Earth 461 Assignment #3

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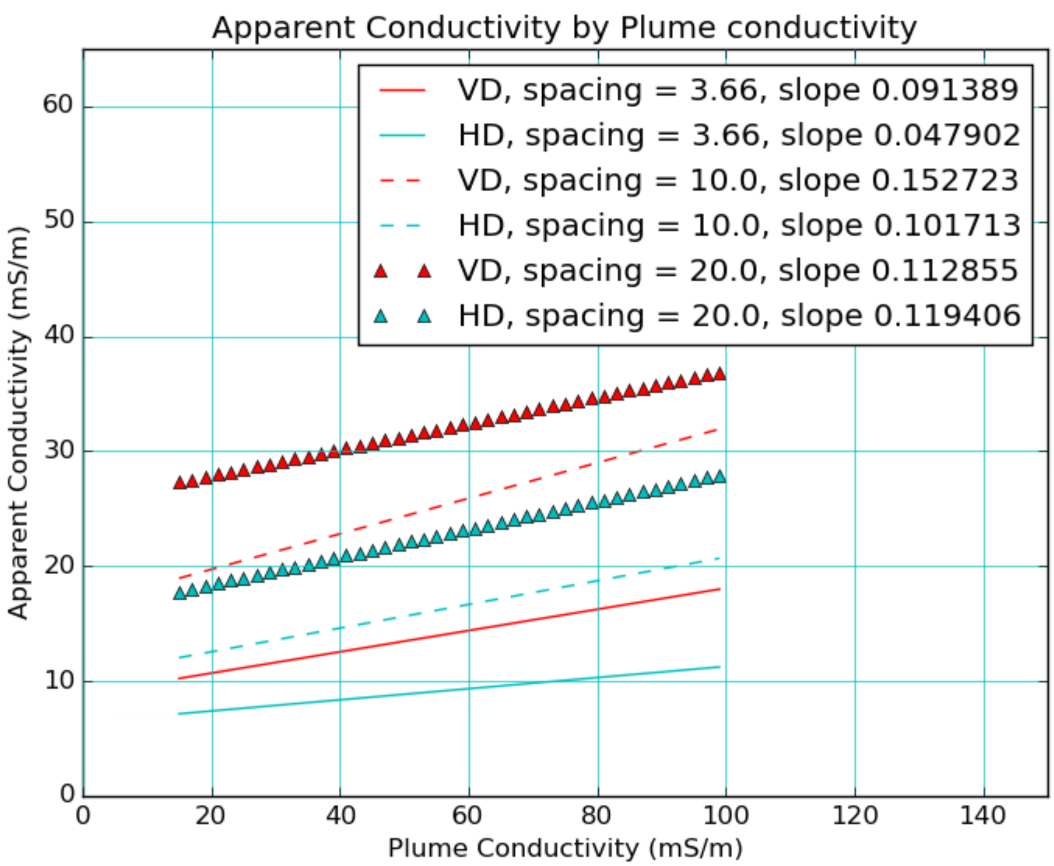
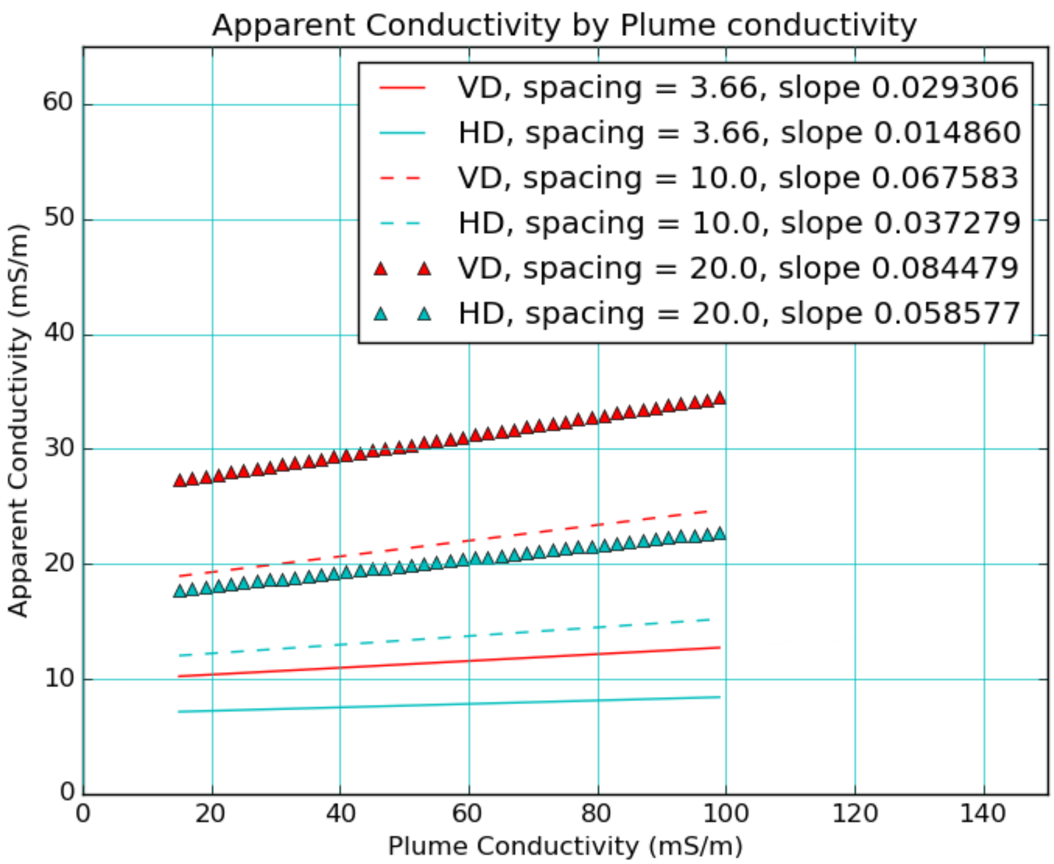
1)



