Recognising perched water

There is a widespread tendency among both hydrogeologists and engineers to mis-identify saturated vertical flow as perched water. It arises during site investigations when adjacent boreholes completed as piezometers within a single formation record different ‘water levels’ (Fig 1).

It should be borne in mind that water levels in piezometers are actually manometers and are measures of pressure and not necessarily measures of the water table. In fact, in non-aquifers they are invariably not measures of the water table. Conversely, if the water levels in Fig.1 are all the same, then they are most probably located in an aquifer!

Fig. 1 can be interpreted in either of two ways, either as a system of perched water levels or as a fully saturated formation exhibiting vertical flow (in this case downwards).

The two alternatives are illustrated in Fig.2 where it should be noted that the perched water tables are located in a highly permeable hydrogeological environment whereas the fully saturated concept is, roughly speaking, everywhere else. To be a bit more precise, any layered sediment that is adjacent to a more permeable one will contain vertical flow. Since that is a very common scenario, that is why the saturated interpretation is invariably the correct one.

The explanation of how the water levels come to be located where they are is also the key to checking that your interpretation is correct.

As groundwater flows downwards across the low permeability sediment, it uses up the potential energy it possesses by virtue of its elevation. Hence, it has zero potential energy at any elevation where it is measured and the head measured will equal its elevation (Fig. 3). In theory, perched water systems should return heads above the elevation of the piezometer in which they are measured. There should also be some ‘dry’ piezometers sampling the unsaturated zone between perched levels. In practice, the generally low permeability means that monitoring zones can remain ‘dry’ for long periods of time and it is easy to believe that they are located within unsaturated zones.
As a ‘first-cut’ at interpretation, it should be borne in mind that:

1. The perched concept is a high permeability one.
2. Perched water tables are usually regarded as transient phenomena.
3. The clue is often in the name. A formation named “lacustrine-fluvial-pebbly clay” is highly unlikely to be permeable enough to contain the perched concept.
4. Lenses of cobbles or gravel within a silt or sand do not constitute a highly permeable configuration.
5. A perched water level is completely surrounded by a water table (both above and below) and a zone where water pressure is less than atmospheric.
6. Groundwater systems are continuous as is the head field.
7. Perched water tables of any appreciable extent require ‘headroom’ within highly permeable material in order to dissipate recharge and not end up coalescing and forming the alternative concept, fully saturated vertical flow. This also means that the perched water concept is inappropriate for low relief landscapes.

There are roughly two methods to distinguish between the two concepts. The first is directly related to Fig. 3. in that potential energy at any point is zero and head should be equal to elevation. A plot of head (as water level) against elevation of the measurement point should yield a 1:1 relationship.

Figure 4 shows results from a limited investigation of a closed landfill (an old brick-pit) located on the top of a small hill in northern England. The hydrogeological configuration includes an aquifer (the Magnesian Limestone) at around 20 m below ground level which is likely to be in direct connection with a local river which encircles the small hill. The relationships are much as Fig. 1.

The blue “boxes” show the average water level plotted versus water level range and thus the range in elevation of the recorded water level in the screened intervals. The key aspect of this representation is that all the water levels, barring that above the Magnesian Limestone interval, occur within the screened interval. This implies a saturated system of downward flowing groundwater that consumes all its excess potential energy in flowing from the water table near the surface to the elevation of the screened interval (as in Figure 7.28d). If this was a series of perched water levels, then at least one could be expected to occur above the screened interval. The Magnesian Limestone is a confined formation with groundwater at the indicated value of head.
There is a river about a kilometre’s distance at an elevation of about 45 mOD to which the whole system would appear to be draining. The position of the water level within the screened interval is a function of the rate at which water comes into the more permeable gravel packed interval versus the rate it exits. If the formation at the top of the interval is more permeable than that at the bottom then the water level will settle towards the top (note the highest glacial till (sand) interval). The lowest Glacial Till interval exhibits the opposite.

