURCE DIRECTED MEASURES

Aquifer Model

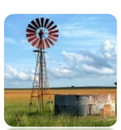
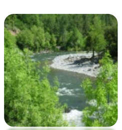


Introduction

The Reserve is water that is ‘set aside’ to:

- provide for **basic human needs**, and
- protect **water ecosystems** (sustain healthy ecosystems).

The Reserve is the only right to water in the NWA and therefore has priority over all other water use.

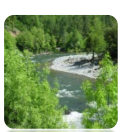

Quantify Basic Human Needs

- Currently, basic human needs (BHN) are set at 25 ℓ/p/d.
- The source of population statistics used for this calculation must be clearly referenced.
- Although normally quite small in comparison to other uses, it must be borne in mind that this is a right to water and must be legally protected.
- It is important to note that BHNs must be calculated for all management scenarios



Quantify Ecological Requirements

- Ecological Water Requirements (EWR) refers to the quantity and quantity of water of that resource that is required to maintain the said water resource in its assigned ecological category.
- It is important to note that this cannot be calculated by the hydrologist or geohydrologist.
- The hydrologist can only quantify the runoff in the river for various scenarios and similarly the geohydrologist can only quantify the groundwater contribution to surface water bodies for various scenarios.

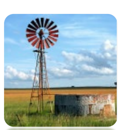
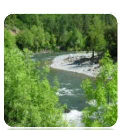




Groundwater Contribution to Baseflow

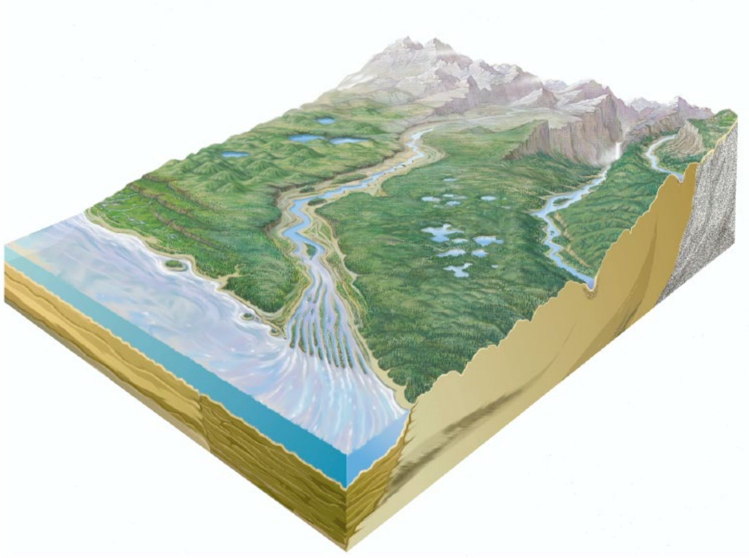
- Auto baseflow separation (Herold method)
- Separation is done until average selected value is reached

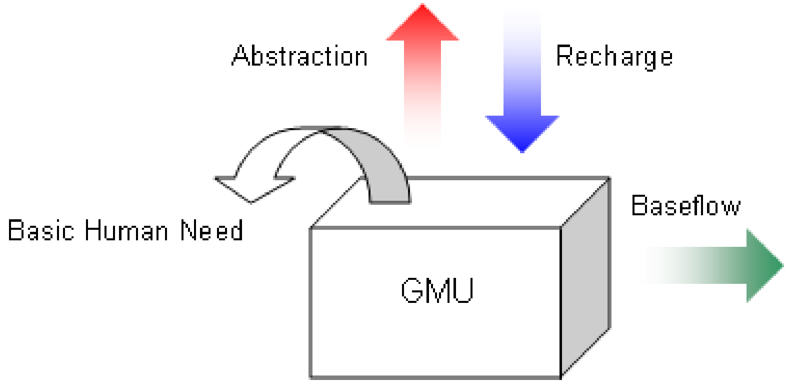
Existing Base Flow Estimations
Pitman
Shultz
Hughes

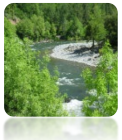
- General:
  - Pitman most conservative
  - Hughes most liberal due to the fact that interflow is included

Calculating the Reserve (Version 1)







Reserve Calculation

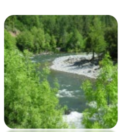
$$Reserve(\%) = \frac{EWRgw + BHNgw}{Re} \times 100$$

where

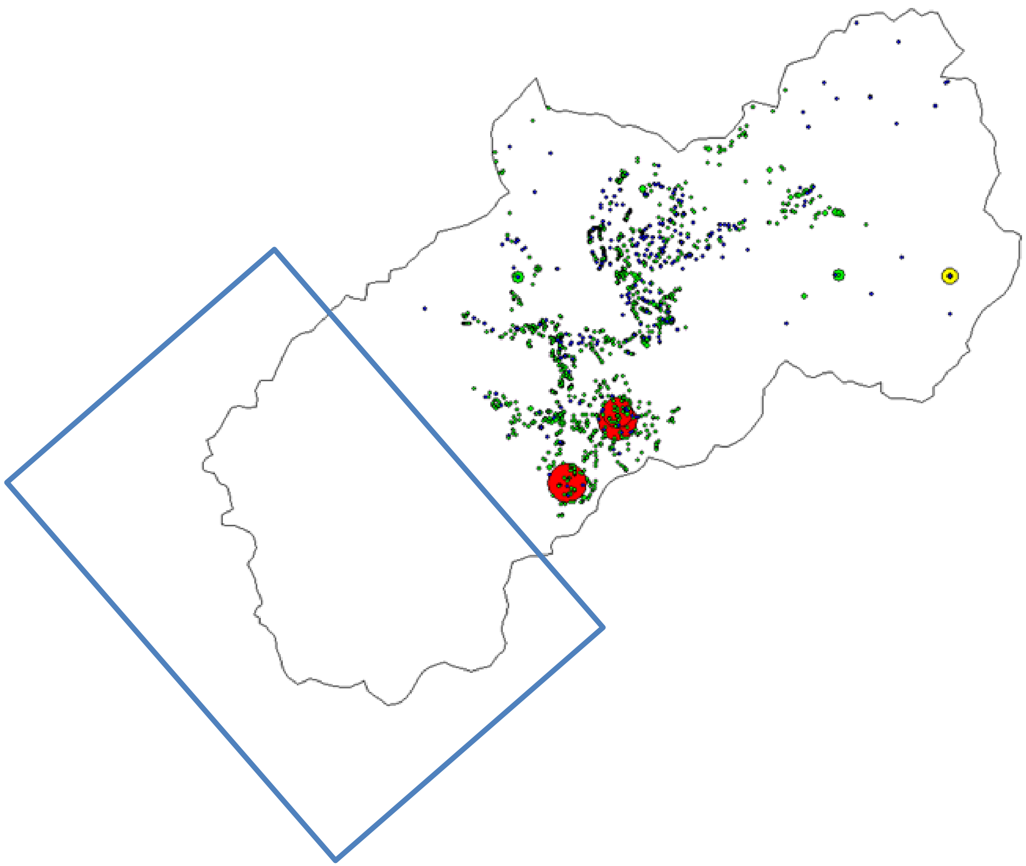
Re = recharge

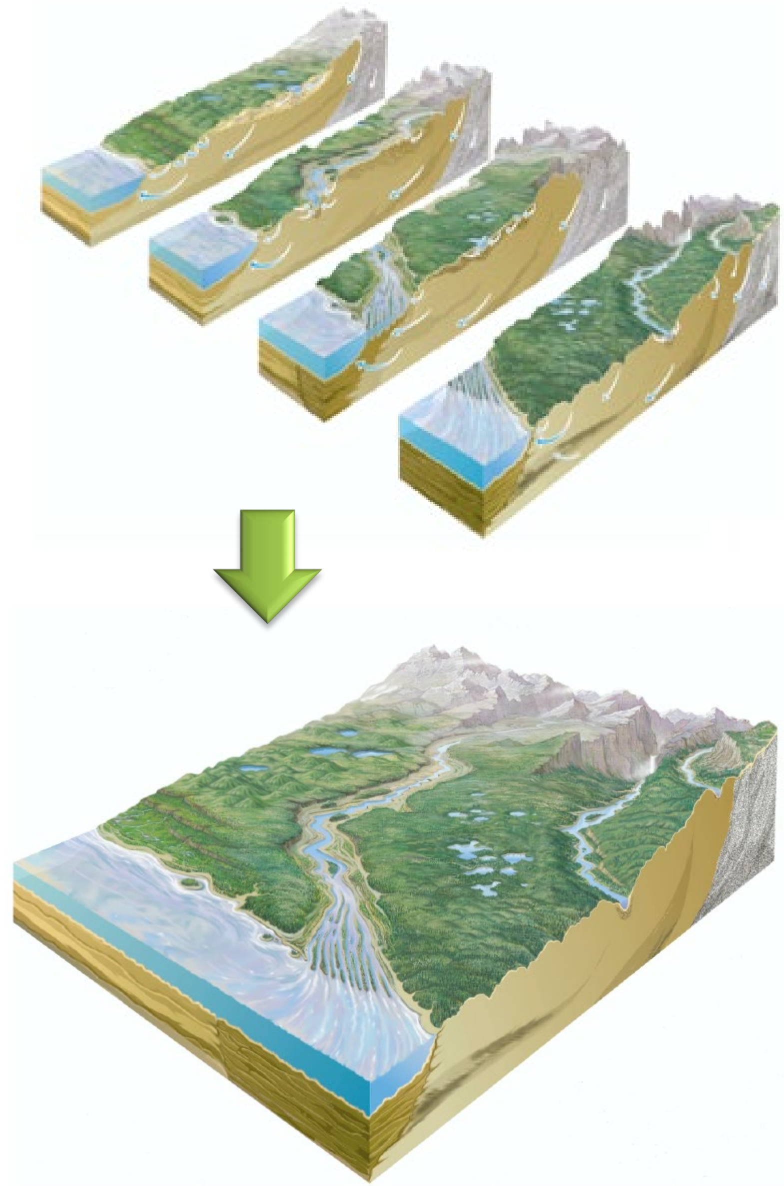
BHN_{gw} = basic human needs derived from groundwater