The sensitivity of GCM measurements to this plume is reflected in the slope of each apparent conductivity as the plume conductivity increases. If the slope of the line is high, the change in apparent conductivity for a change in plume conductivity will be larger, and thus easier to distinguish than for a shallower line.

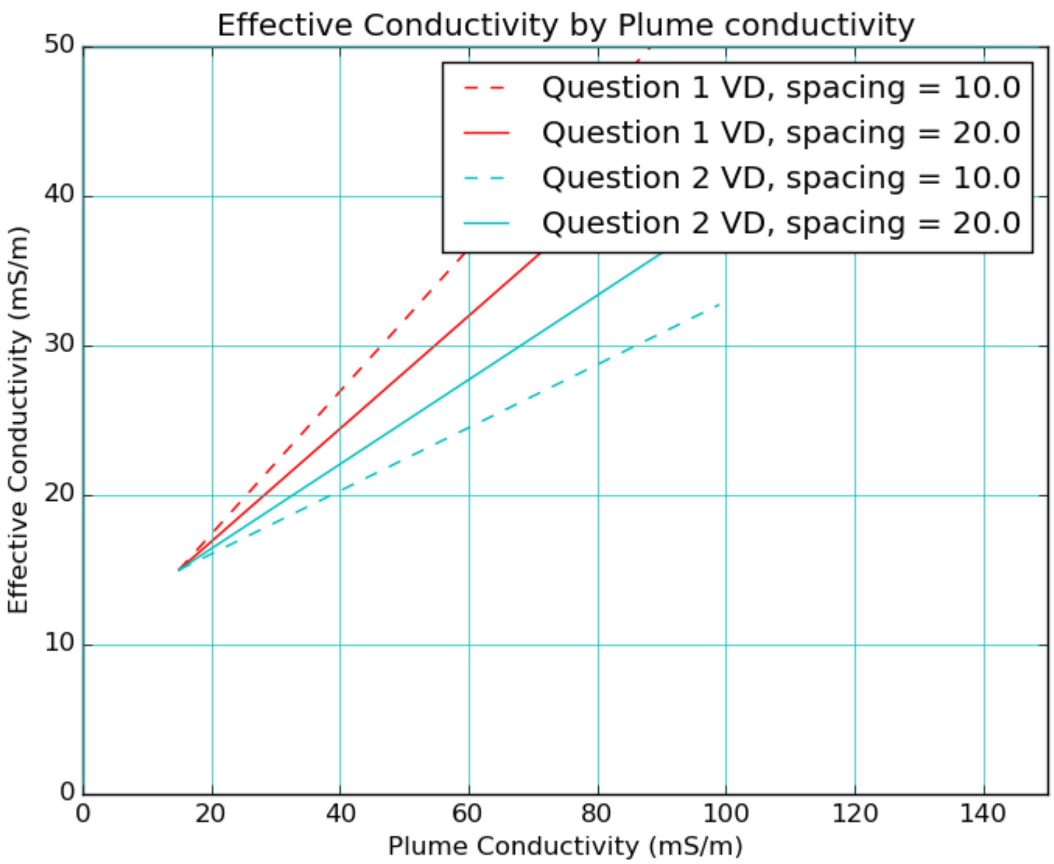
The slope is generally higher for the VD orientation than the HD orientation, and the highest slope for VD orientation is at the coil spacing of 10.0 m. This is due to VD being the most effective at depths of 1.5s. The bottom of the dissolved plume is at 9m, so the z/s ratio for the 10.0 m coil separation is 0.9, closer to 1.5 than the other two z/s ratios (2.45 and 0.45 for 3.66 and 20.0), hence why the 10.0 m spacing was the most responsive to conductivity changes.

