Up to now we have been talking about steady state situations

If we change a boundary condition and wait, the system changes gradually from the initial steady condition to a new steady state condition

The rate at which that change occurs is controlled by the storage properties of the porous medium and its condition with respect to confinement

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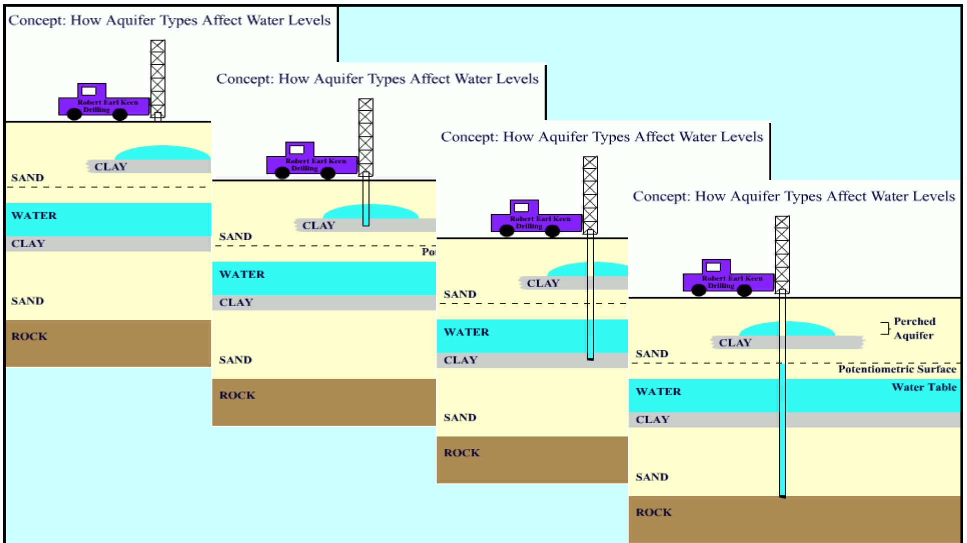
Unconfined / Confined aquifer

Unconfined:

Head in the aquifer is below the "top" of the aquifer
Head decline results in drainage from pores
Releasing substantial volume of water when head declines

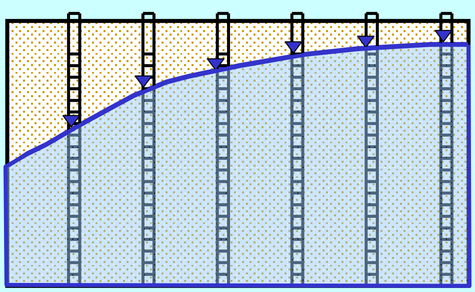
Confined:

Head in the aquifer is above the "top" of the aquifer
Head decline does not drain pores
Rather it reduces the pressure in the pores
Releasing a relatively small volume when head declines



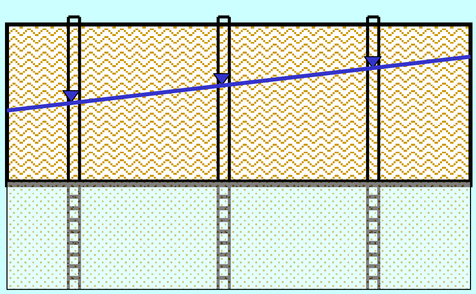
Consider the flash animation on the class web page

Flash Aid for Visualizing Aquifer Types



This an unconfined aquifer.

Heads are within the aquifer.



This is a confined aquifer.

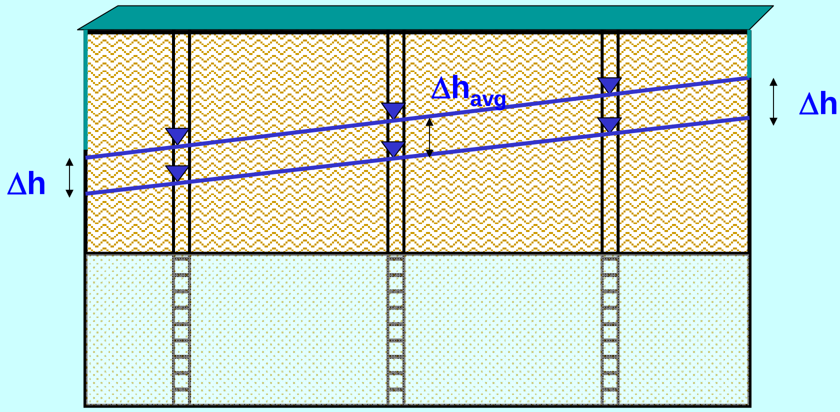
Heads are above the top of the aquifer.