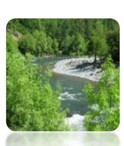
EWR_{gw} = groundwater contribution to EWR

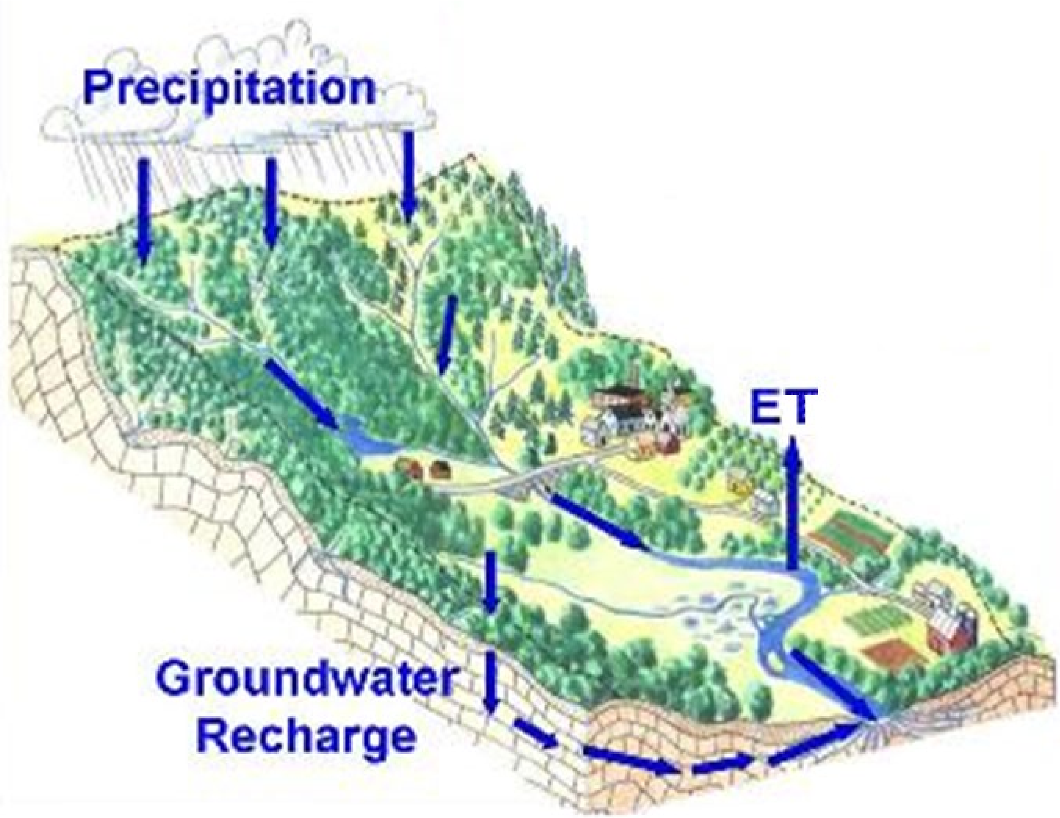

Issues of Scale

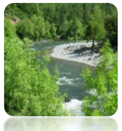




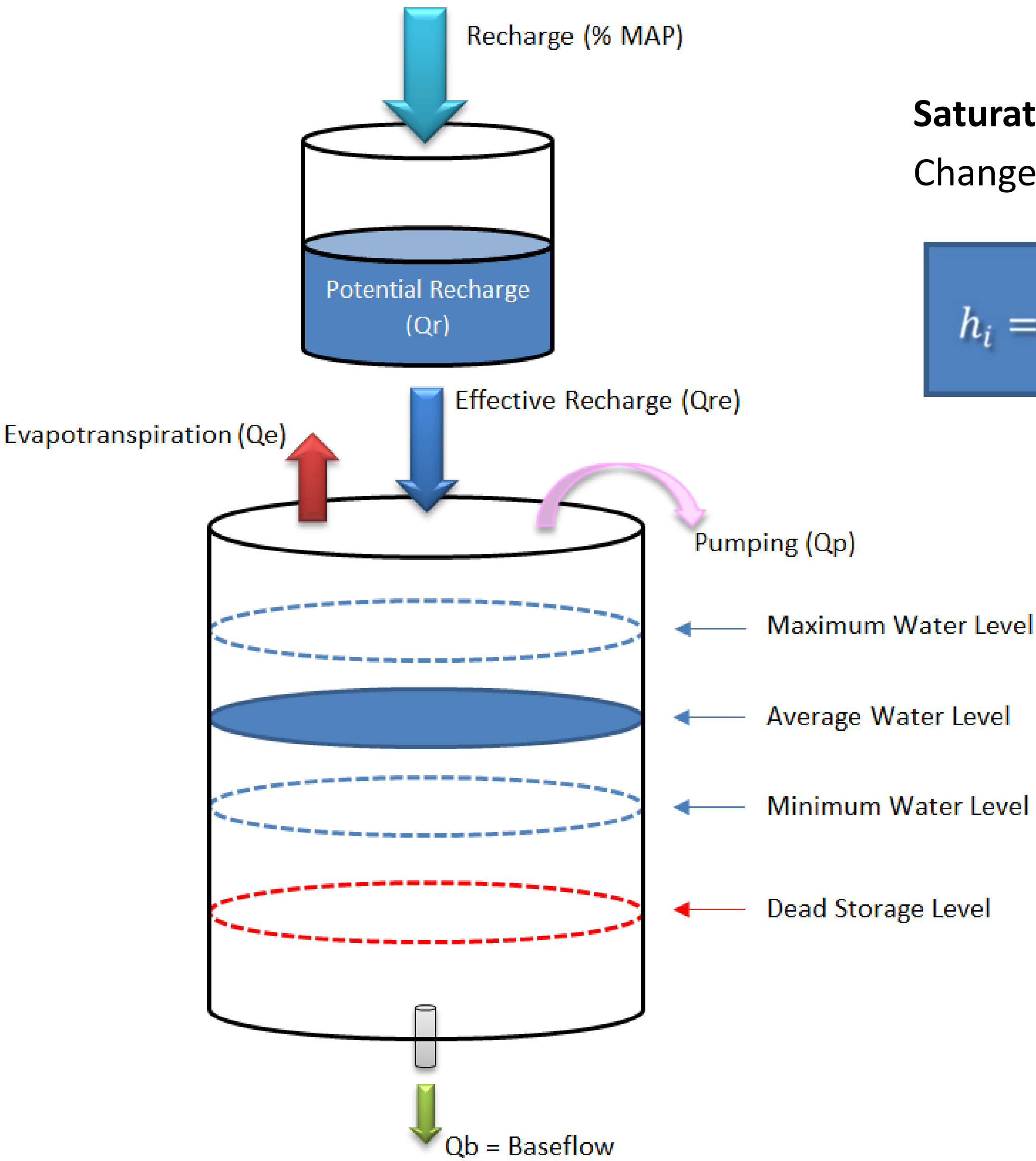


Calculating the Reserve (Version 2)





Yield Model Concept

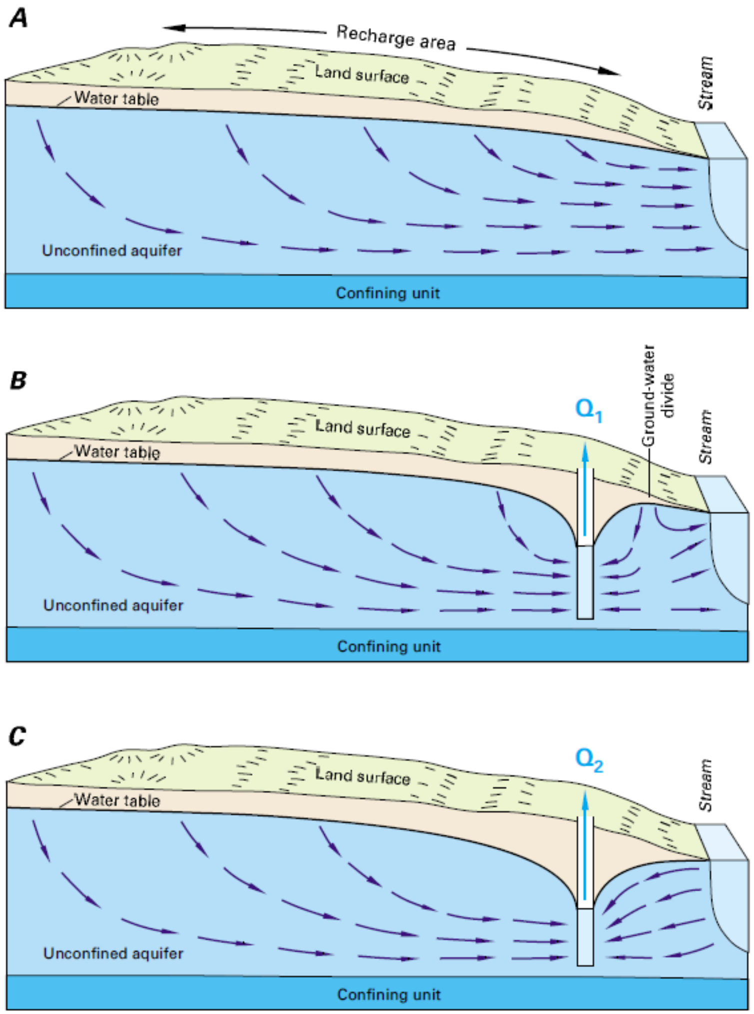


Saturated Volume Fluctuation Water Balance:

Change in Storage = Change in Water Level

$$h_i = h_{i-1} - \frac{R_i}{S_y} + \frac{E_i A_r}{S_y A_t} + \frac{(Q_b + Q_{res} + Q_p)}{S_y A_t}$$

Yield Model States



<u>Scenario A (Ambient State)</u>:

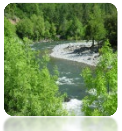
Under natural conditions recharge at the water table is equal to discharge to the stream.

<u>Scenario B (Steady State)</u>:

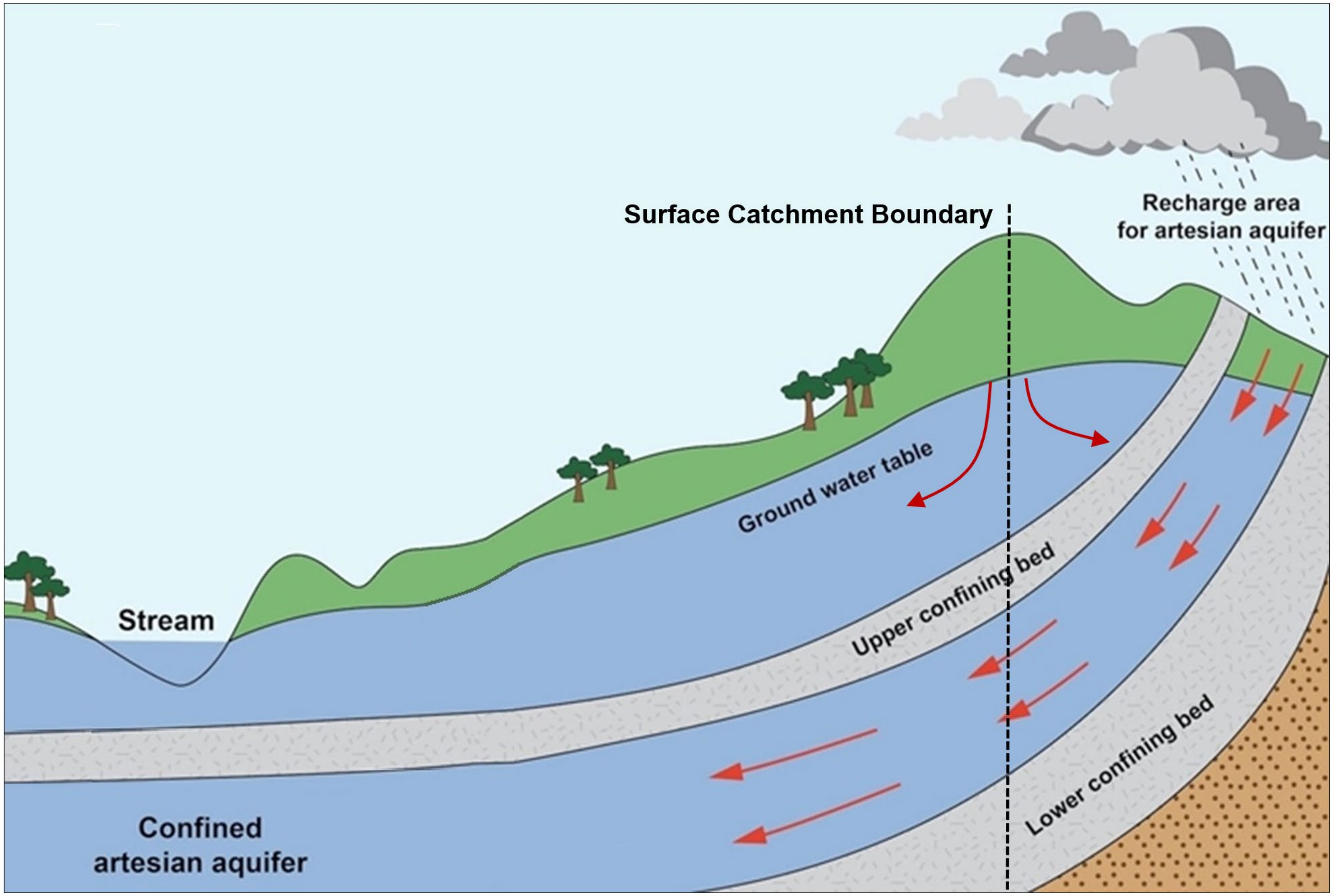
Inflow to the groundwater system from recharge will equal outflow to the stream plus the abstraction from the borehole.

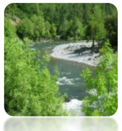
<u>Scenario C (Transient State)</u>:

Baseflow component consumed by high pumping rate.

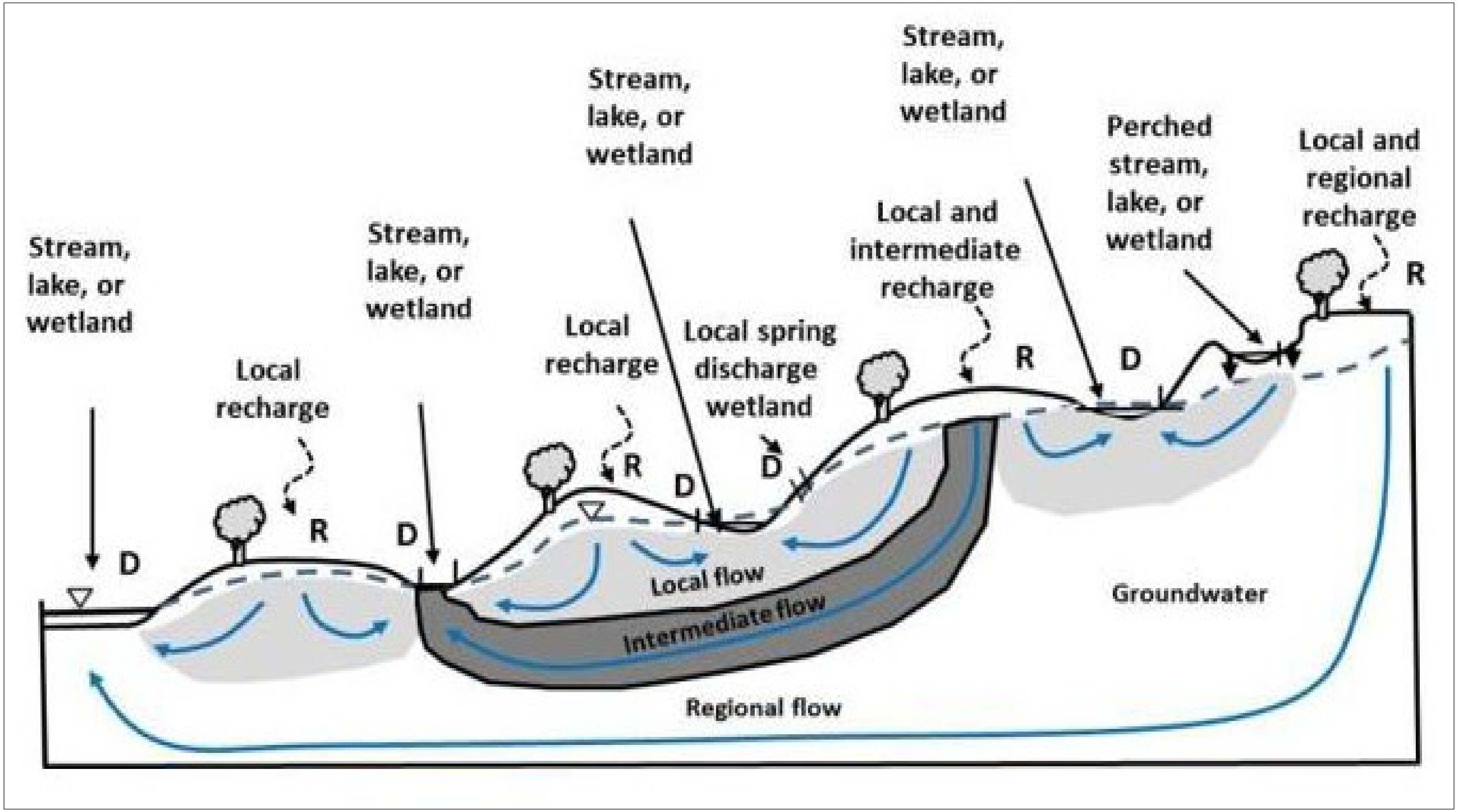



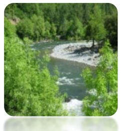

Calculating the Reserve (Version 3)