2)



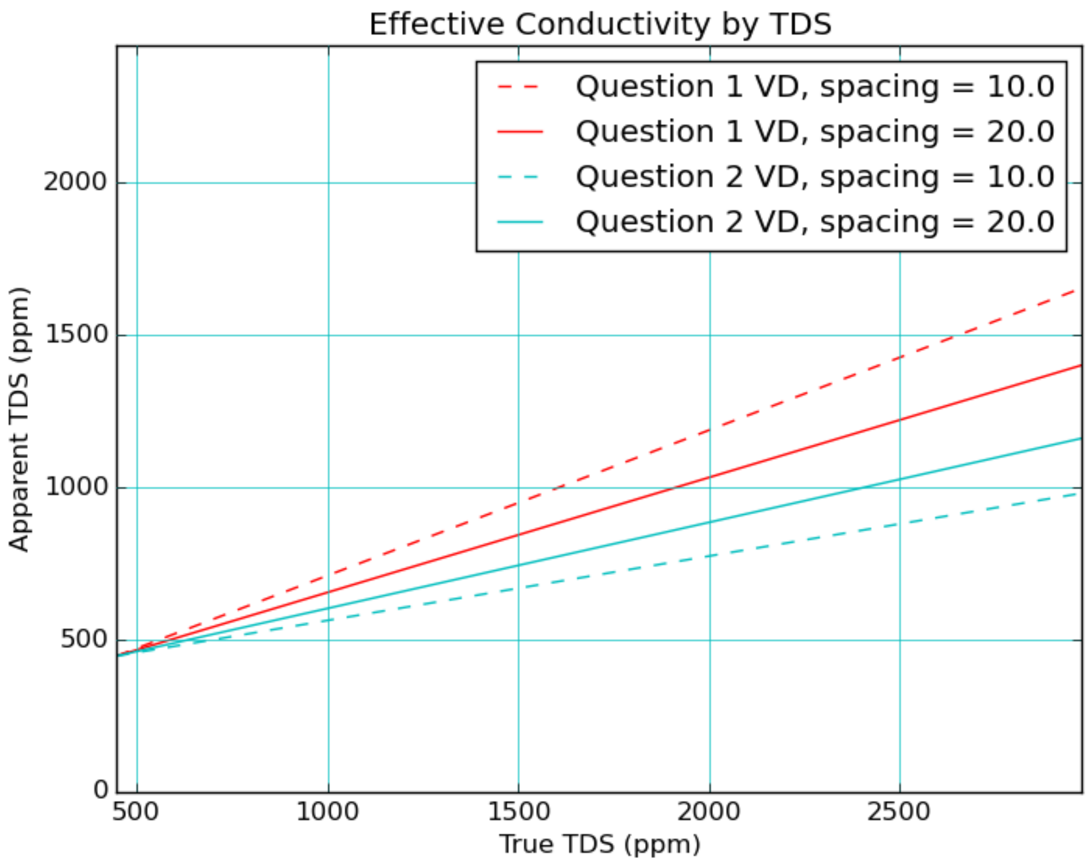
For this case, the plume is located at a deeper depth than the previous problem. As with question 1, VD shows higher slopes than HD orientation, but the greater coil spacing of 20.0 is the most sensitive, as the depth of the plume increases to 15 m, the most sensitive coil spacing increases to 20.0 m.

3a)



Effective Conductivity by Plume conductivity
Question 1 VD, spacing = 10.0
Question 1 VD, spacing = 20.0
Question 2 VD, spacing = 10.0
Question 2 VD, spacing = 20.0
Effective Conductivity (mS/m)
Plume Conductivity (mS/m)
0
10
20
30
40
50
0
20
40
60
80
100
120
140

3b)

