Advances in the Reverse Head Profiling Technique

By

Carl Keller, Ian Sharp, Mark Higgins

FLUTe

2015 NGWA Conference on Groundwater in Fractured Rock

Burlington, VT

September 28-29, 2015

Topics to be covered

- Background
- The method
- How it was done last month
- The results
- Earlier results
- Conclusion

Flexible Liner Methods are Evolving

1. Sealing the borehole to prevent contaminant migration.
2. Mapping NAPLs with a color reactive cover on the sealing liner
3. Mapping the dissolved contaminant phase (a FACT)
4. Mapping the borehole transmissivity or formation conductivity (a FLUTe transmissivity profile)
5. **Mapping the vertical head profile (the FLUTe reverse head profile)**
6. Monitoring the ground water quality and head history

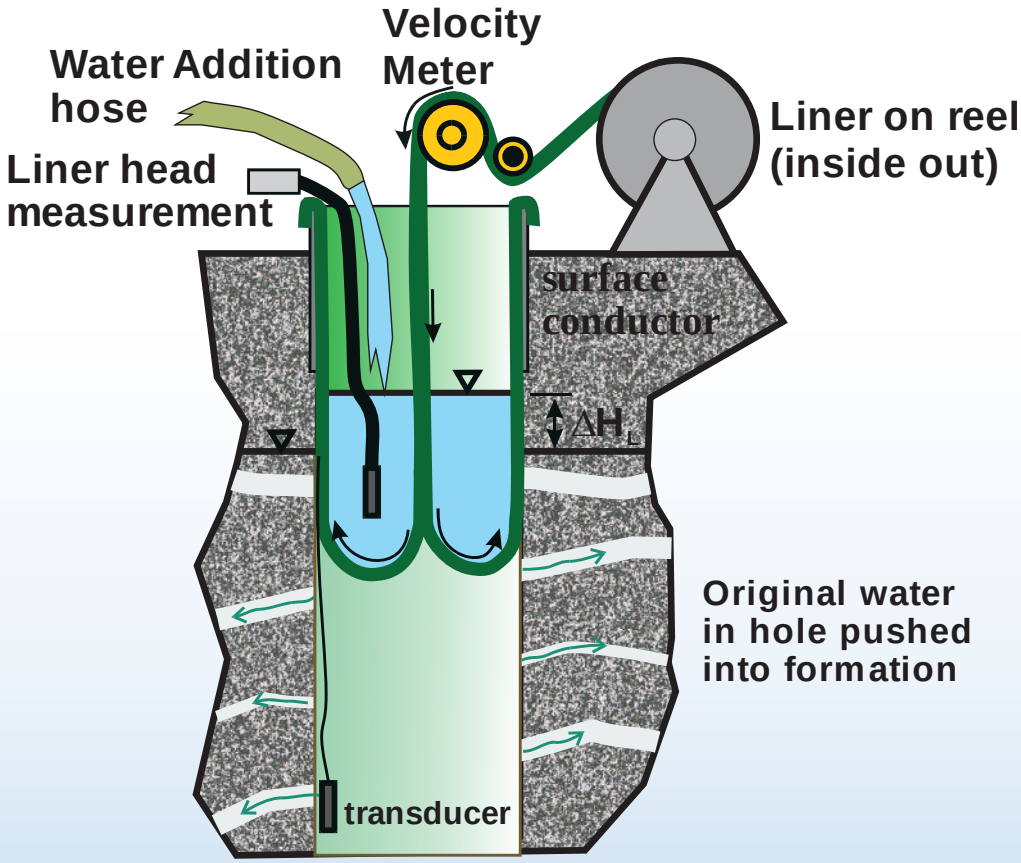
The reverse head profile method:

1. First a transmissivity profile is performed with a flexible liner to obtain a continuous transmissivity profile of the borehole.
2. When the liner is stopped near the bottom of the borehole, the transducer at the bottom of the borehole is allowed to equilibrate with the formation pressure.
3. The liner is then inverted for a short distance up the borehole and the head in the open interval is allowed to equilibrate again.
4. Then the process is repeated with the stepwise inversion of the liner and the equilibrium pressure is measured beneath the liner for each new position of the liner.
5. Using the equilibrium head measurements, and the known transmissivity distribution, the formation head profile is deduced.

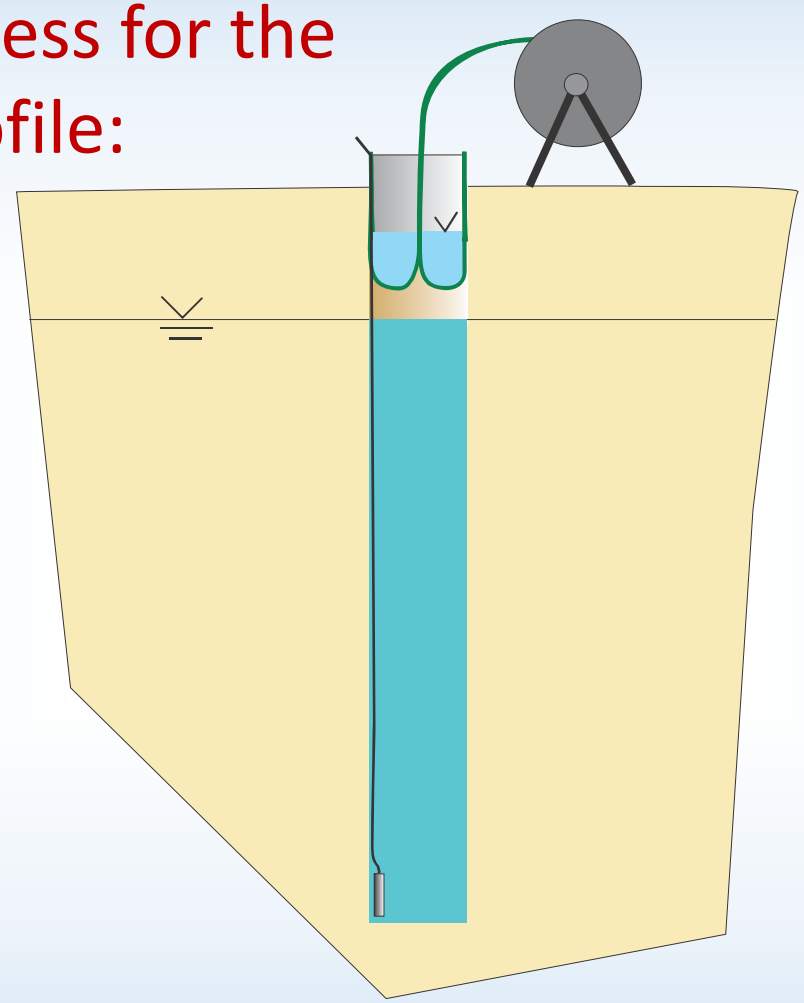
First the transmissivity profile:

1. A transducer is lowered to the bottom of the borehole prior to the transmissivity profile.
2. A blank FLUTe liner is everted continuously into the borehole with a careful measurement of the descent rate of the liner.
3. As the liner seals each flow feature in the formation, the liner descent rate slows.
4. From the descent rate, a transmissivity profile is calculated for each half second of the eversion.
5. When the liner descent rate has slowed sufficiently to make any further measurement impractical, the liner descent is halted and the tether is anchored to prevent any further descent.
6. The transducer then equilibrates with the head in the remaining unsealed portion of the hole.

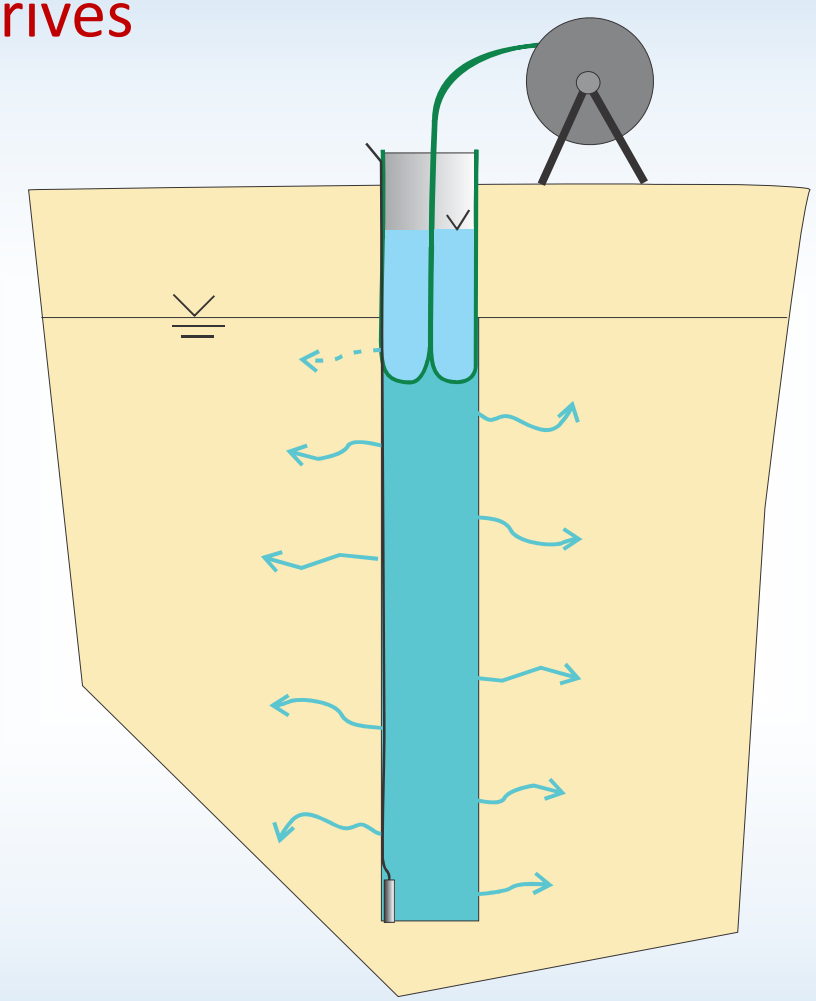
The transmissivity measurement apparatus