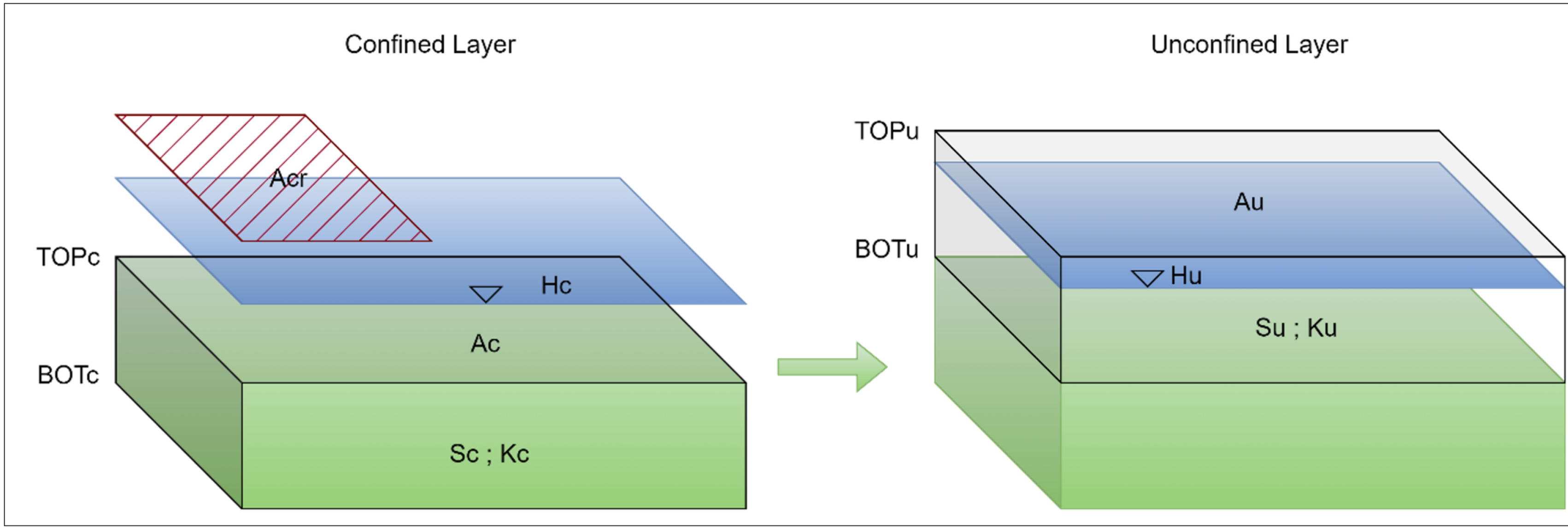


Local and Regional Flow





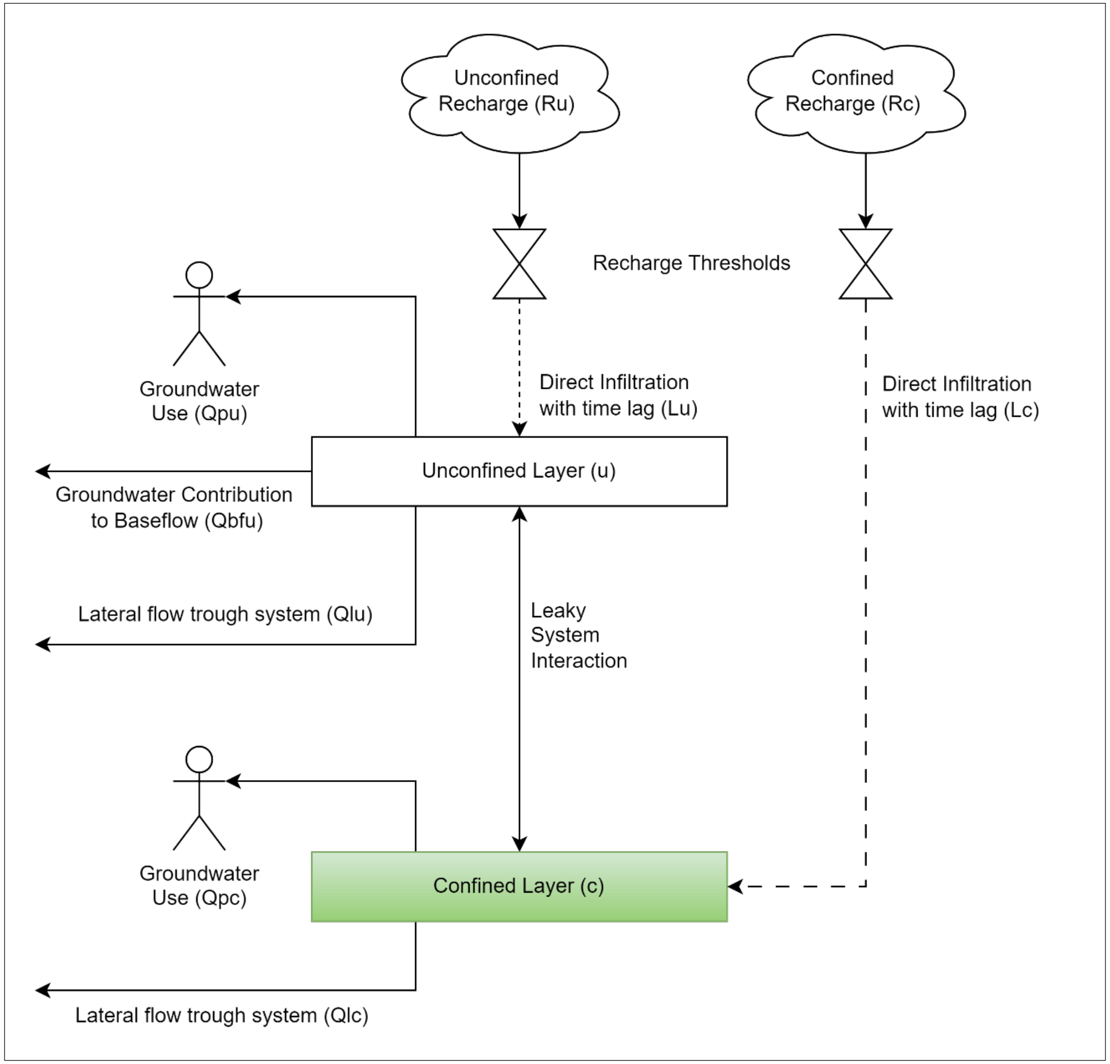
Conceptual Model

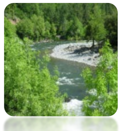


Parameter	Description
A_u , A_c	Area of layer u and c respectively [L^2]
A_{cr}	Recharge area associated with the confined system [L^2]
H_u , H_c	Head value of layer u and c respectively [L]
S_u , S_c	Storativity of layer u and c respectively
K_u , K_c	Hydraulic Conductivity of layer u and c respectively [L/T]
TOP_u , TOP_c	Top of layer u and c respectively [L]
BOT_u , BOT_c	Bottom of layer u and c respectively [L]



Recharge and Discharge





Formulation

$$RIB(i)_m^n = \sum_{i=m}^{n} P_i - \left(2 - \frac{1}{P_{av}(n-m)} \sum_{i=m}^{n} P_i\right) \sum_{i=m}^{n} P_t \qquad \text{Equation 4}$$

where,

i	=	$1,2,3,\ldots,I$
n	=	$i,i-1,i-2,\ldots,N$ $\quad M < N < I$
m	=	$i,i-1,i-2,\ldots,M$
P_i	=	*Precipitation amount in the* i^{th}*-month*
P_{av}	=	*Average precipitation of all precipitation events*
P_t	=	*Threshold value representing aquifer boundary conditions (0 to* P_{av}*) with 0 indicating aquifer being closed and* P_{av} *implying the aquifer is open, perhaps regulated by spring flow*

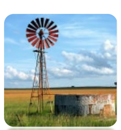
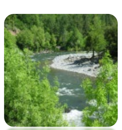


Formulation

$$\Delta h_i = \frac{rA_r RIB(i)_m^n}{AS} - \frac{(Q_{p_i} + Q_{out_i})}{AS} \qquad \text{Equation 5}$$

where,

i	=	$1,2,3,\ldots,I$
n	=	$i, i-1, i-2, \ldots, N$ $\quad M < N < I$
m	=	$i, i-1, i-2, \ldots, M$
Δh_i	=	*Change in water level representing a change in storage in the i^{th}-month*
$RIB(i)$	=	*RIB term in the i^{th}-month (see Equation 4)*
r	=	*Fraction of CRD that contributes to recharge*
S	=	*Storativity*
A	=	*Model area $[L^2]$*
A_r	=	*Recharge area $[L^2]$*
Qp_i	=	*Groundwater abstraction in the i^{th}-month*
$Qout_i$	=	*Natural groundwater outflow in the i^{th}-month*


Formulation

$$H_{u_i} = H_{u_{i-1}} + \frac{A_{ru}R_{u_i} - Q_{pu_i} - Q_{lu_i} - Q_{bfu_i} - Q_{leak_i}}{A_u S_u} \qquad \text{Equation 6}$$

