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MEMORANDUM

DATE: December 16, 2008
TO: Christopher Prucha (WM)
C.C:
FROM: Philip Tibble and François Richard (WESA)
PROJECT #: K-B5691-6
SUBJECT: **Effect of groundwater density on pressure head, Richmond Landfill**

MESSAGE:

Chris:

During our last meeting with MOE hydrogeologists Kyle Stephenson and Frank Crossley (MOE Kingston office, Nov. 25, 2008), the effect on potentiometric groundwater elevation for higher density saline water compared to fresh groundwater was briefly discussed. Increased water density causes the measured groundwater elevations to be lower than they would be under identical physical conditions for fresher groundwater. The magnitude of this effect is addressed in this document, specifically to determine whether it has any significant impact on the groundwater contouring and flow patterns derived from groundwater elevation measurements collected at the WM Richmond Landfill site.

Hydraulic head is the sum of two components: the elevation of the point of measurement (elevation head) and the pressure head. The elevation head is simply the elevation of the screened interval (usually mid-point of the screen is used) and the pressure head component is a function of the height of the fluid column above the measuring point and the properties of the fluid.

At a point (p) the fluid pressure is given by:

$$p = \rho g \Psi + p_0$$

Where:

ρ Is the density of the fluid,

g is the acceleration due to gravity,

Ψ is the height of the fluid above the measurement point, and

p_o is atmospheric pressure

For groundwater it is common to set the atmospheric pressure (p_o) to zero and work in pressures above atmospheric (gauge pressure). Thus the pressure head component of hydraulic head is directly proportional to the density of the fluid. Localized increases in groundwater density, for example where saline formation groundwater is present, results in a lower groundwater elevation than if the water was less dense. The density of fresh water is 1000 kg/m^3 (at 4°C). For a fluid with a different density the density component of the pressure head may require correction to allow hydraulic gradients between monitoring locations to be evaluated.

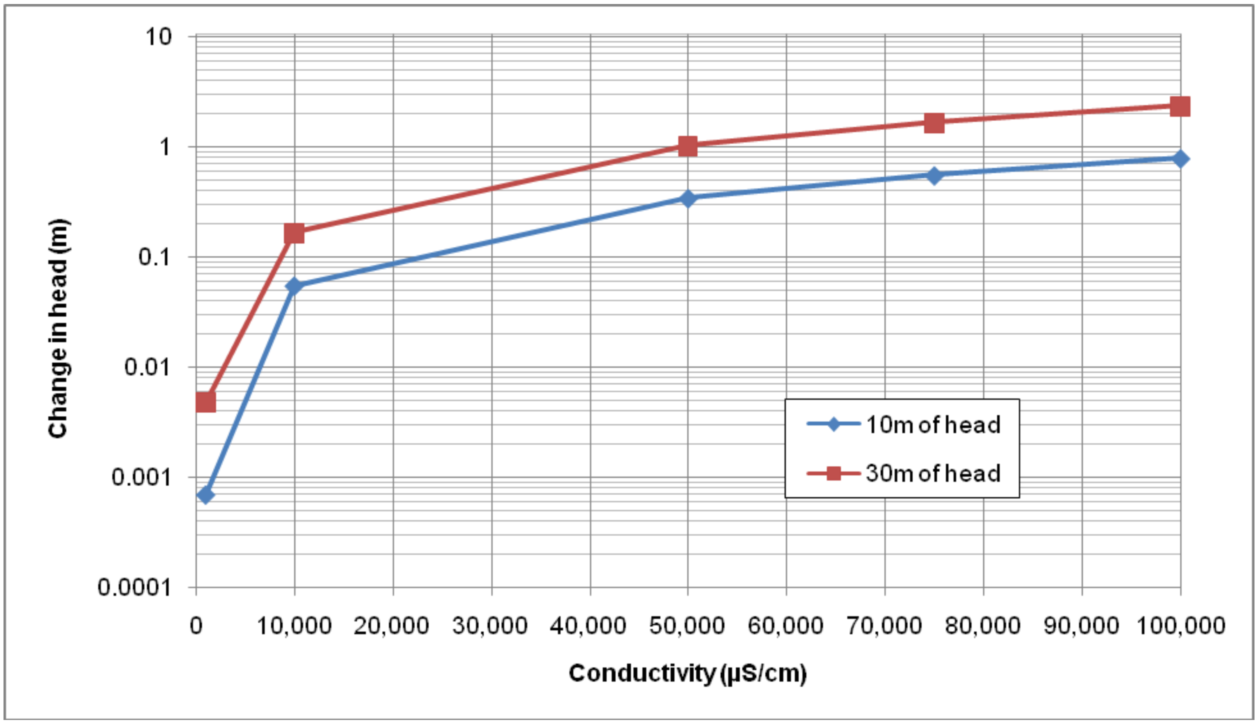
Methods and Observations

The UNESCO International Equation of State [1] (IES 80) was used to determine the density of the groundwater based on electrical conductivity results from groundwater sampling, and to adjust the height of the water column measured in several on-site monitors. The results from this exercise are used to comment specifically on the potential density effect on data used for piezometric contouring at the Richmond Landfill site. The equation of state of water is a complicated curve fit to precise measurements and was calculated using a JavaScript calculator provided on the Ocean Remote Sensing Group at Johns Hopkins University website[2]. The ratio of computed density to the density of fresh water (1000 kg/m^3 at 4°C) was used to correct the measured water level.