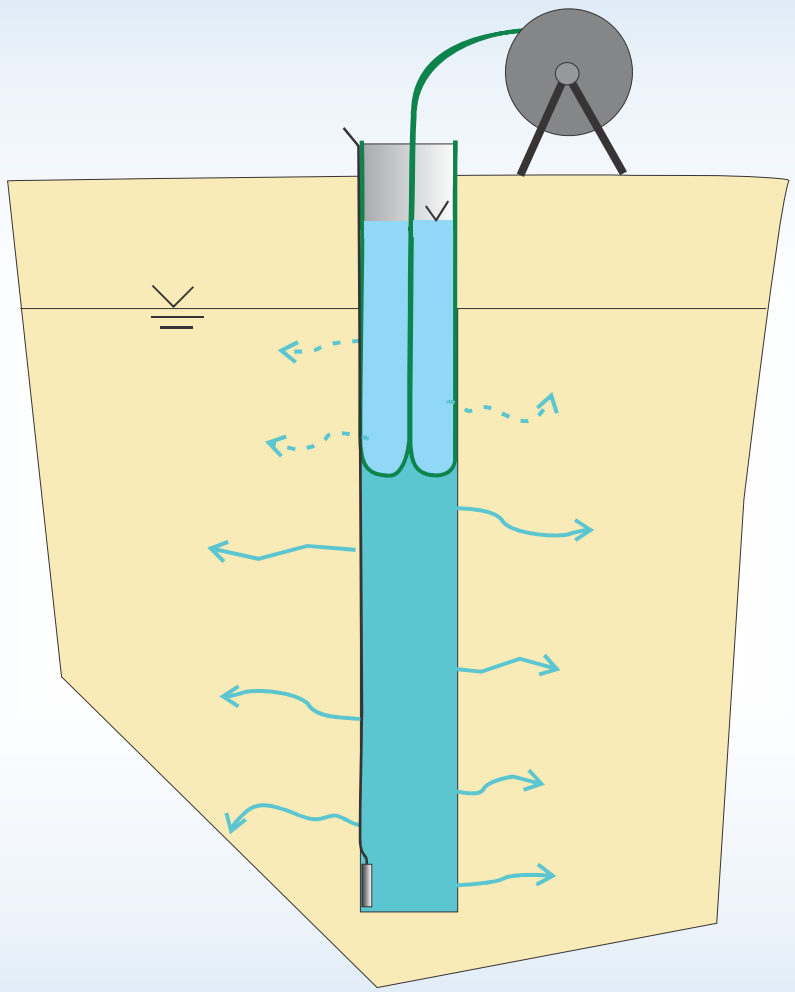


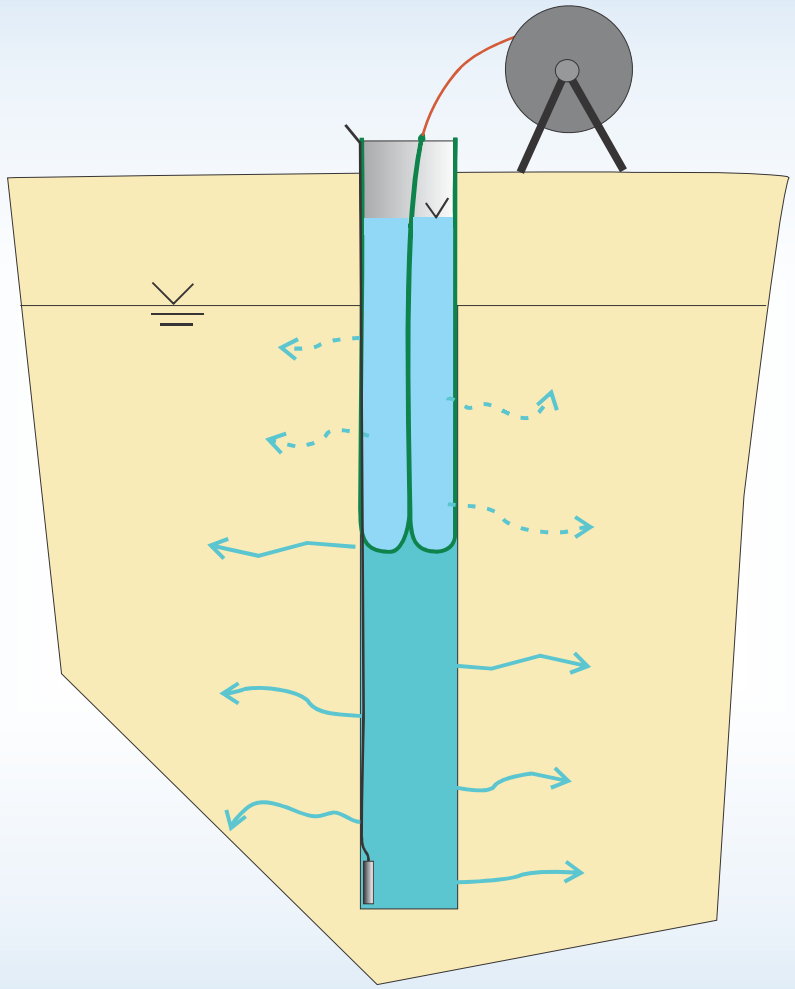
The eversion process for the Transmissivity profile:

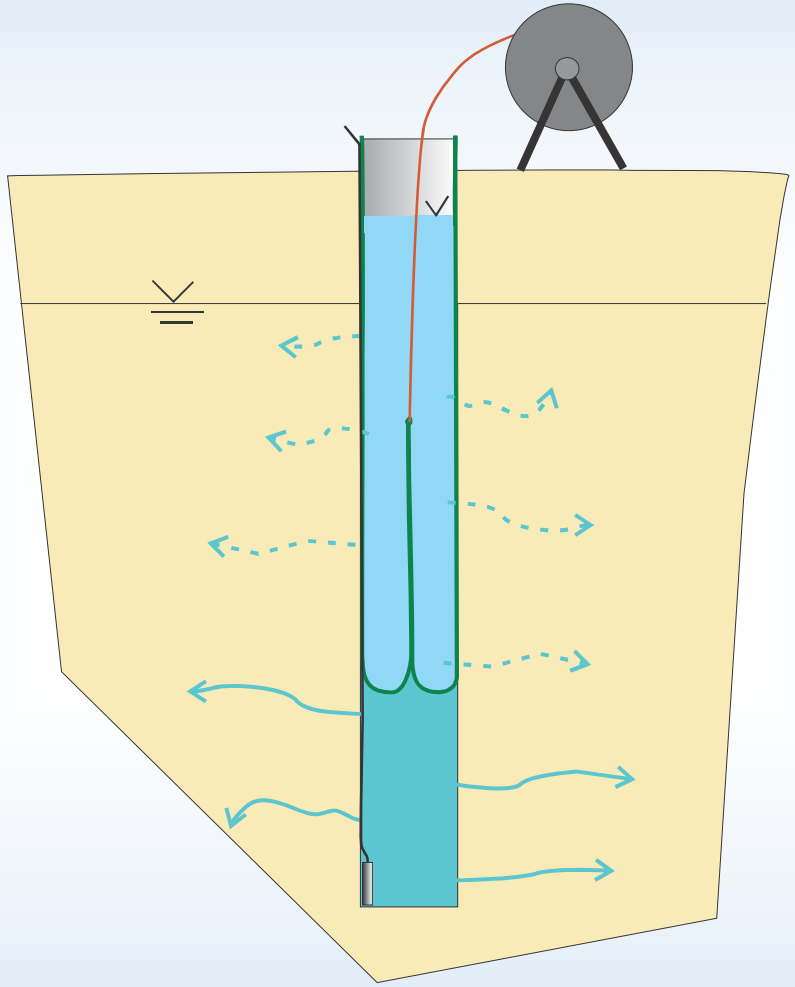


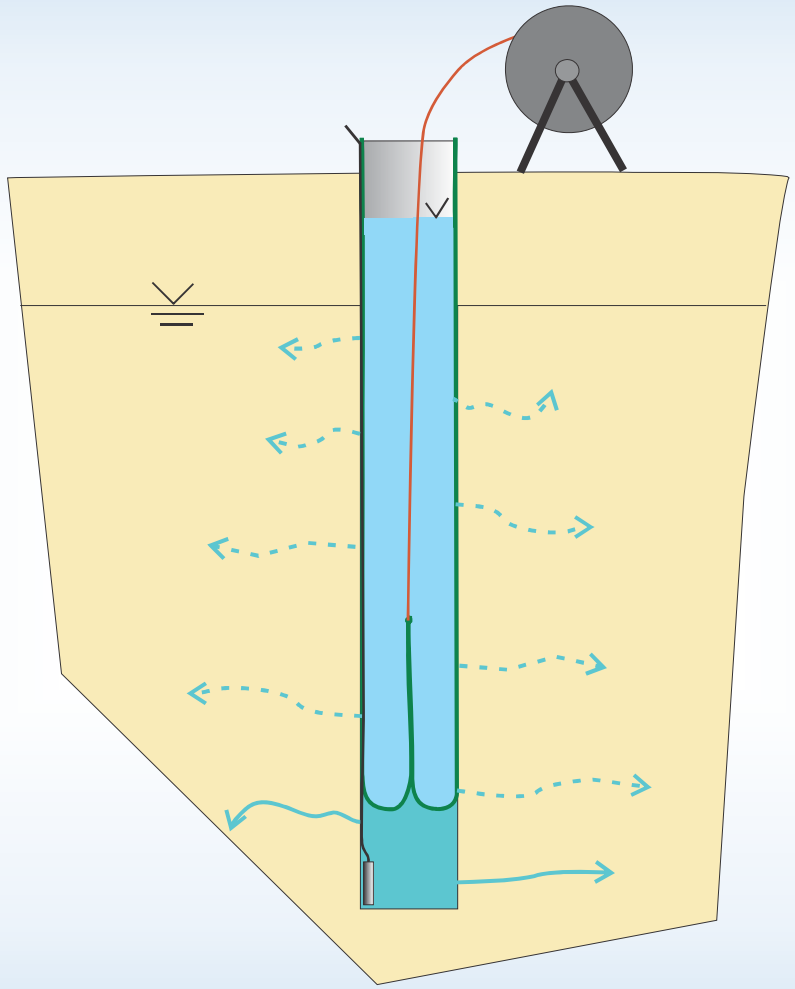
The everting liner drives the borehole water Into the formation



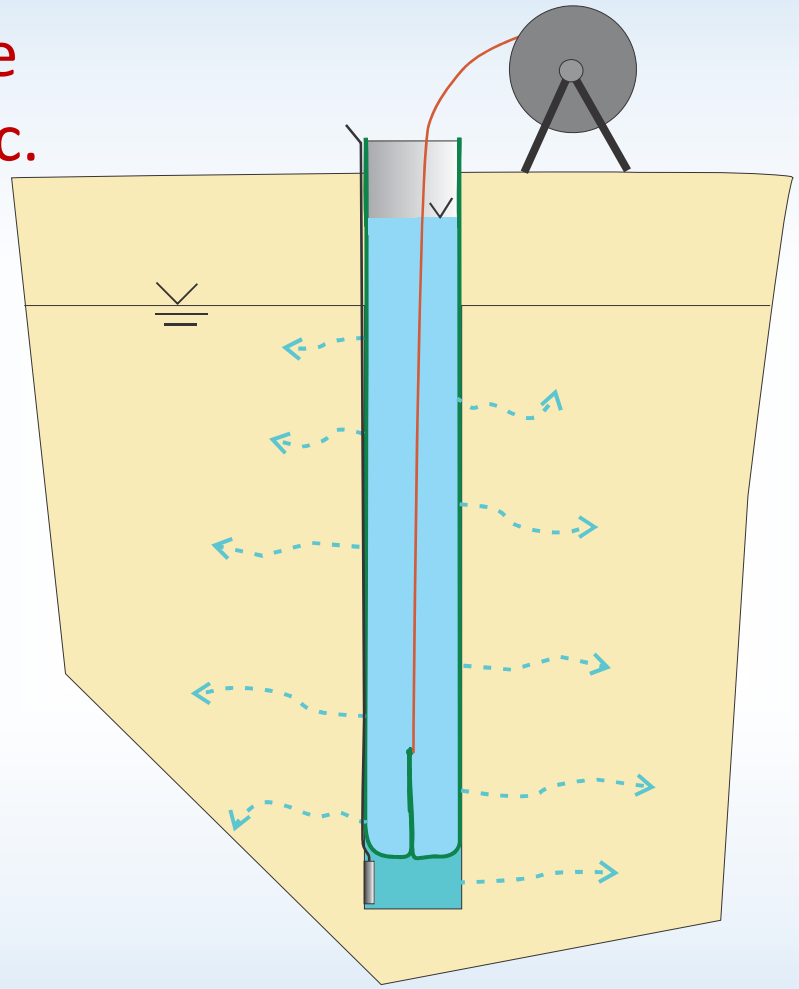








The transmissivity profile is halted when the descent rate drops to < 0.001 ft/sec.

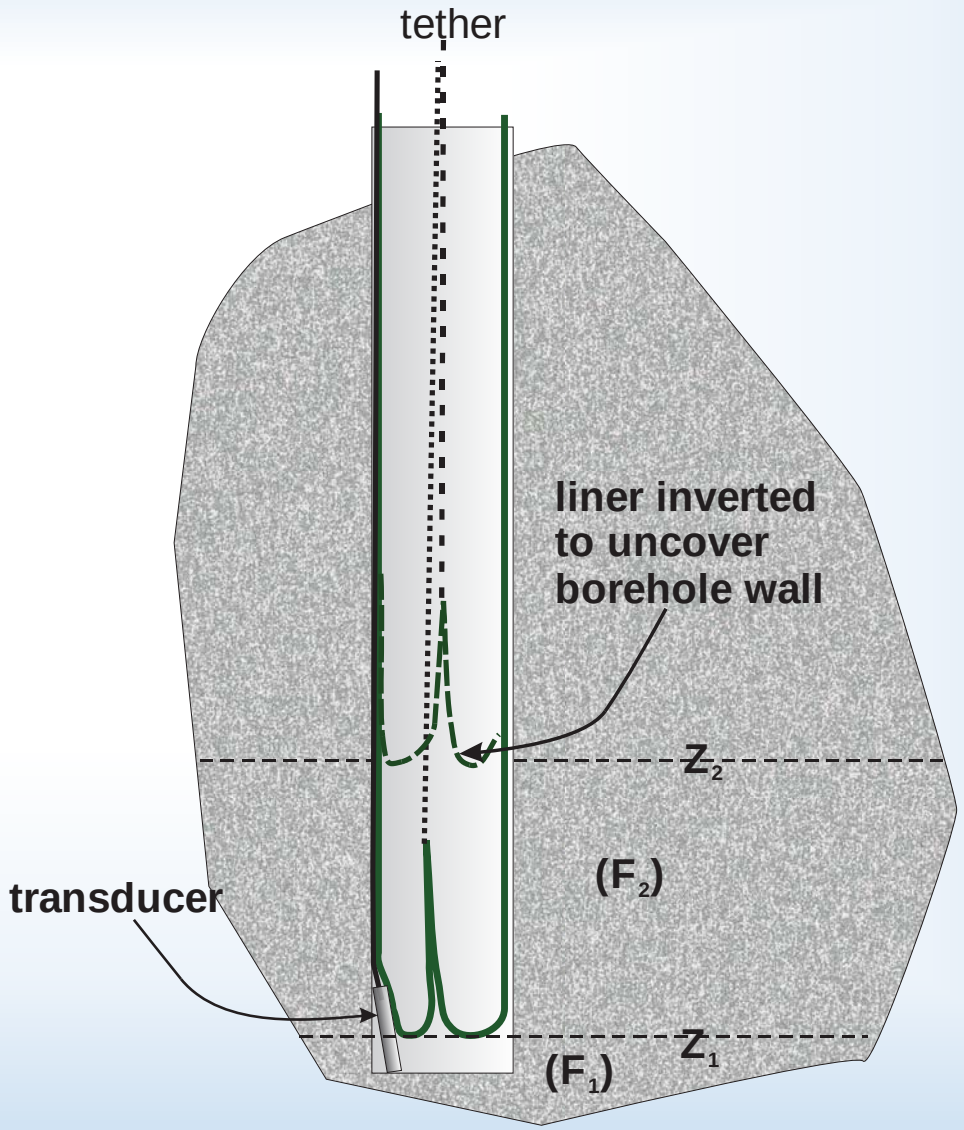


The reverse head profile is then performed:

1. The pressure transducer is allowed to equilibrate with the formation pressure/head at the bottom of the borehole.
2. The transmissivity measurement is examined to determine where the head is to be measured in the formation.
3. The liner is then inverted a short distance, ΔZ, to the top of the first interval to be measured.
4. The transducer pressure is allowed to equilibrate again.
5. The liner is then inverted to the next position and the transducer is allowed to equilibrate again.
6. This is repeated until the liner reaches the water table or the surface casing.