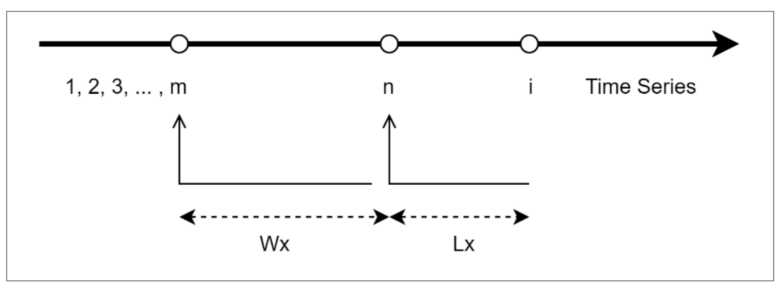
where,

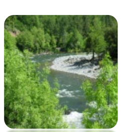
$$R_{u_i} = r_u RIB_u(i)_{(L_u - w_u)}^{(i-L_u)}$$

$$H_{c_i} = H_{c_{i-1}} + \frac{A_{rc}R_{c_i} - Q_{pc_i} - Q_{lc_i} + Q_{leak_i}}{A_c S_c} \qquad \text{Equation 7}$$

where,

$$R_{c_i} = r_c RIB_c(i)_{(L_c - w_c)}^{(i-L_c)}$$





Formulation

$$\frac{1}{C_v} = \frac{1}{\dfrac{A_u K_u}{(1/2)(TOP_u - BOT_u)}} + \frac{1}{\dfrac{A_u K_c}{(1/2)(TOP_c - BOT_c)}} \qquad \text{Equation 8}$$

$$Q_{leak_i} = C_v\left(H_{u_{i-1}} - H_{c_{i-1}}\right) \qquad \text{Equation 9}$$

$$Q_{t_i} = Q_{bfu_i} + Q_{s_i} \qquad \text{Equation 10}$$

where,

i	=	*1,2,3,…,I*
Q_{bfu}	=	*Groundwater contribution to baseflow from unconfined system*
Q_t	=	*Total flow during month*
Q_s	=	*Surface runoff during the month*



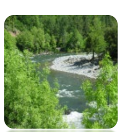
Formulation

$$GG_{MAX_i} = \left(D_G GG_{MAX_{i-1}}\right) + \left(P_G Q_{s_{i-1}}\right) \text{ with } GG_{MAX_i} > Q_{GMAX} \qquad \text{Equation 11}$$

where,

GG_{MAX}	=	*Maximum groundwater contribution*
D_G	=	*Groundwater decay factor* $(0 < D_G < 1)$
P_G	=	*Groundwater growth factor* $(0\% < P_G < 100\%)$
Q_{GMAX}	=	*Specified maximum used as fitting parameter*

$$\begin{gathered} Q_{s_i} = Q_{t_i} - GG_{MAX_i} \;\; for\; Q_{t_i} > Q_{GMAX} \\ Q_{s_i} = 0 \;\; for\; Q_{t_i} \leq Q_{GMAX} \\ Q_{bfu_i} = Q_{t_i} - Q_{s_i} \end{gathered} \qquad \text{Equation 12}$$

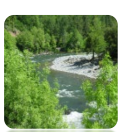




Formulation

$$Q_{lx_i} = C_{lx}\left(H_{x_i} - BOT_x\right) \qquad \text{Equation 13}$$

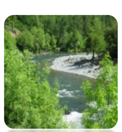
where,

x	=	*Layer u (unconfined) or c (confined)*
Q_{lx}	=	*Lateral flow for layer x*
C_{lx}	=	*Conductance for layer x*
H_x	=	*Head value for layer x*
BOT_x	=	*Bottom of layer x*

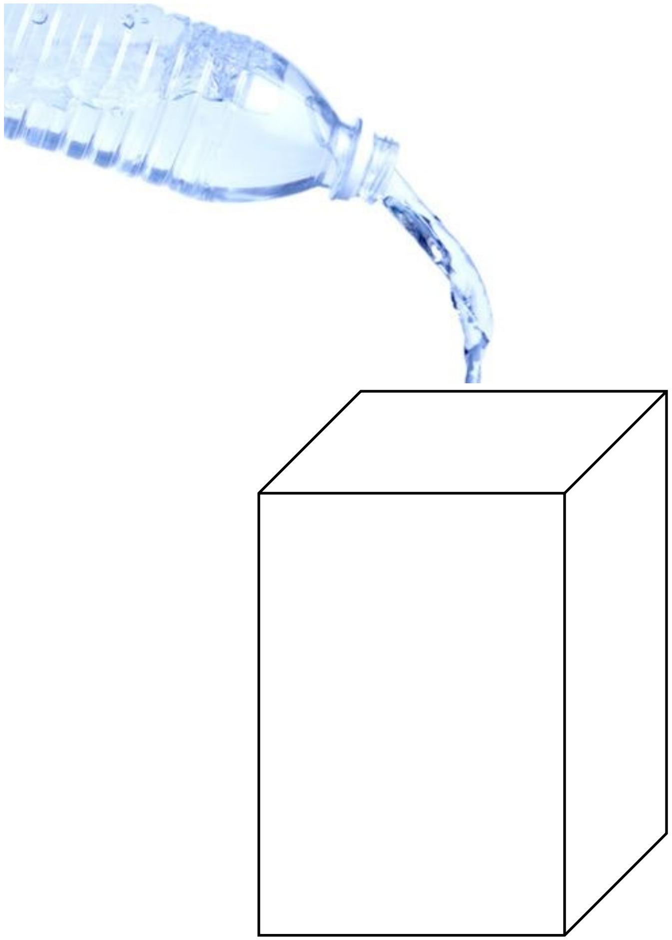




Auto Calibration Steps

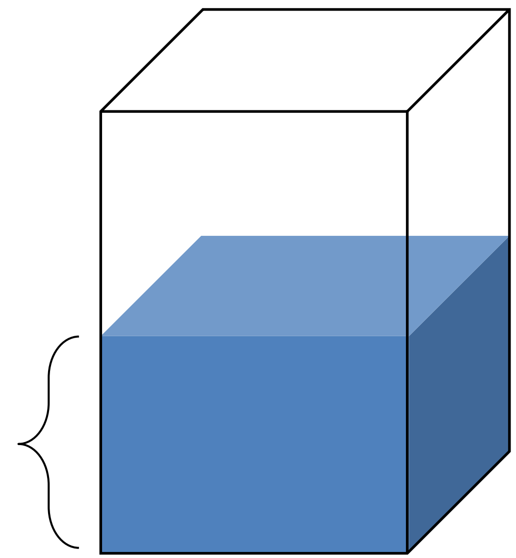
1. Verify valid input to the model.
2. Set Q_{leak} to zero (layers are independent of each other).
3. Set Q_{pu} and Q_{pc} to zero (assume a natural state where no abstraction takes place).
4. Calculate Q_{bfu} by setting $D_G = 0.1$ and $P_G = 0.1$ and fitting Q_{GMAX} so that the long-term annual average of Q_{bfu} is equal to the specified annual average baseflow figure.
5. Solve for Q_{lu} and Q_{lc} so that the long-term water level response for each layer exhibits no increasing or decreasing water level trend.
6. Solve for C_u and C_c making use of Q_{lu} and Q_{lc} and assuming the head difference causing Q_{lu} and Q_{lc} is the difference between the long-term average water level in each layer and the bottom of the respective layers.
7. Enable Q_{leak} to connect the layers.