Fig. 4. Plot of water level variation as head versus the elevation of the screened interval

The ‘dry’ long borehole in the landfill is interpreted as being a function of the large volume of bentonite pellets used to backfill up to the required level. Lying in the bottom of a borehole within low permeability landfill material, they hadn’t fully hydrated at the time of measurement.

In general, Fig. 4. reveals that interpretation of water levels is seldom clear-cut. Knowledge of the wider regime often provides clarity.

A more complex relationship is illustrated by the hydrogeology of the Drigg low level nuclear waste site (on the coast of West Cumbria) because it contains a complicated ‘pile’ of glacial sediments and many dozens of boreholes completed as piezometers. The original hydrogeological concept was closely based on the geological interpretation (Fig. 5a) and included the physical concept of cascading perched water tables (Fig. 5b). As is apparent in Fig. 5c, this cascading system was required to fit within a maximum formation thickness of 16 m which left little headroom for the water tables to form and not coalesce. The interpretation also included a sort of intermittent water table/piezometric surface that seemed over complicated. Attempts to build a numerical model capable of simulating the system in Fig 5c proved fruitless despite several years of effort. Eventually
a new consultant produced a sensible, much simpler concept based on fully saturated, vertical flow in the small hills of drift deposits above a larger scale flow system in the underlying Sherwood Sandstone (Fig. 5d).

The revised concept is readily supported by a similar analysis to that shown in Fig. 4 albeit with many more measurements (Fig. 6). The small hills with a maximum elevation of 22 m above sea level are mainly composed of Lacustrine Fluvial/Pebbly Clay (Fig. 5a) and contain heads indicating saturated downward flow. The small elevations above the 1:1 line probably reflect water levels in piezometers above the mid-point elevation. There is a small component of downward flow in the sandstone.
A second method of distinguishing between concepts depends on having time-series data of water level fluctuations. It depends on the concept that, when there is no recharge, a water table declines at a rate proportional to its height above its discharge point (Olin and Svensson, 1992). The problem traditionally lay in not being able to wait for a long enough dry period to observe sufficient of the recession curve to extrapolate to ‘base level’. The problem has been partly solved by the advent of accurate pressure transducers and large capacity data storage. The method is summarised in Fig. 7 and relies on the idea that the water level will attempt to decline at the highest rate possible all the time and will do so during any period of zero recharge however short. Hence, using modern frequent data, the rate of change is calculated for every two data points and yields a data set of ‘spot rates’ versus elevation. This is plotted (as a cloud) in Fig. 7c. Only the rate of fall data is of interest since the rate of rise data is entirely dependent on the rate of rainfall/recharge.

Fig. 7. Using detailed short-term hydrograph data to predict long term base level.
As shown in Fig. 7c, the water level can decline at any rate but cannot exceed some maximum rate which is related to base level. This maximum rate should form a reasonably linear envelope that can be projected to zero rate which is the base level of the groundwater system under scrutiny. In the case of perched water levels, the base level indicated should coincide with some identifiable low permeability layer. It is of note that the period shown in Fig. 7a was followed by a long period of near-drought and water level decline that confirmed the projection shown in Fig. 7c.

A further benefit of the ‘spot rate’ method is that water table conditions can be separated from confined conditions on the basis of how they behave. In the case of water tables, they have a rate of fall envelope that is roughly linear and indicates the base level (as in Fig. 7c). On the positive side of the zero line (i.e. rate of rise) virtually any rate is possible and the ‘spot rate’ cloud is distinctly asymmetric (Fig. 8b). In contrast, where the ground water is confined, the rate of change of pressure is a function of the elasticity of the formation as it is ‘weighted-up’ and then released. This results in a symmetric ‘spot rate’ cloud. Clearly, the ground water hydrographs yield no such definitive information.

Fig. 8. Characteristic responses of water tables and confined conditions in terms of ‘spot rates’.