The liner stops at Z_1.

The first inversion uncovers a segment of the borehole wall from Z_1 to Z_2



The first calculation

Q1 is the flow into the bottom open interval after the T profile is halted.

The flow into or out of the interval is:

$$Q1 = T1\ (BH1 - F1)\ 2\ \pi / \ln R \quad \text{(the Thiem equation)}$$

where T1 is the transmissivity of the open interval at the bottom of the hole. BH1 is the equilibrium head in the borehole. F1 is the formation head. R is the ratio of the range to drawdown divided by the radius of the borehole. R is assumed to be constant.

But, when the head has equilibrated, Q1 = 0.

Hence, BH1 = F1, the initial condition.

Then the liner is inverted to Z_2 and the liner inversion is stopped,

A second flow equation is written for the newly uncovered interval of the borehole:

$$Q2 = T2\ (BH2 - F2)\ 2\pi/\ln R,$$

where BH2 is the new equilibrium head beneath the liner and F2 is the formation pressure in the newly uncovered portion of the formation. Since the final state is one of equilibrium,

$Q1 + Q2 = 0$, leading to $T1\ (BH2-F1) + T2\ (BH2-F2) = 0$. the only unknown is F2. Solving for F2,

$$F2 = T1\ (BH2-F1)/T2 + BH2$$

Inverting the liner again a new distance

Upon equilibration, Q1+Q2+ Q3 = 0 from which the head F3 in the newly uncovered portion of the formation is:

F3 = **(**T1 (BH3-F1) + T2 (BH3-F2)**)**/T3+ BH3

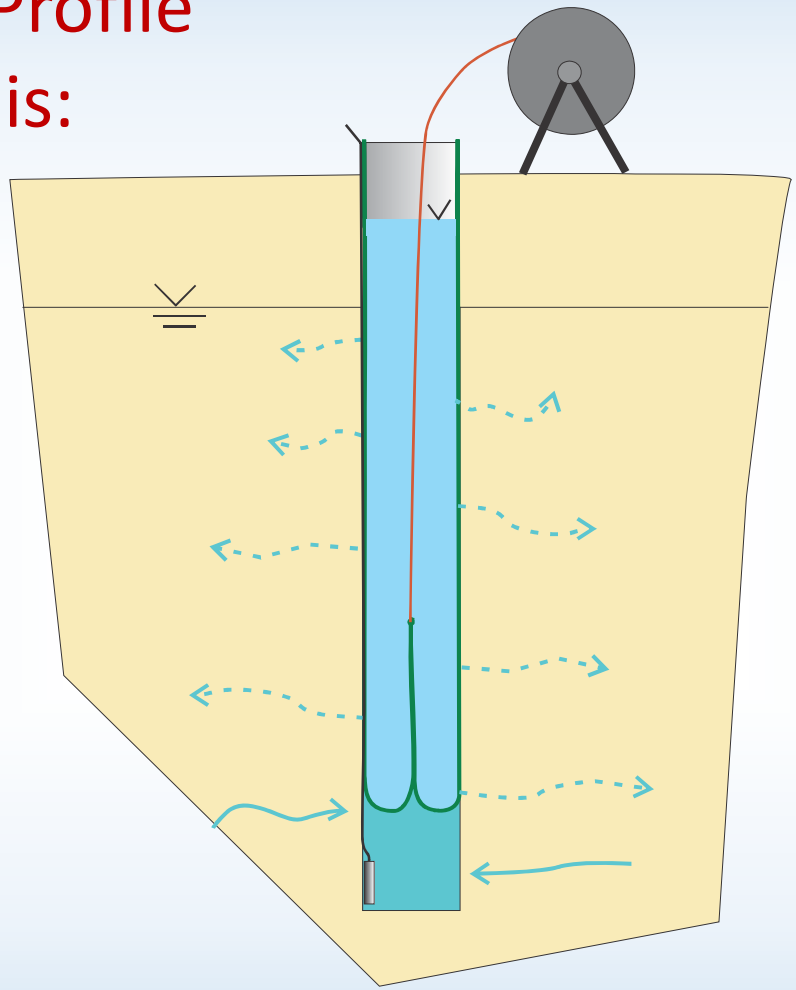
For each additional ith interval:

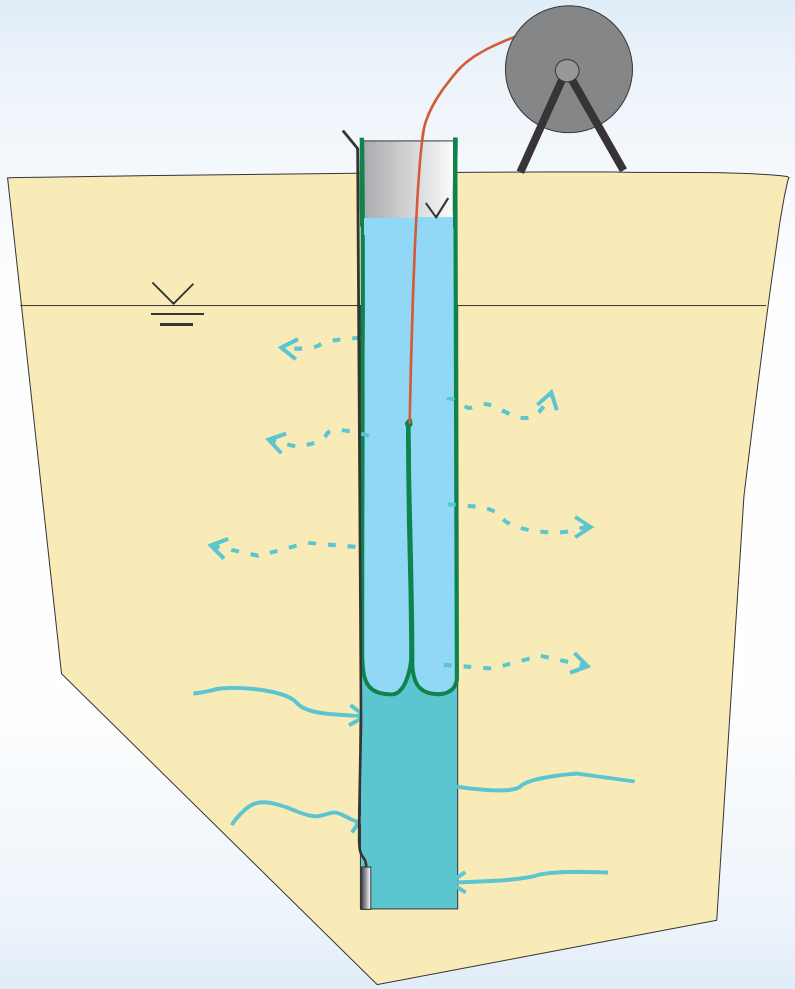
Fi = (T1 (BHi –F1) + T2 (BHi-F2)+T3 (BHi –F3) …..)/Ti +Bhi

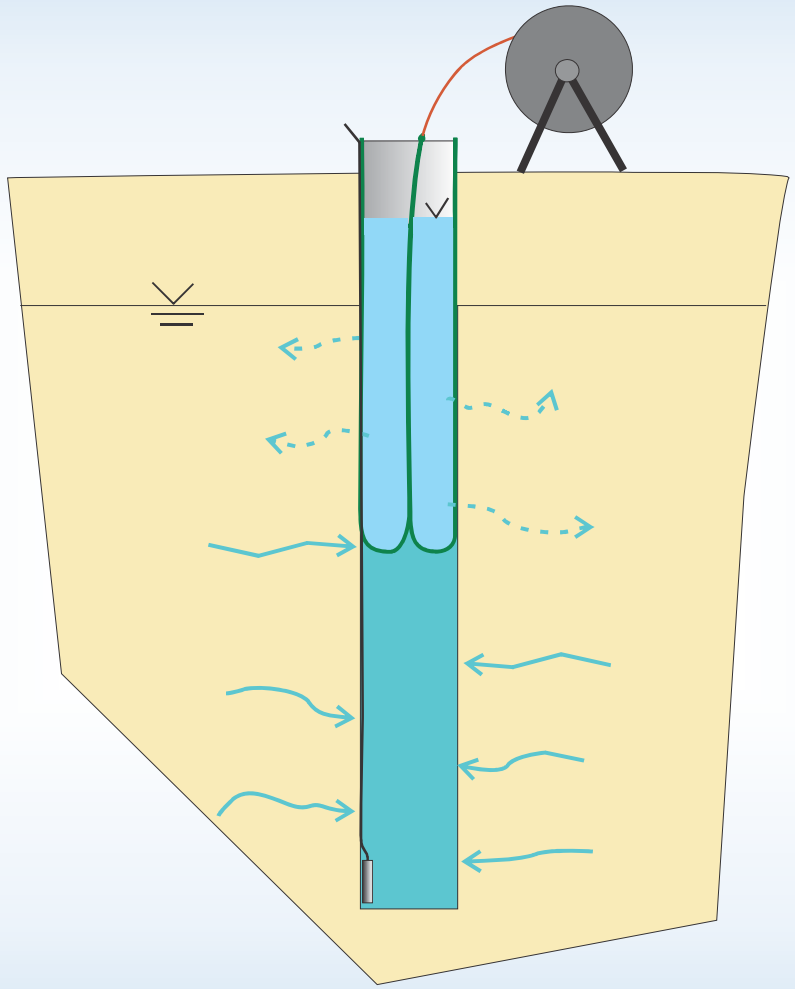
(note Ti in the denominator)