Water level decline in a Confined Aquifer

water pressure decreases in pores which stay full of water

Volume Yielded = Δh_{avg} * S * Area

(plan area of surface extending "into" the drawing)



Where does the water come from?

STORATIVITY - S : unitless

Also called Storage Coefficient

VOLUME OF WATER AQUIFER RELEASES

PER UNIT SURFACE AREA

PER UNIT CHANGE IN HEAD

NORMAL TO THE SURFACE

SPECIFIC STORAGE - s or S_s : L^{-1}

VOLUME OF WATER AQUIFER RELEASES

PER UNIT VOLUME

PER UNIT CHANGE IN HEAD

NORMAL TO THE SURFACE

For aquifer thickness = b

$S = S_s b$ $\quad$ $S_s = S / b$

Define:

ϕ - POROSITY
α - VERTICAL COMPRESSIBILITY OF AQUIFER SKELETON
β - COMPRESSIBILITY OF WATER
b – THICKNESS

Compressibility - relative volume change
in response to a pressure change
Units: (1/pressure units) Pascals^{-1} or ft^2/lb

IF WE
IGNORE LATERAL COMPRESSIBILITY
IGNORE COMPRESSIBILITY OF SOLID

And **EXPLORE** PARTS OF STORAGE TERM:

IF AQUIFER IS RIGID - water given up from a unit volume for a unit drop in head would be entirely due to expansion of water

$\phi b \beta \gamma$ units cancel: $[\ L^3 L^{-3} \quad L \quad L^2 M^{-1} \quad M L^{-3}\ ]$

IF WATER IS RIGID - water given up from a unit volume for a unit drop in head would be entirely due to compression of aquifer skeleton

$b \alpha \gamma$ units cancel: $[\ L \quad L^2 M^{-1} \quad M L^{-3}\ ]$

STORAGE COEFFICIENT (STORATIVITY) = sum of those contributions:
$S = \gamma b (\phi \beta + \alpha)$ [unitless]

SPECIFIC STORAGE is STORAGE COEFFICIENT per unit thickness
$S_s = S/b$ $[L^{-1}]$

VOLUME of water released for a head change Δh over an area A :
$S \Delta h A$ $[LL^2]$: $[L^3]$

RECALL STORAGE IN AN UNCONFINED AQUIFER
WE CAN'T RECOVER ALL THE WATER FROM THE PORES, SO ONLY A PORTION IS AVAILABLE

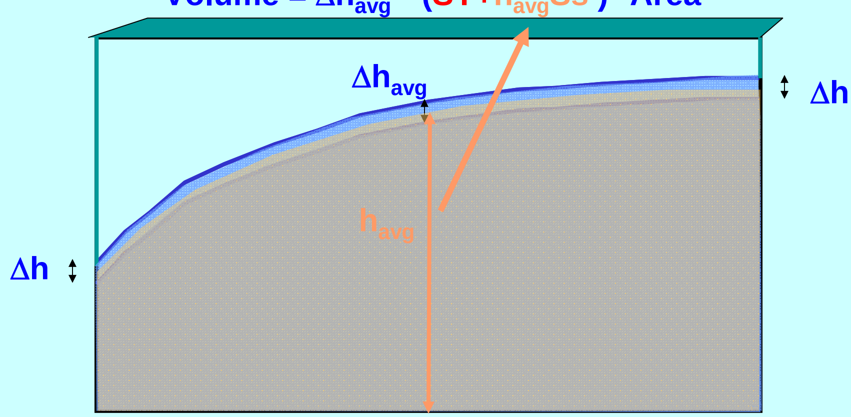
SPECIFIC YIELD - % OF TOTAL VOLUME THAT CAN BE DRAINED BY GRAVITY

SPECIFIC RETENTION - % OF TOTAL VOLUME HELD AGAINST GRAVITY

BY DEFINITION THEY SUM TO TOTAL POROSITY

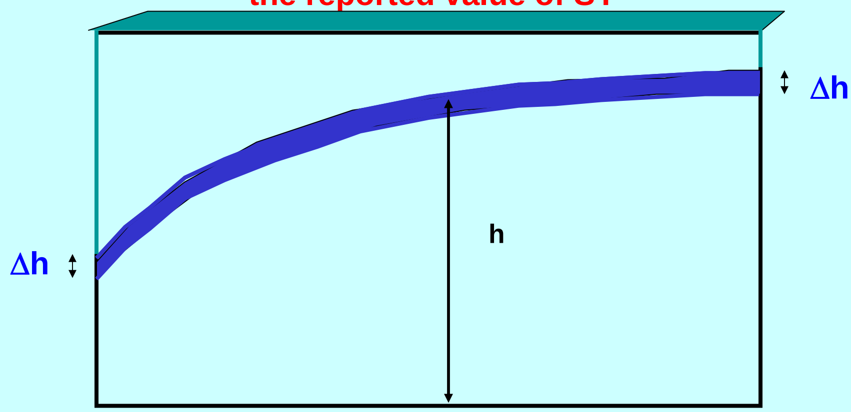
$$\phi = SY + SR$$

Water level decline in an Unconfined Aquifer
water drains from pores which fill with air
Volume Yielded = Δh_{avg} * SY * Area
(plan area of surface extending "into" the drawing)
Some water is released when pressure decreases due to drainage of the overlying pores, so total
Volume = Δh_{avg} * (SY+h_{avg}Ss)* Area