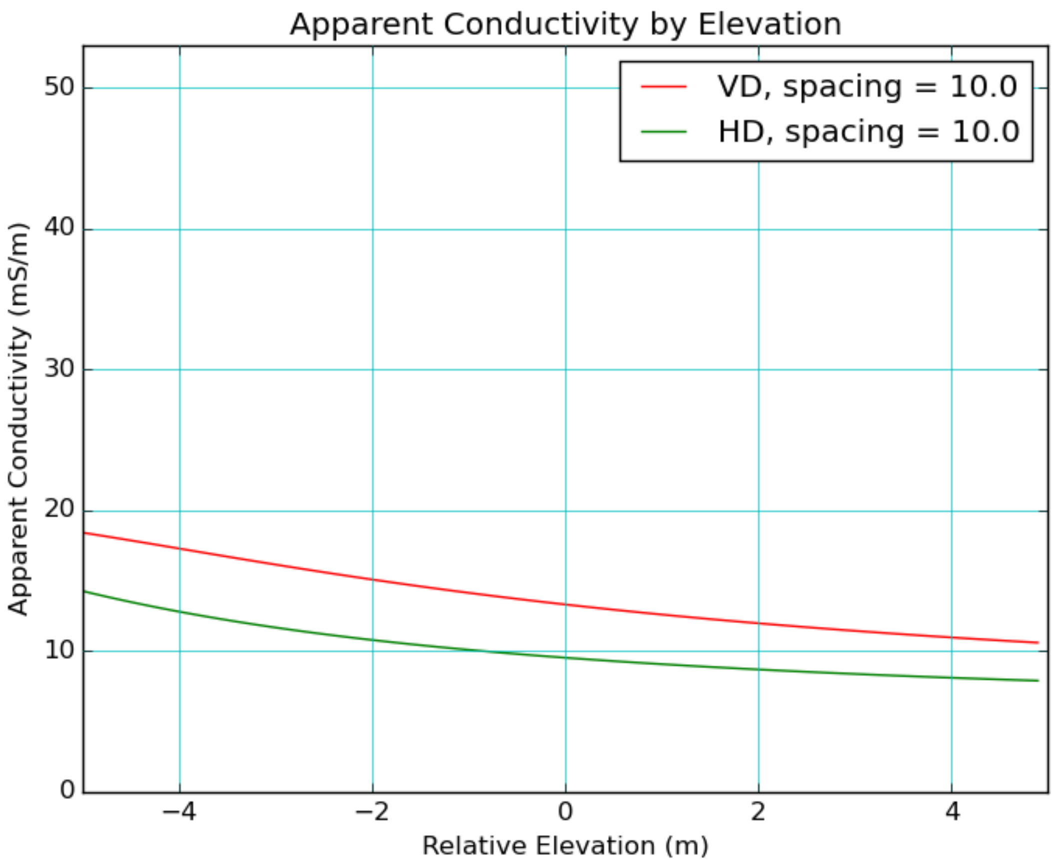


When using an effective aquifer to infer TDS values, the apparent values of TDS tend to skew below the actual (True) values of TDS, likely because the effect of the one small highly contaminated (and higher conductivity) layers is being spread out over the larger/thicker effective aquifer layer. The aquifer closer to the surface in question 1 shows higher apparent TDS, closer to the actual value that should be measured (the y = x line, where apparent TDS and true TDS are the same).

The deeper aquifer in question 2 shows an apparent TDS much lower than question 1, likely due to the decreasing sensitivity of the GCM in VD orientation as depth increases. The effect of this is less pronounced with coil spacing of 20.0 m than 10.0 m, likely due to the larger spacing being more sensitive to the deeper depth of the aquifer in question 2.

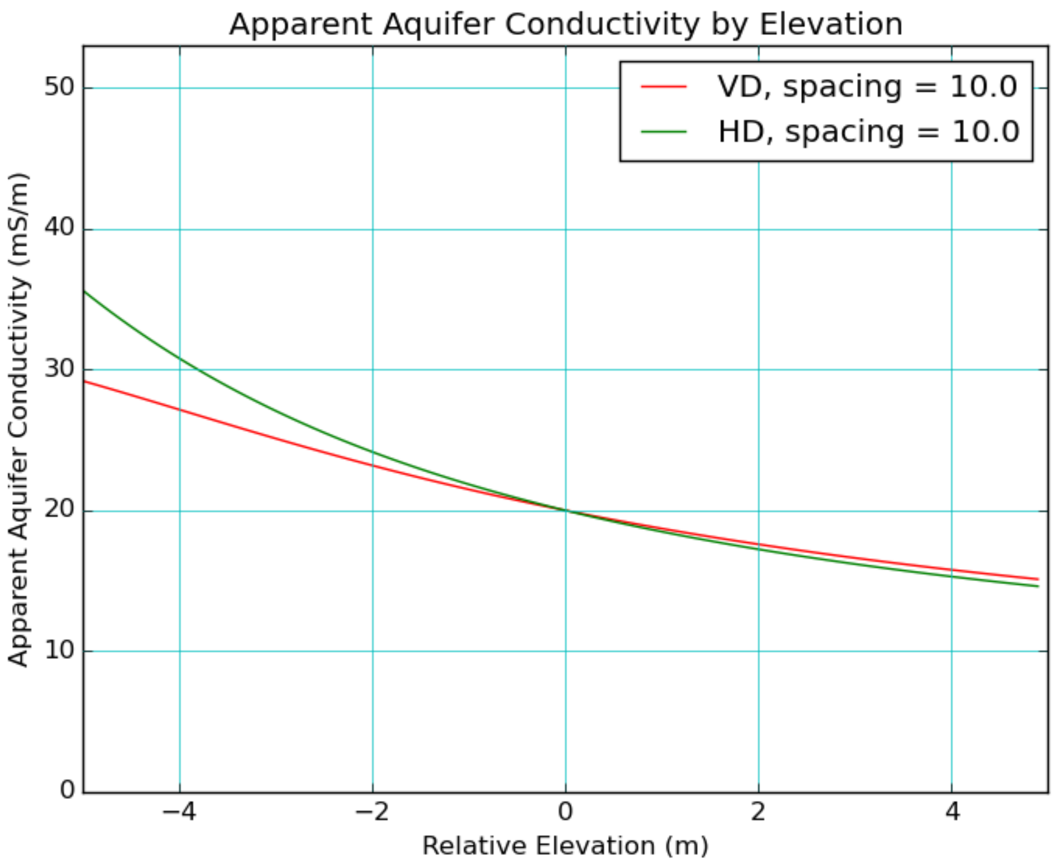
The range of TDS estimates when using an effective aquifer tend to be lower than they should be, and the effect of this under-estimation grows with increasing true TDS and the depth of the plume relative to the whole aquifer (If the plume is at the bottom of the aquifer, the estimated TDS will err on the low side compared to if it was at the top of the aquifer). As a result of this, total contaminant mass estimates will be lower than their true values for more concentrated and deeper plumes)