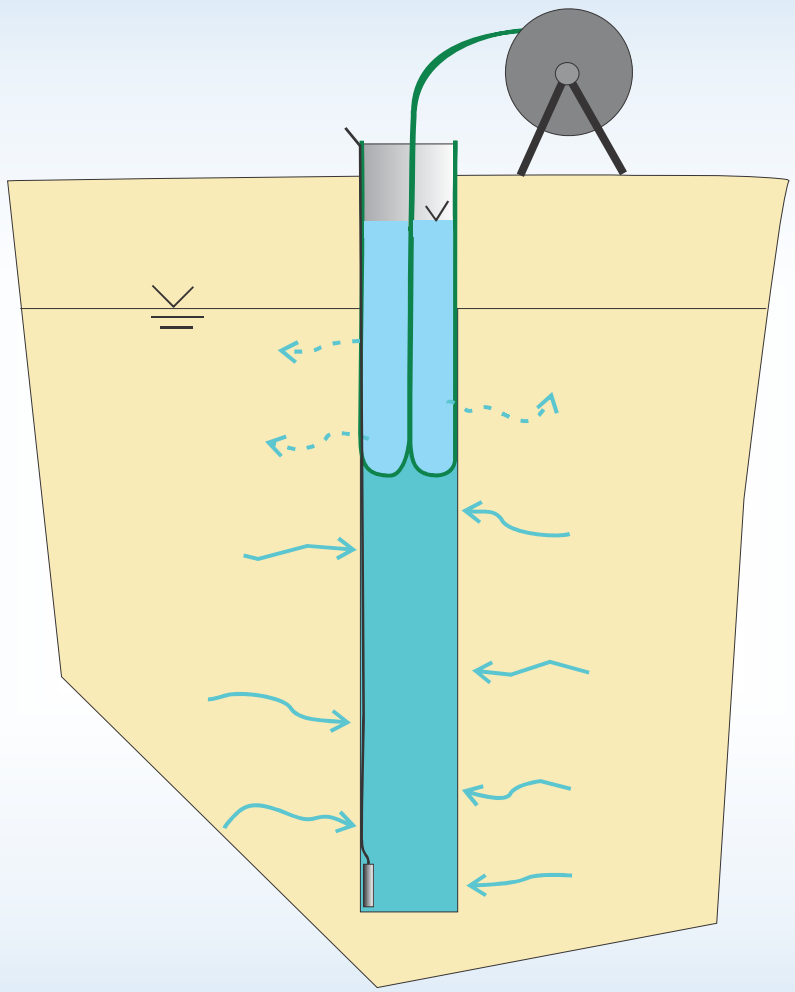
This leads to a solution for the formation head between each of the stopping elevations in the borehole.

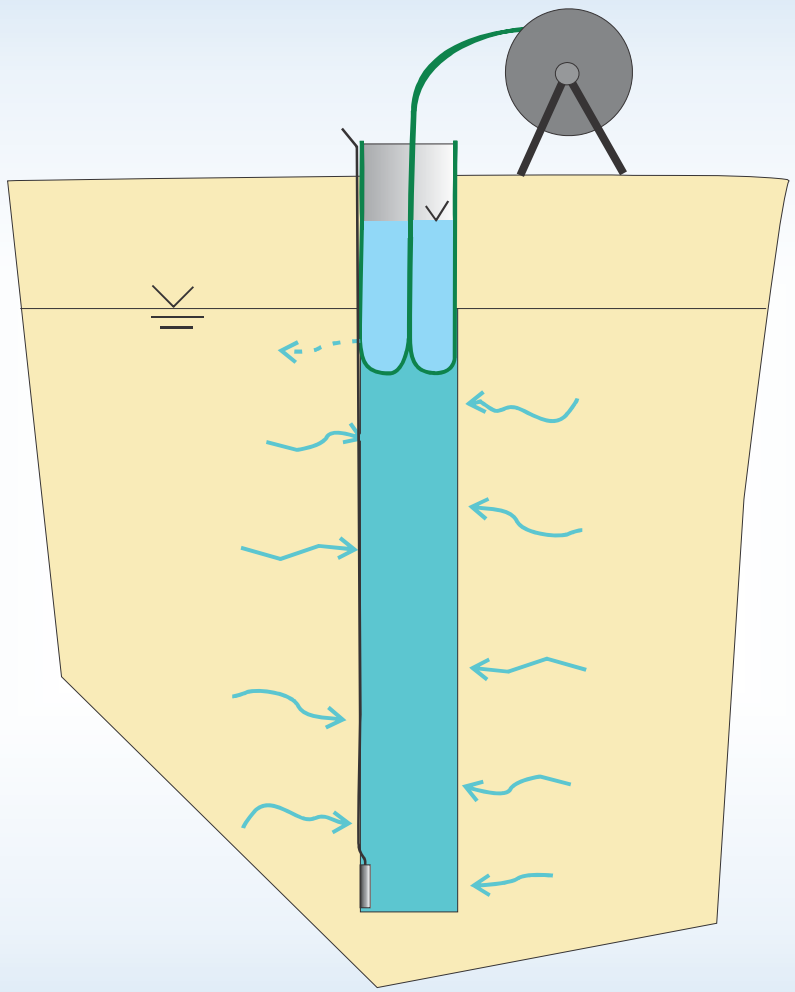
The Reverse Head Profile procedure is like this:







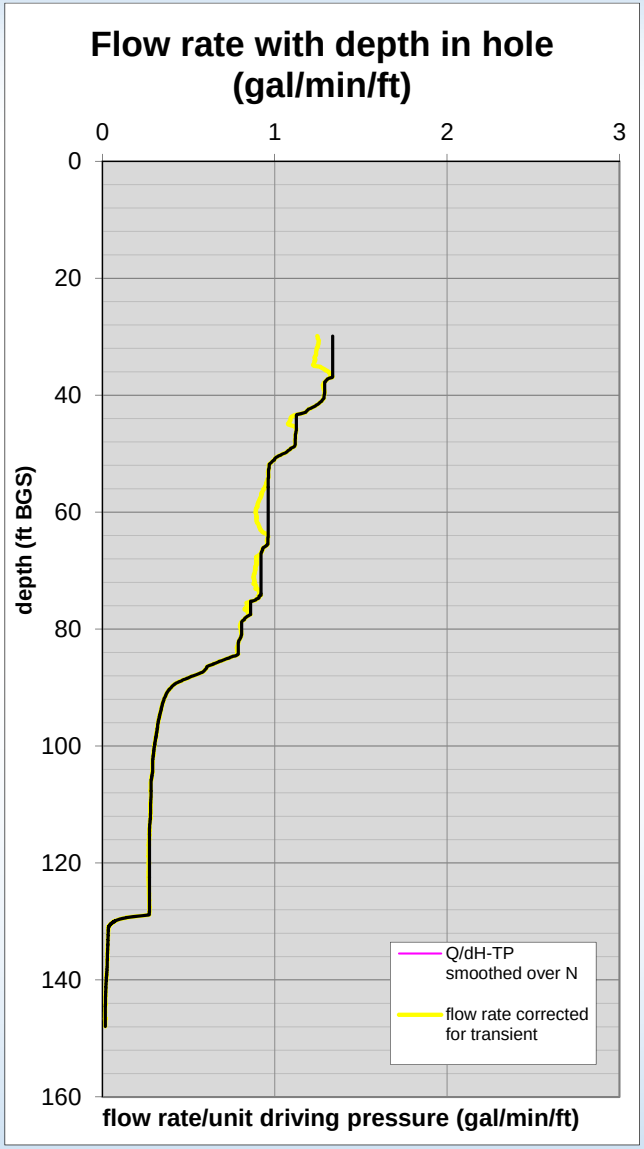


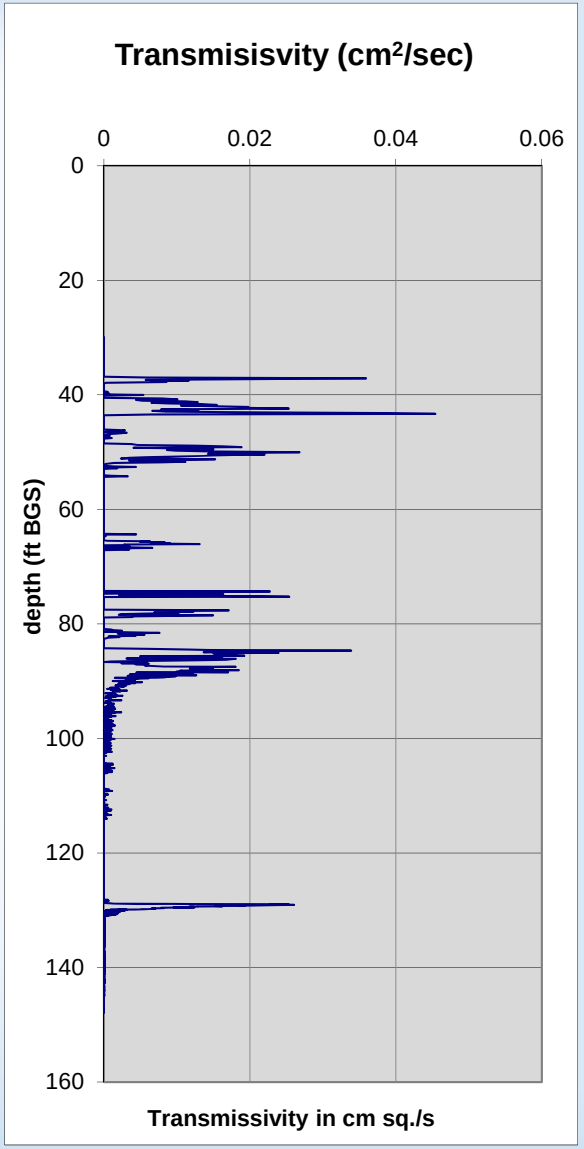


The transmissivity profile produced the following results in 94BR

6660 data points

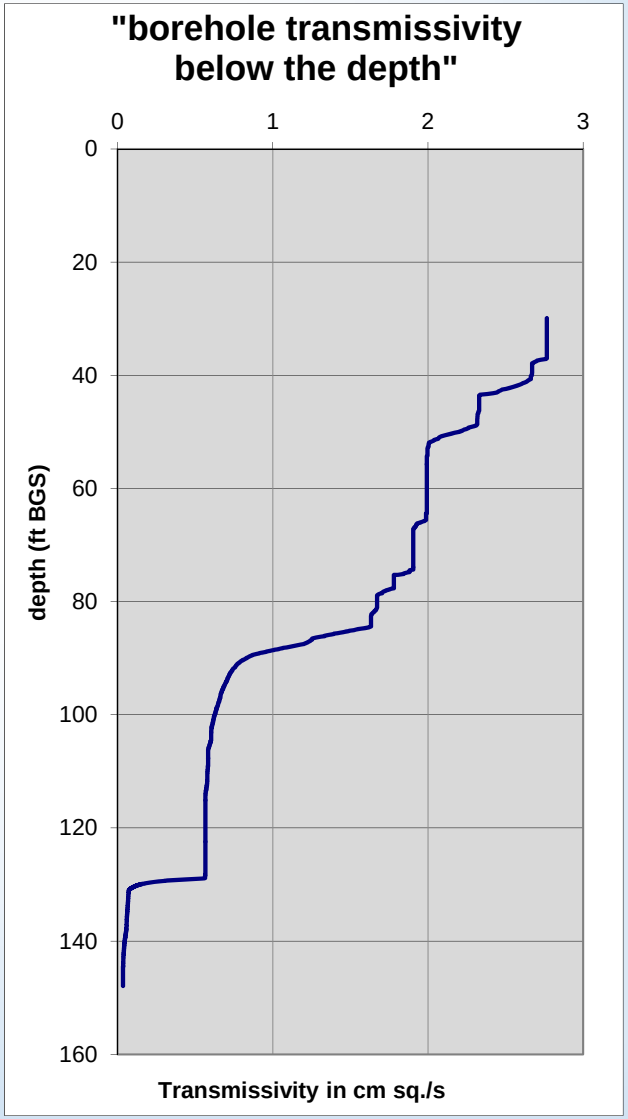
The transmissivity measurement took 0.9 hr.





Integrating the 6660 data points from the bottom of the hole to the top:

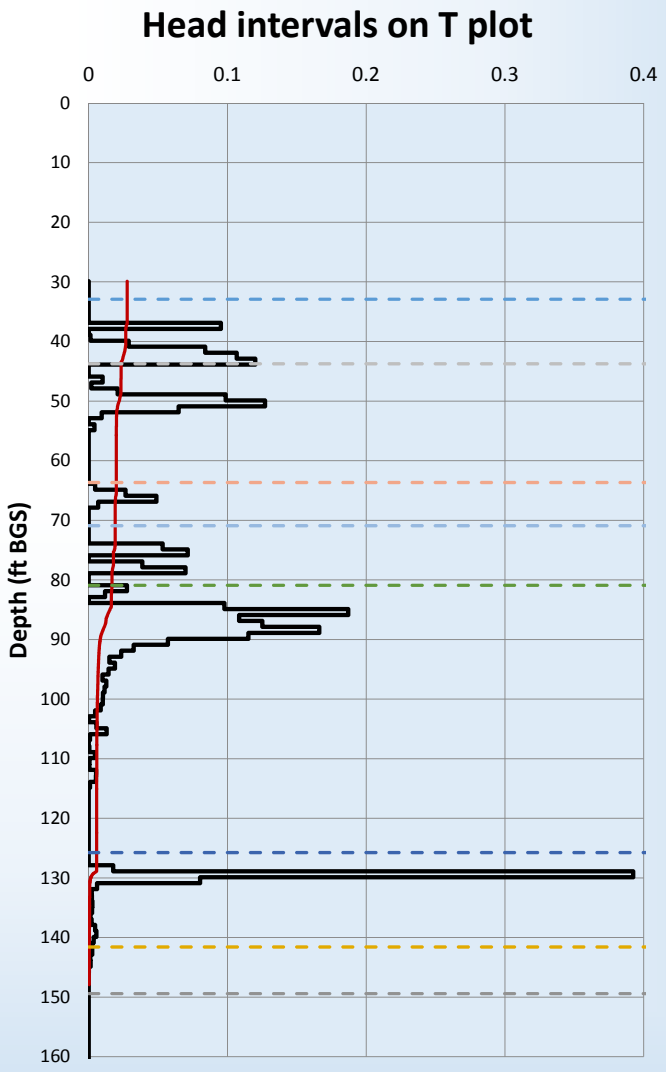
- This curve is the transmissivity of the borehole below each elevation
- Therefore the difference in any two points on the curve is the transmissivity of that interval.



The transmissivity of each foot of the borehole

- We can sum the 6660 data points over one ft intervals for the equivalent of 150 one ft packer tests.

- It is clear from this plot where the major flow zones exist.
- Using this plot, we picked the intervals to be measured while inverting the liner. Those were picked to encompass the major flow zones.
- The dashed horizontal lines are where the liner inversion was to be halted.