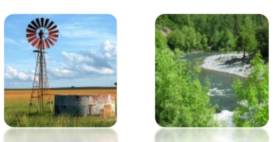




Change in Storage → Change in Level

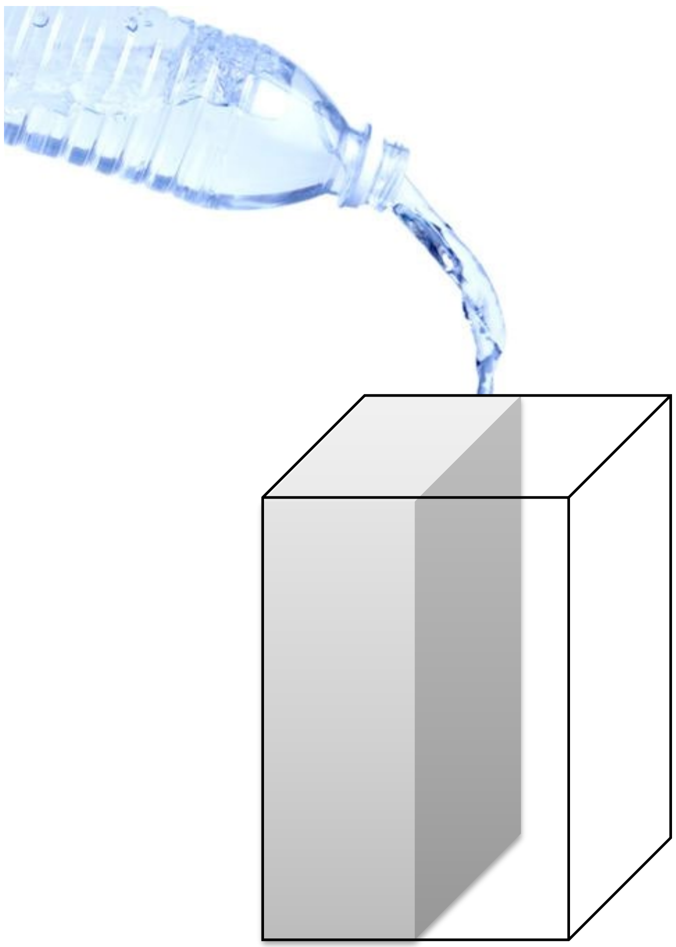


$$\Delta h = \frac{Volume\ (m^3)}{Area\ (m^2)}$$

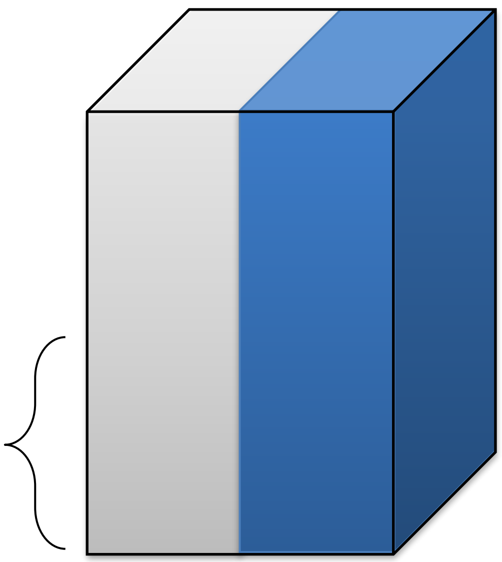




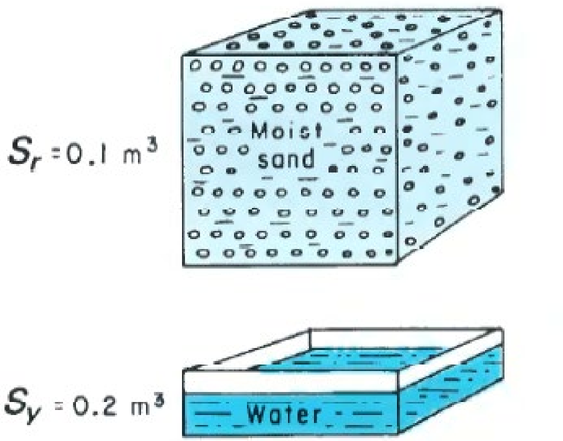
Change in Storage → Change in Level



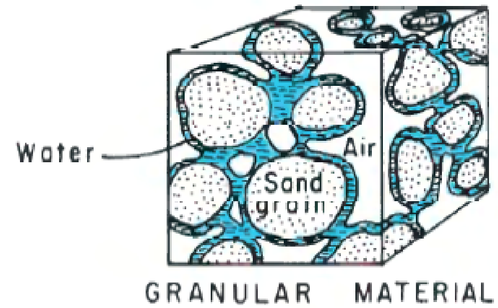
$$\Delta h = \frac{Volume\ (m^3)}{Area\ (m^2)}$$



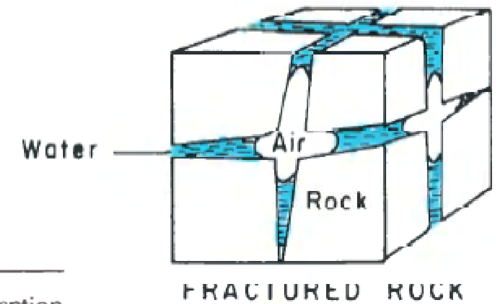
Specific Yield and Specific Retention



$$n = S_y + S_r = \frac{0.2\ m^3}{1\ m^3} + \frac{0.1\ m^3}{1\ m^3} = 0.30$$



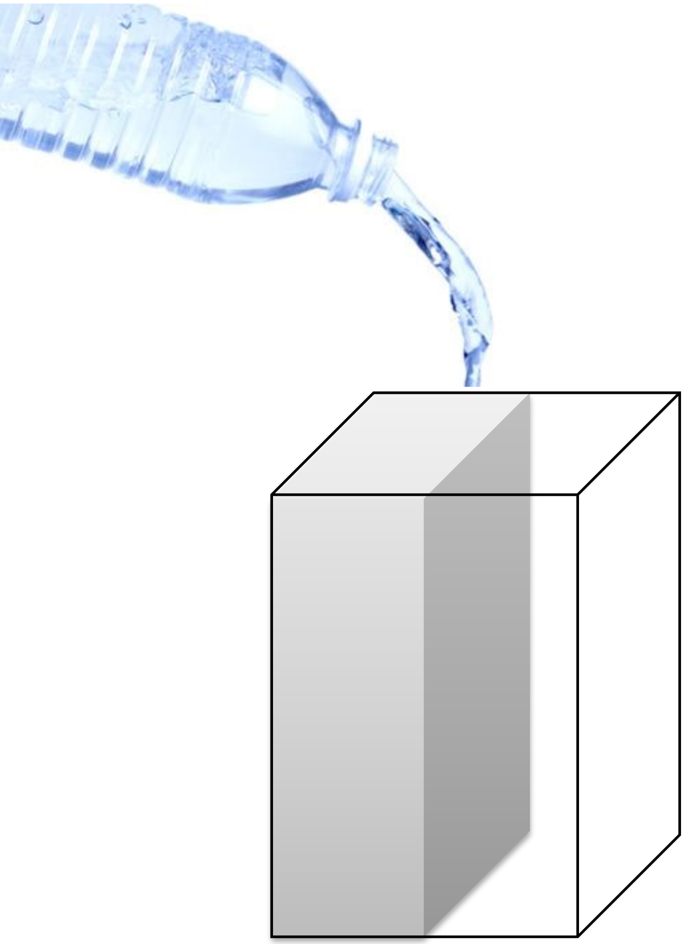
Water retained as a film on rock surfaces and in capillary-size openings after gravity drainage.



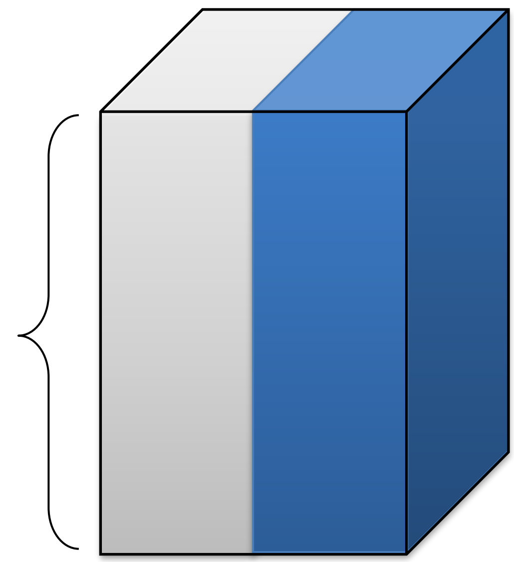
Material	Porosity	Specific yield	Specific retention
Soil	55	40	15
Clay	50	2	48
Sand	25	22	3
Gravel	20	19	1
Limestone	20	18	2
Sandstone (semiconsolidated)	11	6	5
Granite	.1	.09	.01
Basalt (young)	11	8	3