4a)



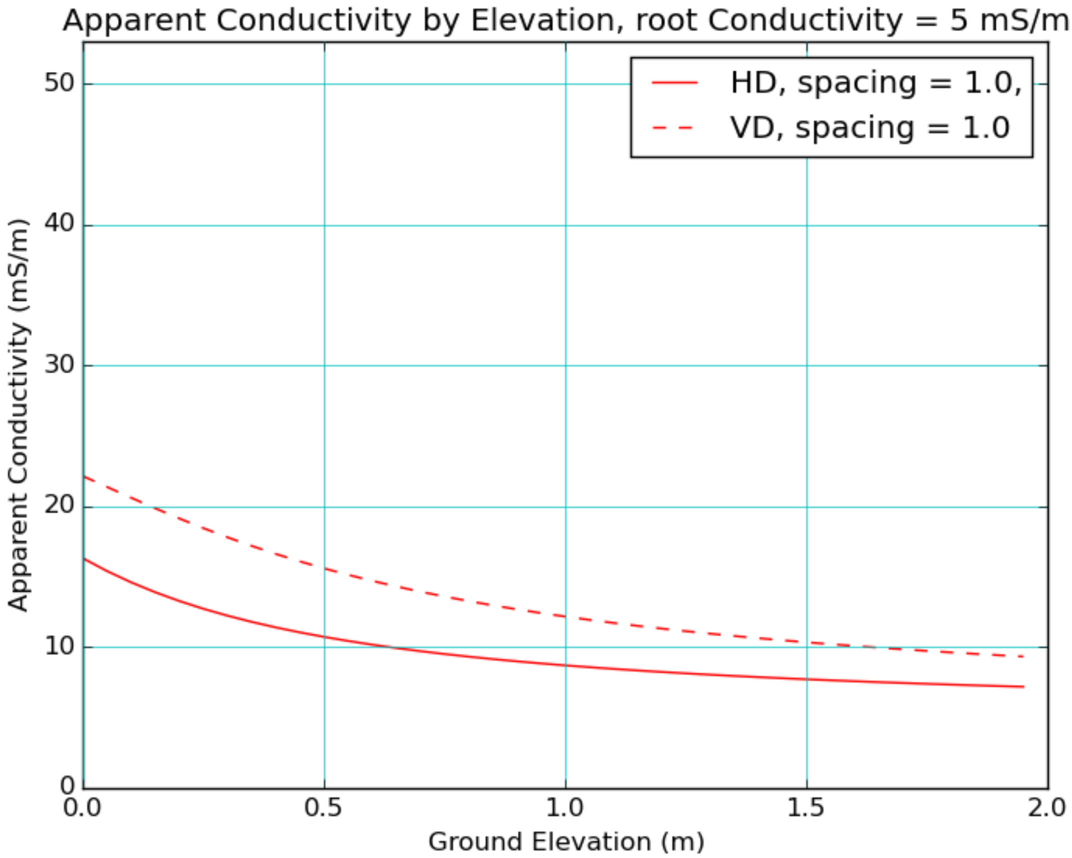
Apparent Conductivity by Elevation
VD, spacing = 10.0
HD, spacing = 10.0
Apparent Conductivity (mS/m)
Relative Elevation (m)
0
10
20
30
40
50
−4
−2
0
2
4