The effect of correcting for density increases in magnitude as electrical conductivity becomes higher, and also with increasing height of water column. To illustrate this, the change in pressure head is plotted below as a function of electrical conductivity from 1000 μS/cm (characteristic of relatively fresh water with low salinity) to 100,000 μS/cm (highly saline water), comparing hypothetical scenarios with a 10 m and 30 m column of water. Note that the correction in pressure head is negligible (< 0.01 m) for conductivities less than approximately 4,000 μS/cm at a groundwater monitor with less than 10 m of head.

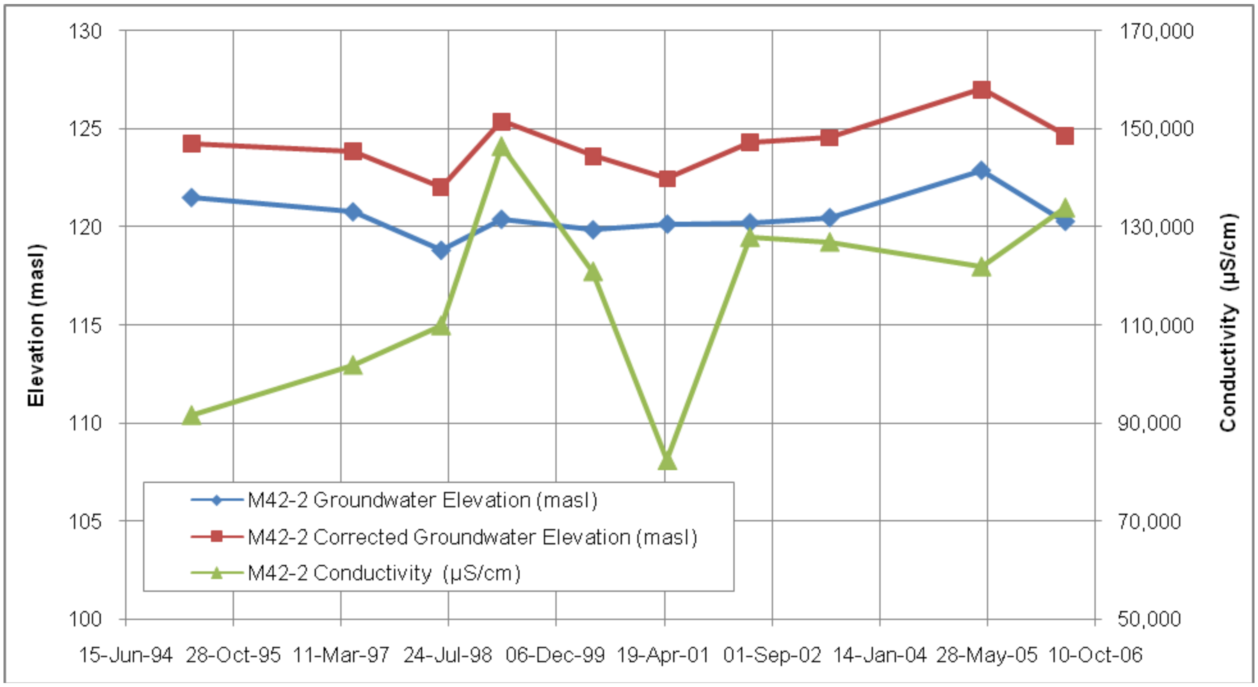
[1] Fofonoff, N. P., 1985: *Physical Properties of Seawater: A New Salinity Scale and Equation of State of Seawater*, J. Geophys. Res., Vol. 90 No. C2, pp. 3332-3342