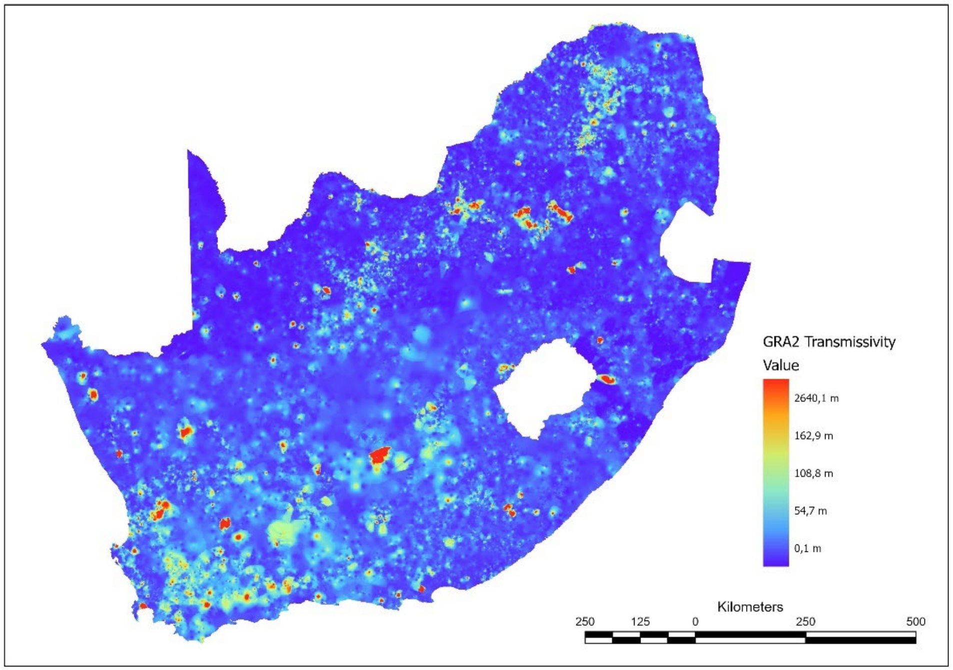
Change in Storage ⟶ Change in Level

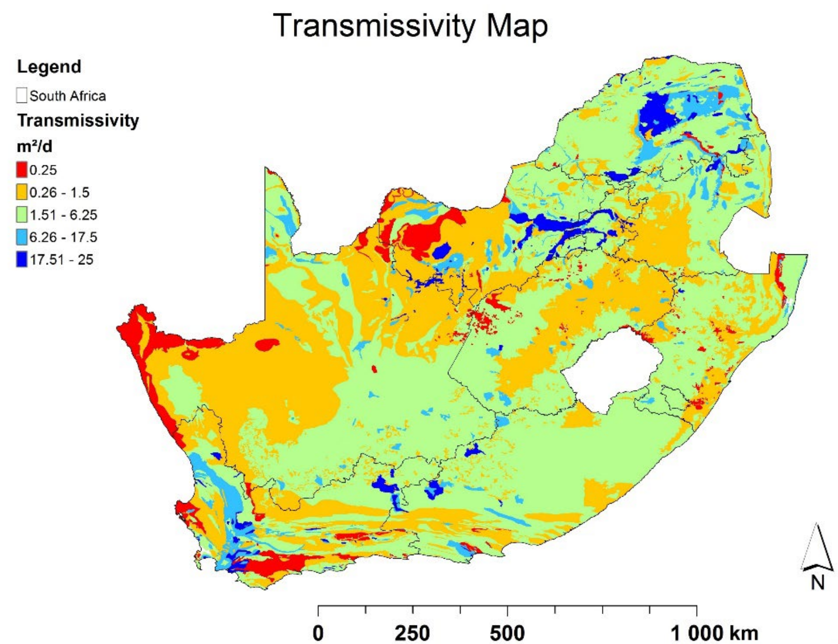


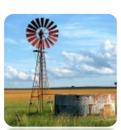
$$\Delta h = \frac{Volume\ (m^3)}{S_y Area\ (m^2)}$$