4b)

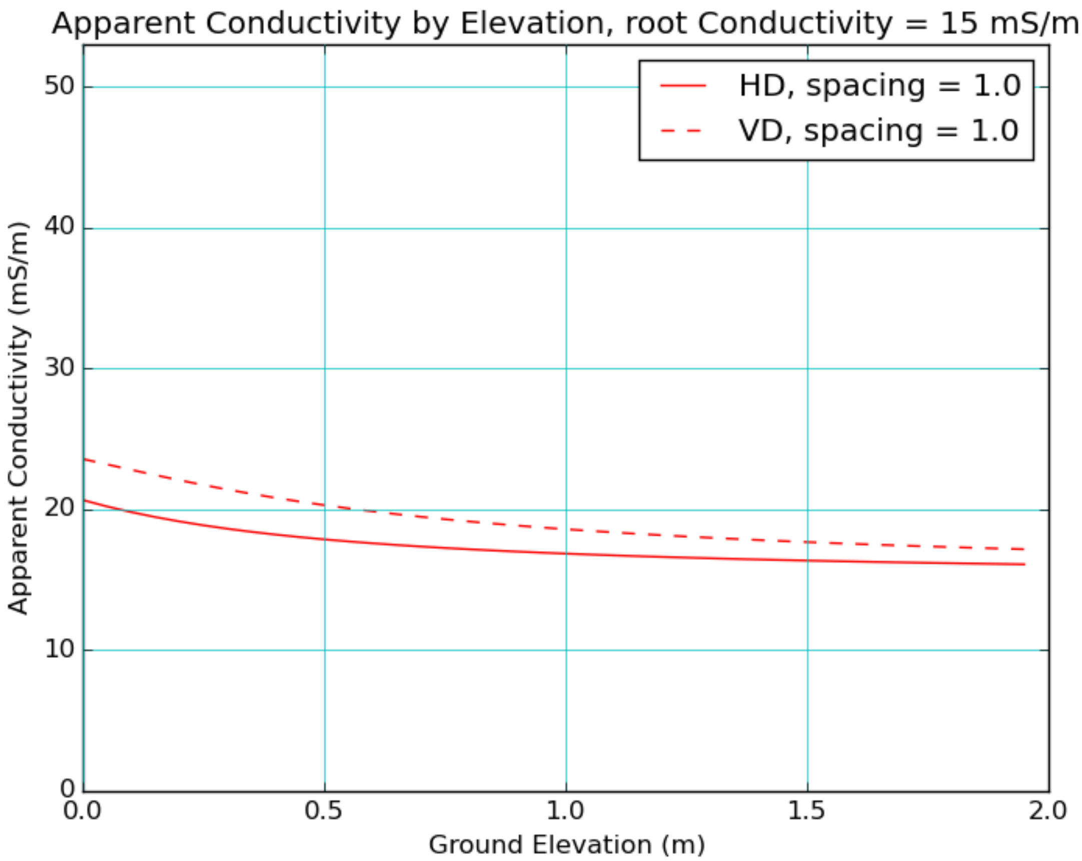


If the effects of elevation are not accounted for when measuring apparent conductivity, the values measured tend to be much higher than they should be, most strongly affecting the HD orientation in areas where the ground surface is depressed, HD orientation measuring significantly higher apparent conductivity than VD in this situation due to its higher sensitivity at shallower depths. (in this case the normalized depth is $z' = \frac{z}{s} = \frac{7.5 - 5}{10.0} = 0.25$). Looking at the chart of response functions (note set 4b, page 5) at a normalized depth of 0.25, the HD orientation is much greater than for VD, and when integrated with the same conductivity functions, will produce a higher apparent conductivity. The effect is much less on the right hand side of the chart, where $z' = \frac{z}{s} = \frac{7.5 + 5}{10} = 1.25$, the values of the response functions for HD and VD orientations differing much less at that point, with VD being slightly higher than HD. (also reflected on the above graph where apparent conductivity from 0 to 5 m relative elevation is slightly higher for VD than HD orientation.