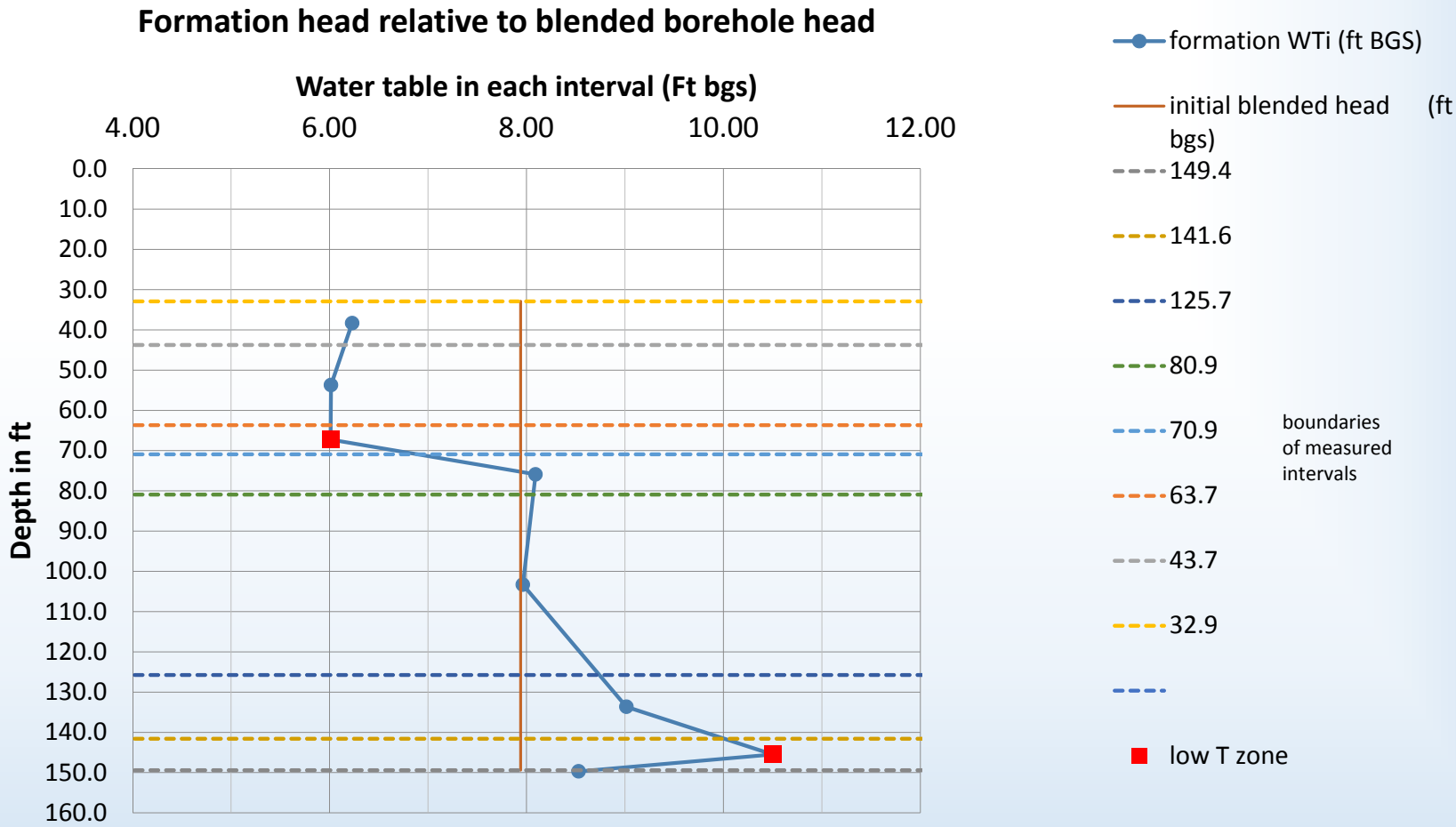


The results

The head profile took 2.5 hrs.

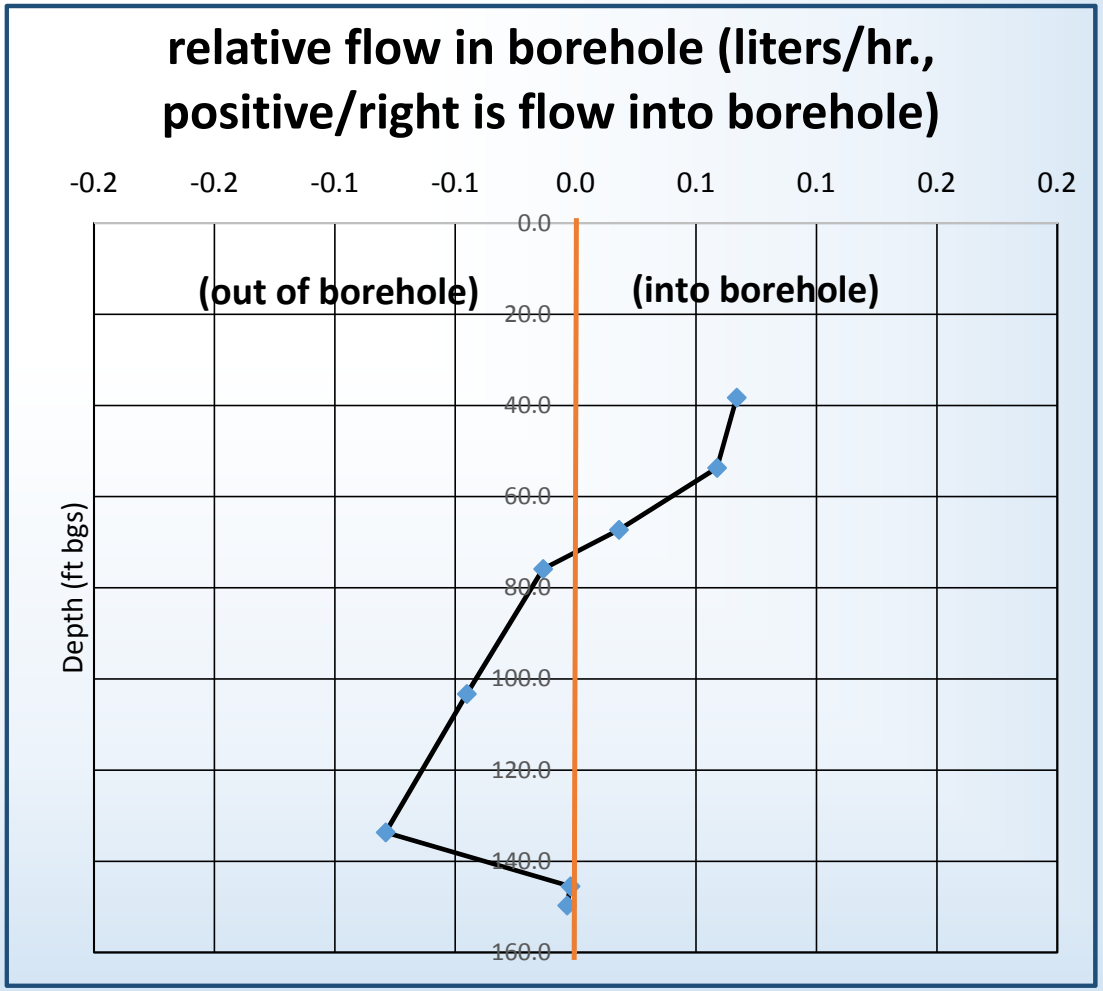
zone no.	Z_i ft. bgs	T_i (cm^2/s)	DT_i	BH_i (ft)	F_i (ft H2O)	F WT (ftbgs)	Flow(l/hr)
1	149.4	0.03506	0.0351	141.47	141.47	8.53	-0.00358
2	141.6	0.041604	0.0065	141.16	139.50	10.50	-0.00211
3	125.7	0.566572	0.5250	140.998	140.99	9.01	-0.08216
4	80.9	1.65094	1.0844	141.68	142.04	7.96	-0.04209
5	70.9	1.905748	0.2548	141.715	141.91	8.09	-0.01355
6	63.7	1.992756	0.0870	141.81	143.99	6.01	0.01565
7	43.7	2.33274	0.3400	142.127	143.99	6.01	0.06099
8	32.9	2.763254	0.4305	142.383	143.77	6.23	0.06686

The reverse head profile result



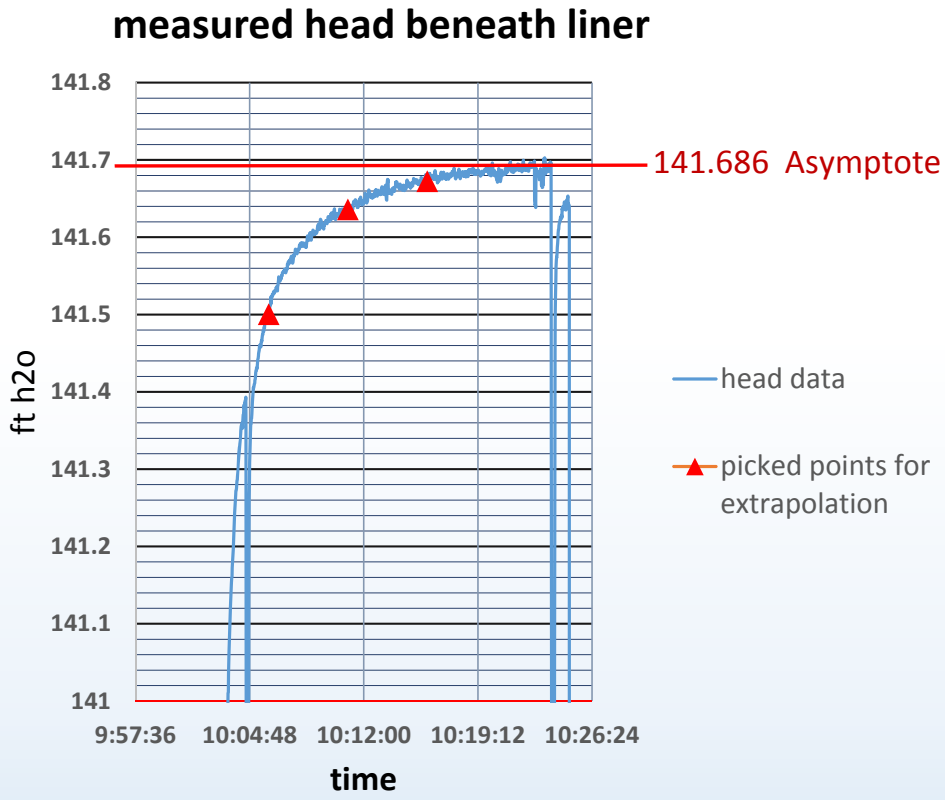
Flow in the open hole

Using the last measurement as the borehole equilibrium pressure, and the formation heads, one can calculate the flow into or out of each interval when the borehole is fully open to achieve its state of “blended head”.