[2] http://fermi.jhuapl.edu/denscalc.html



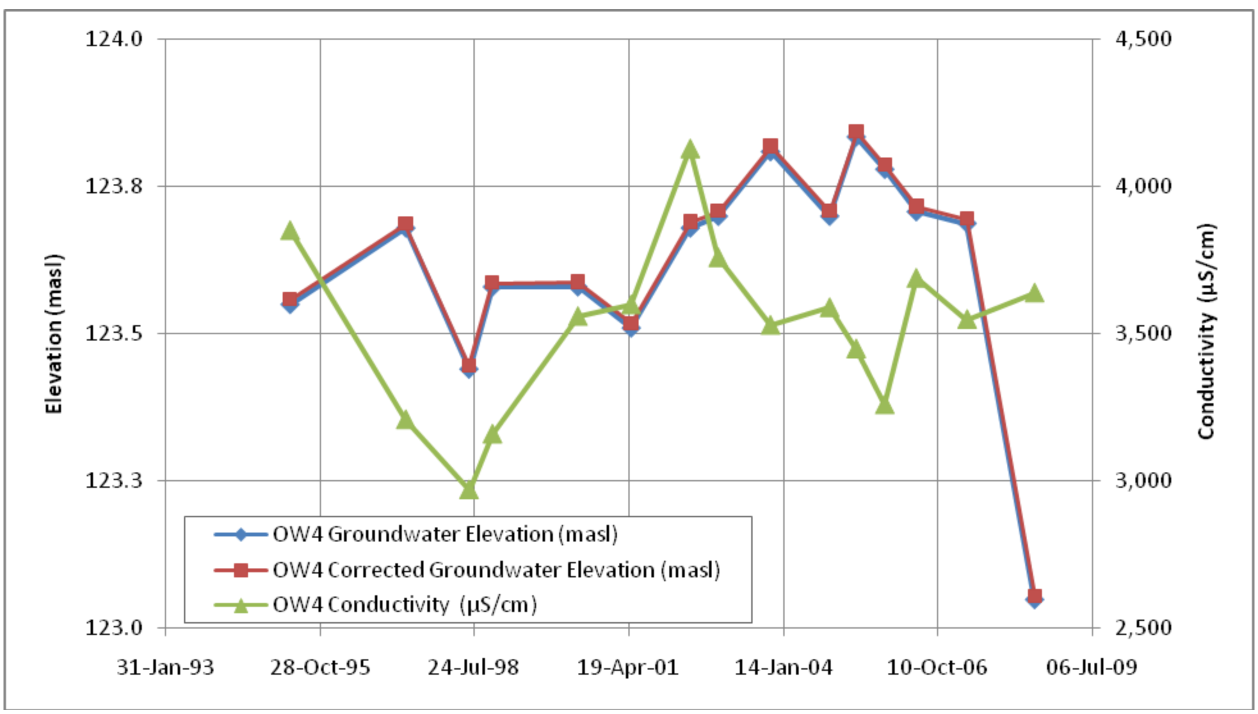
Electrical conductivities measured at groundwater monitors at the WM Richmond site exhibit an extremely large range of values from hundreds of µS/cm to over 100,000 µS/cm at some locations. This is illustrated below for two on-site monitors: M42-2 (a deep bedrock monitor with saline groundwater and very high electrical conductivity) and OW4 (a shallow bedrock monitor with fresher groundwater conditions and moderate conductivity).

Groundwater Monitor M42-2 consistently yields very high conductivity values and has approximately 40 m of water column (height of water above the screen mid-point). The effect of density on measured water levels for this monitor for 12 years of data is shown in the plot below.



For this dataset, representative of extremely saline groundwater, the correction to measured pressure head values is on the order of 2 to 4 m.

Conductivity data at groundwater monitor OW4 ranges from approximately 3,000 to 4,000 µS/cm (moderately high salinity) over a 12 year period. The pressure head in this monitor is approximately 5 m. The historical hydrograph, corrected hydrograph and electrical conductivity results for OW4 are plotted below.



For the OW4 dataset the correction to measured head value is less than 0.001 m.

Not all groundwater monitors at the Richmond site are used for interpreting the elevation of the water table; groundwater flow interpretation is based on water levels from monitors that have been determined to be hydraulically responsive and representative of a specific hydrostratigraphic zone (hydraulic connectivity). The groundwater in this zone typically exhibits low electrical conductance values.

In April 2007, 41 shallow groundwater monitors screened in the overburden and upper 10 metres below bedrock were classified as suitable for contouring. Electrical conductivity results are available for 20 of these 41 locations, with results ranging from 616 to 20,200 µS/cm. Only two of the 20 locations yielded electrical conductivity values higher than 3,000 µS/cm (M6-3: 11,800 µS/cm, and M50-3: 20,200 µS/cm). These wells have pressure heads of 5.44 m and 8.74 m, respectively. Using the methodology described above, the pressure head at these two monitors would be increased by 0.04 m and 0.12 m, respectively. Corrections to the remaining pressure head measurements would be less. These adjusted elevations are relatively insignificant in relation to the interpreted contours developed at a 1 m contour interval.

Conclusions

- When the depth to the water level measured in the field is used to calculate hydraulic head, a false low is produced for groundwater with a density greater than fresh water. At the Richmond site increased groundwater density is directly attributable to increased salinity at some wells.
- Analysis of the relationship of electrical conductivity to correct pressure head value suggests that the density effect is negligible (< 0.01 m) for conductivities less than approximately 4,000 µS/cm at a groundwater monitor with less than 10 m of head.
- Review of the conductivity values for the shallow groundwater monitors used to interpret the location of groundwater contours at the Richmond Landfill site indicates that density effects are minimal even at the monitors with the highest recorded electrical conductivity, and correction does not significantly alter the piezometric interpretation, thus density correction is not required.
- It is noted that some groundwater monitors that are used in developing piezometric contours are not part of the annual monitoring program for water quality and therefore any potential effect from elevated salinity on the measured groundwater value cannot be evaluated or potentially corrected for.