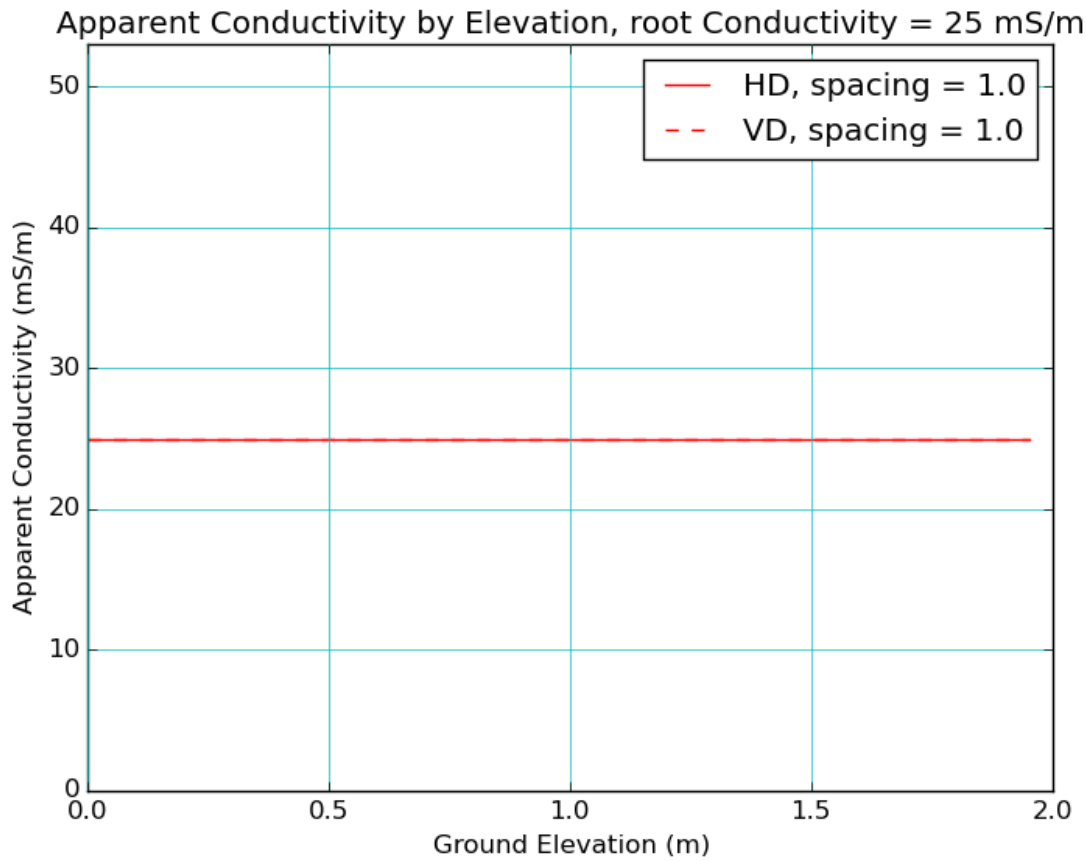
5)