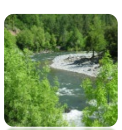


Aquifer Transmissivity

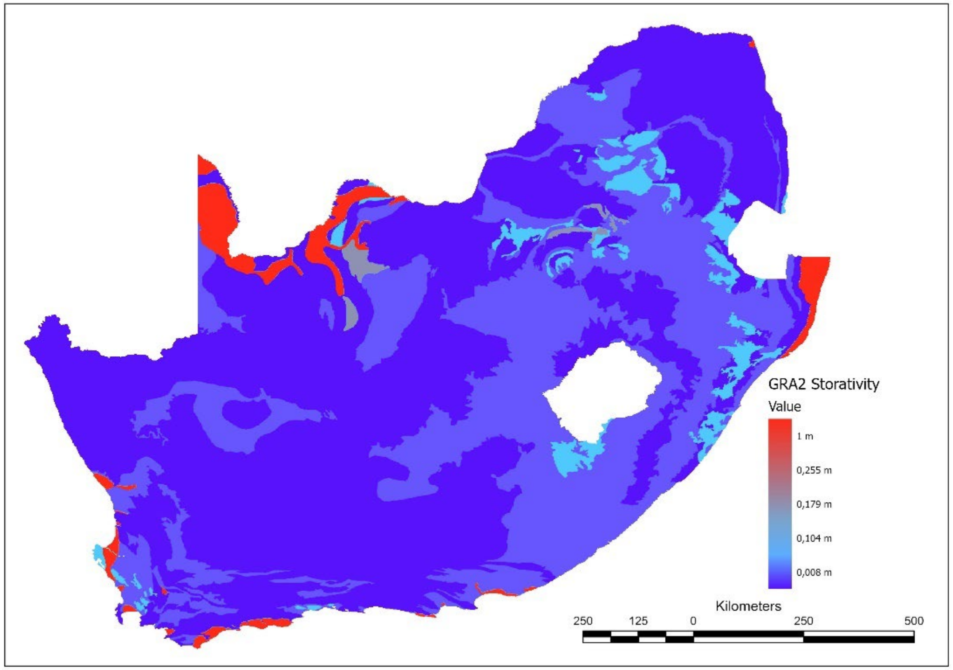


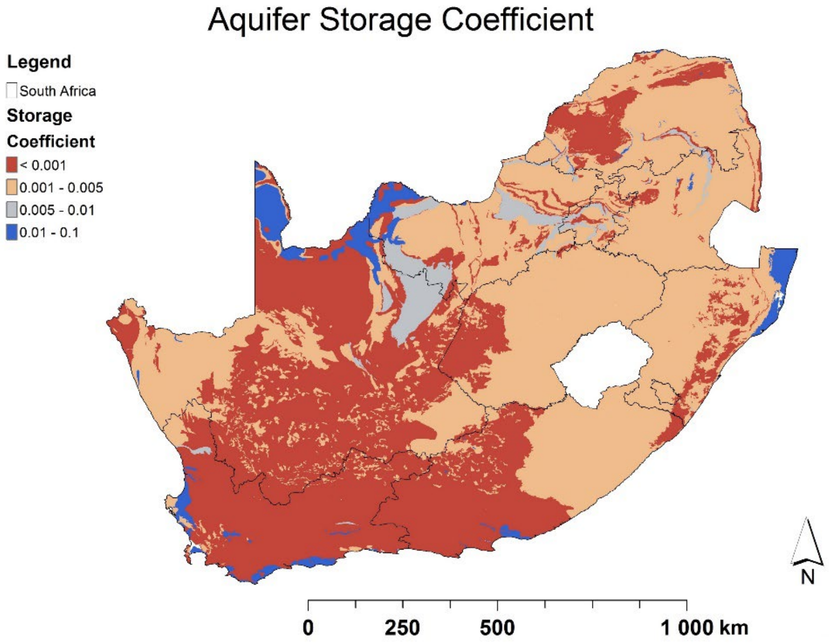


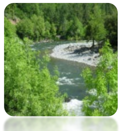




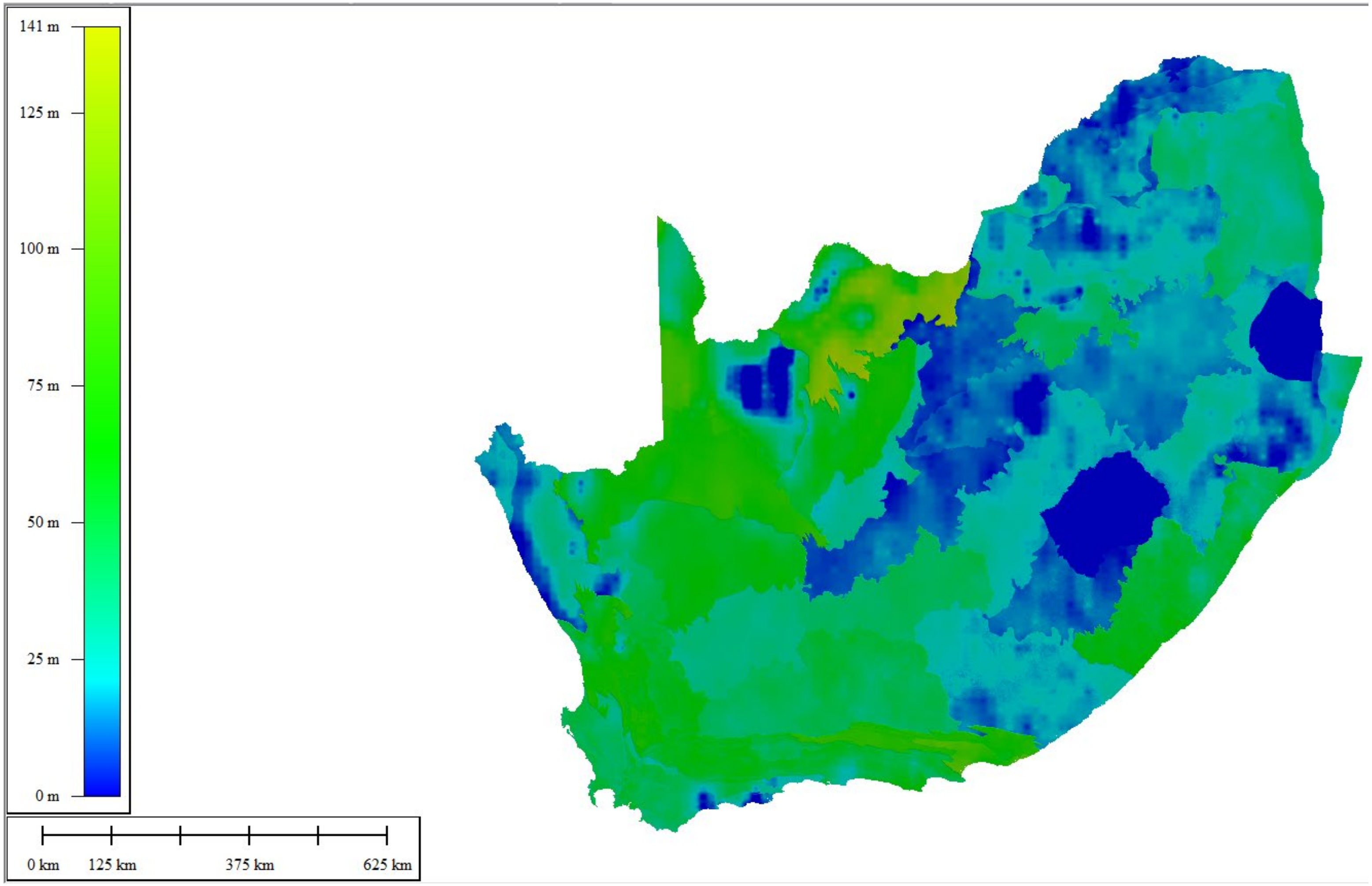
Aquifer Storativity

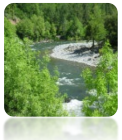




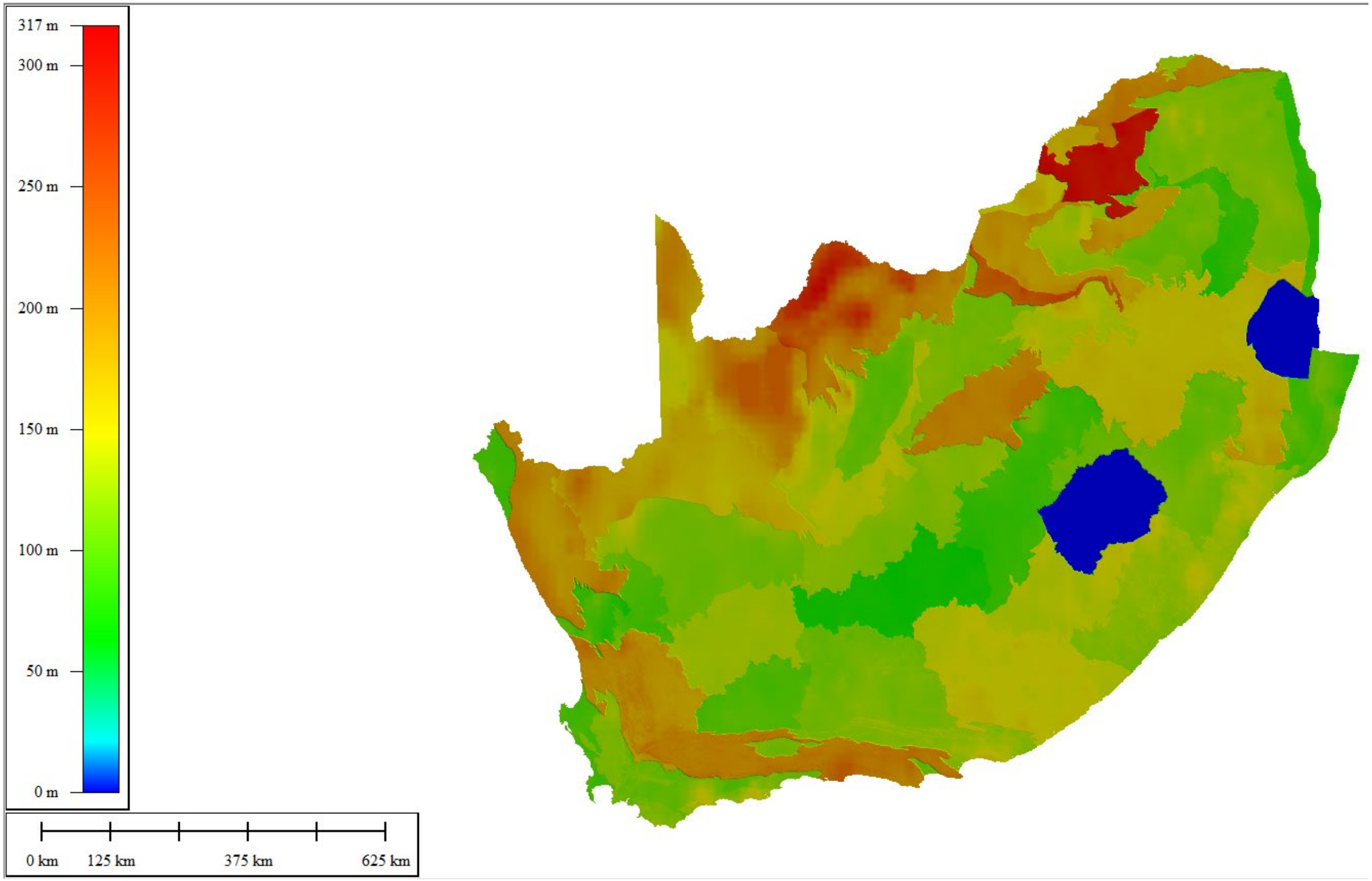



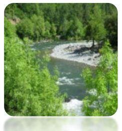

Weathered Thickness



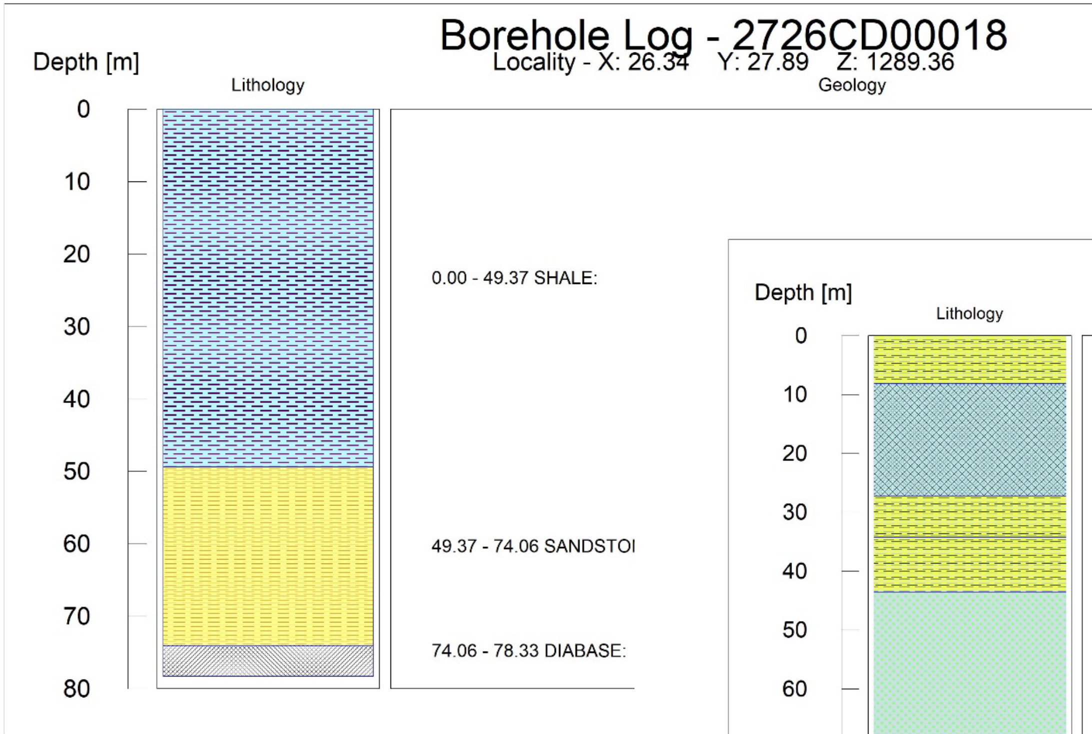



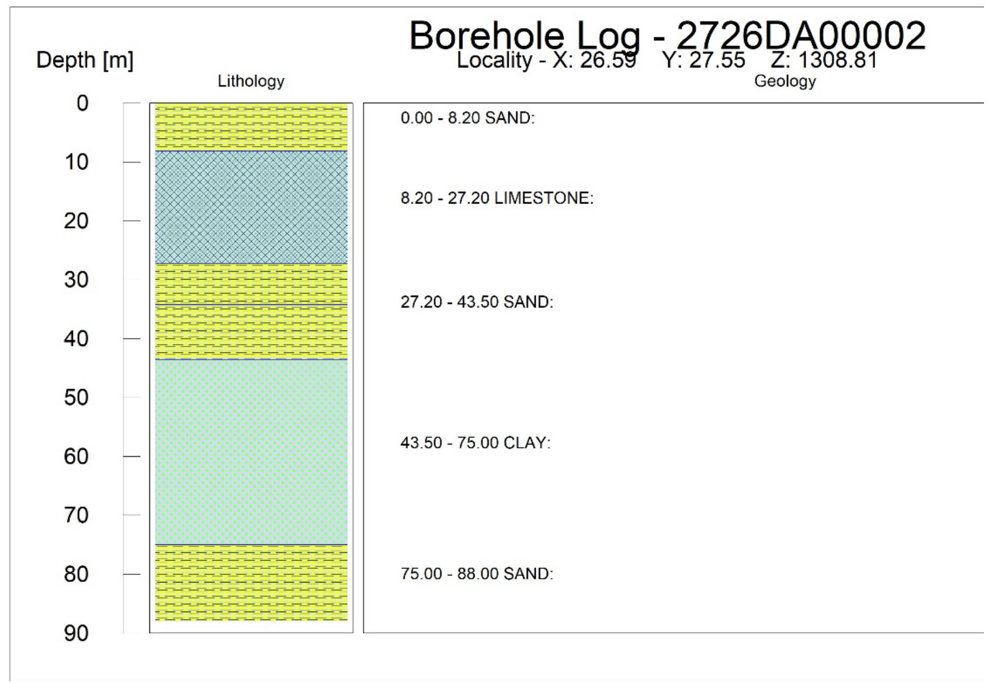

Fractured Thickness

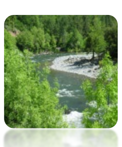




Borehole Logs






Vegter Statistics