Often SY is measured in the field and includes (h_{avg}Ss)

Generally either the $S_s h$ term is small and ignored,
Or is "lumped" into SY
Volume Yielded = Δh * (SY) * Area
But this can lead to significant error in, for example a clay
where $S_s h$ may be on the order of, or exceed,
the reported value of SY



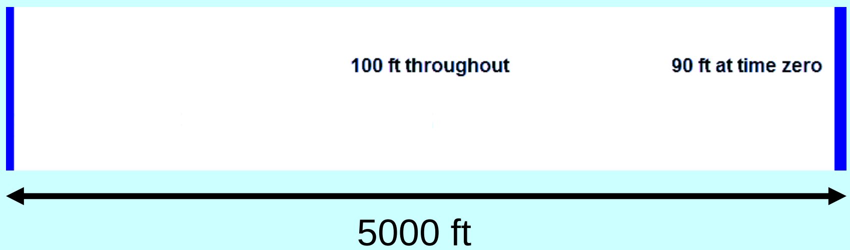
SOME REPRESENTATIVE VALUES OF COMPRESSIBILITY

	Pa^{-1}	ft^2/lb	Typical Porosities
CLAY	10^{-6} - 10^{-8}	$5X10^{-5}$ - $5X10^{-7}$	0.33-0.60
SAND	10^{-7} - 10^{-9}	$5X10^{-6}$ - $5X10^{-8}$	0.25-0.50
GRAVEL	10^{-8} - 10^{-10}	$5X10^{-7}$ - $5X10^{-9}$	0.25-0.50
JOINTED ROCK	10^{-8} - 10^{-10}	$5X10^{-7}$ - $5X10^{-9}$	<0.01-0.17
SOUND ROCK	10^{-8} - 10^{-11}	$5X10^{-8}$ - $5X10^{-10}$	<0.01-0.12
WATER	$4.4X10^{-10}$	$2.1.4X10^{-8}$	1.00

STORAGE COEFFICIENT:

$$S = \gamma\, b\, (\phi\, \beta + \alpha)$$

What will the steady state head distribution look like after decreasing the head from 100 to 90 on the right side?

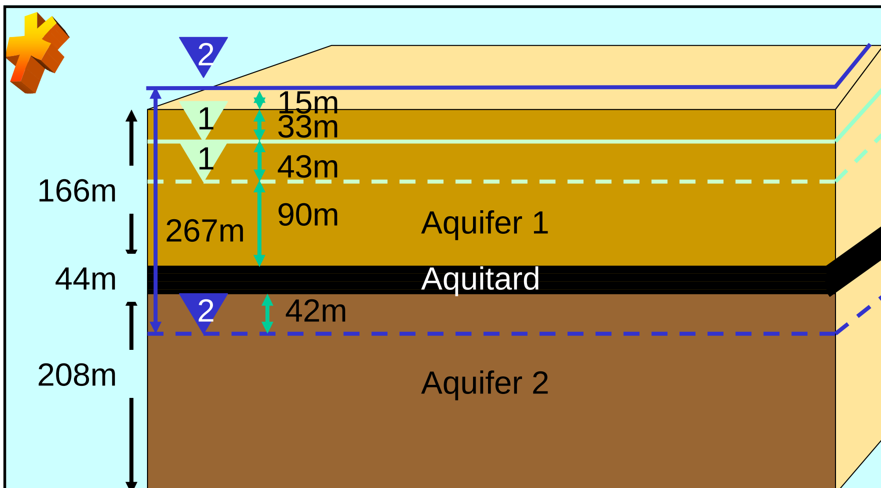


Aquifer 10 ft thick

Ss = 0.0001 ft^{-1}

S = 0.001

K = 100 ft/day



	Sy	S
Aquifer 1	0.3	4×10^{-3}
Aquitard	0.02	5×10^{-4}
Aquifer 2	0.1	6×10^{-5}

If the water level in piezometers open in aquifer 1 and 2 drop from their solid line levels to the dashed line levels over a square kilometer

How much water is released from the aquifers?

WHAT IF IT IS NOT A SIMPLE SHAPE?