How long does one need to wait for equilibrium?

- Not long. 10-15 minutes.



We can calculate the asymptote from three data points with good resolution.

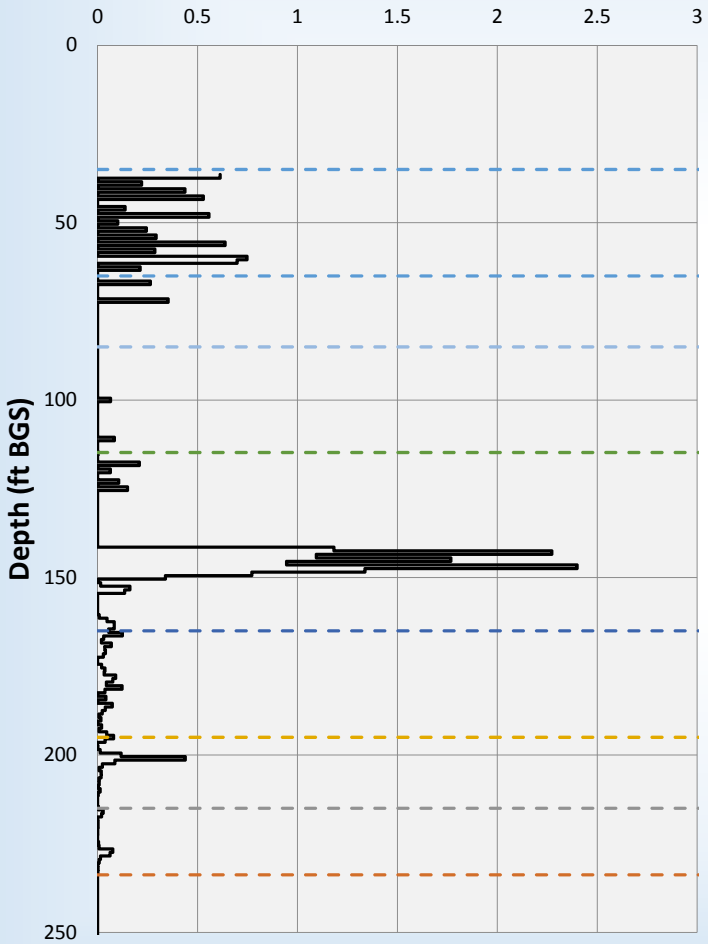
But, alas, we do not have a comparable head data set yet.

The hope is to do one more reverse head profile and then immediately install a Water FLUTe for comparable head measurements in a sealed hole.

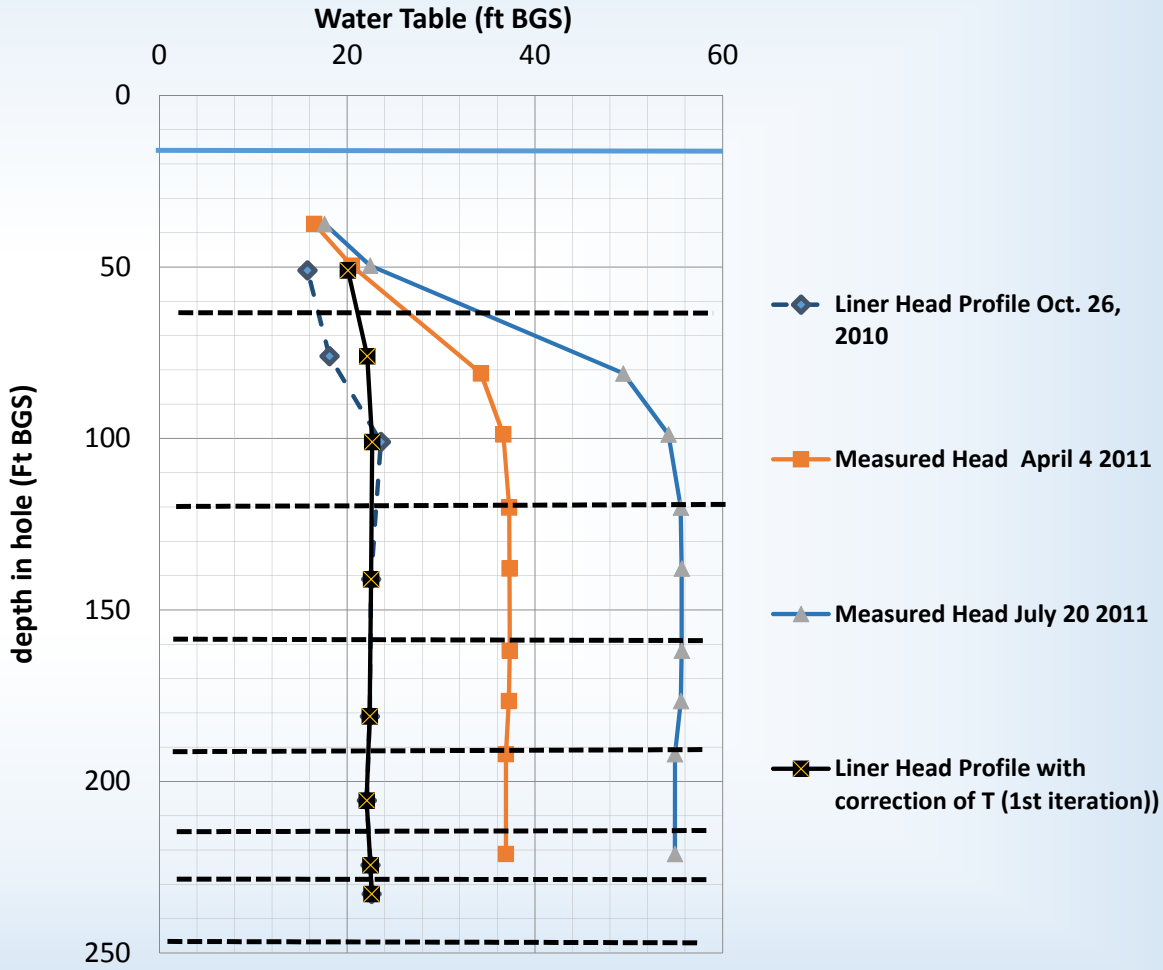
Five years ago, (Oct. 2010) the only previous reverse head profile was performed.

- The results are shown quickly hereafter.
- However, the comparable head measurement with a Water FLUTe installation was not done until April 2011 and again in July 2011.
- During that time the lower aquifer was heavily pumped for summer irrigation.
- The aquitard is seen in all three measurements, but not a definitive test of the reverse head profile method.

Oct. 2010 Transmissivity over 1 ft. intervals (cm^2/s)



Comparison of head measured with RHP in Oct 2010 with Water FLUTe measurement in April 4 to July 20, 2011



Why perform a head profile with a liner?

1. Identify aquitards?
2. Locate artesian zones.
3. Support of the conceptual site model.
4. Aid in the selection of the sampling intervals for a multi-level sampling and head measurement system.
5. One might reduce the cost of performance of other traditional measurements. Those might be ??? It is hard to give up a traditional measurement.
6. Use the head results to refine the T profile.

Conclusion

- The transmissivity profile makes a reverse head profile possible.
- The reverse head profile requires a relatively short time to perform.
- The short time for the T profile plus the reverse head profile minimizes concern for cross connection of contamination in an open hole.
- One should be able to easily identify artesian intervals in a borehole.
- The reverse head profile and other liner measurements greatly aid the site conceptual model.
- Much more testing of the reverse head profile is needed to gain confidence and therefore the full utility of the method.

We appreciate:

- Those who helped to arrange the two test boreholes
- The FLUTe staff who build these systems and install them.
- The customers who let us try things

More information?

FLUTe web site: www.flut.com
Or, Call 505-8520129

Questions?

A copy of this paper is available upon request in the hall.

You may ask why not use packers??

- Packers leak so the head measured is usually between the head above the packers and the head below the packers in the open hole.
- Packers can be entrapped in the borehole, liners are not.
- Packer tests for T on a 1 ft scale are not realistic.
- Packer tests take a long time to perform even on a 5 ft interval so the borehole is long open.
- Packer tests require heavy lifting equipment, especially for 8 inch holes.
- Other packer uses such as T or water quality are frustrated by the leakage and the open hole condition. They are misleading.
- The liner is left in the hole to seal the borehole. Packers are not.
- Do packers need an expensive core-hole??