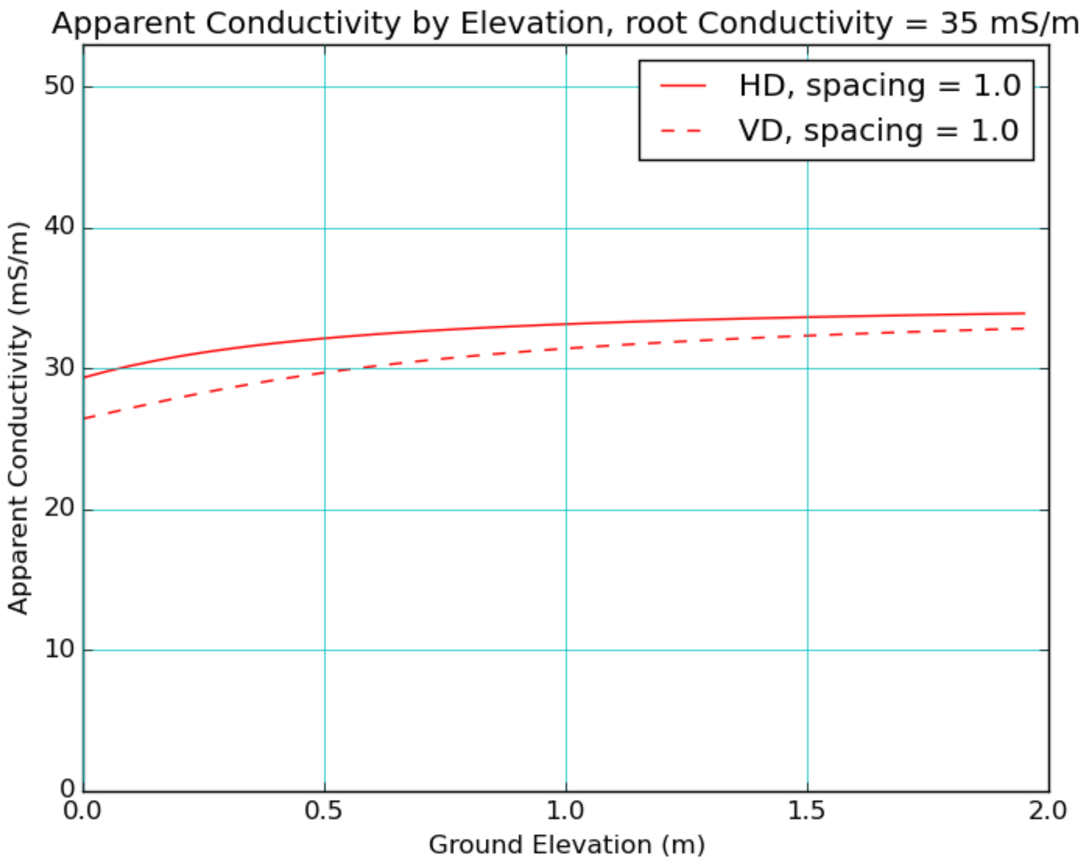


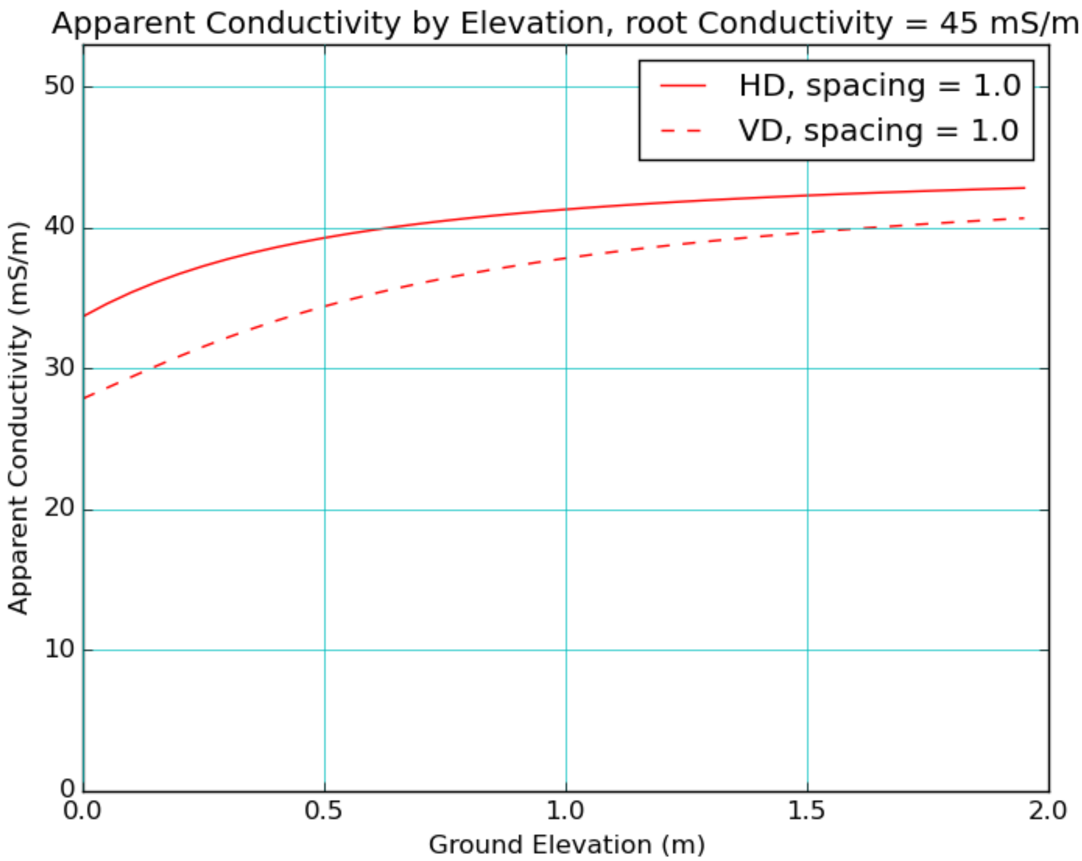
Apparent Conductivity by Elevation, root Conductivity = 5 mS/m
HD, spacing = 1.0,
VD, spacing = 1.0
Apparent Conductivity (mS/m)
Ground Elevation (m)
0
10
20
30
40
50
0.0
0.5
1.0
1.5
2.0



Apparent Conductivity by Elevation, root Conductivity = 15 mS/m
HD, spacing = 1.0
VD, spacing = 1.0
Apparent Conductivity (mS/m)
0
10
20
30
40
50
0.0
0.5
1.0
1.5
2.0
Ground Elevation (m)


Apparent Conductivity by Elevation, root Conductivity = 25 mS/m
HD, spacing = 1.0
VD, spacing = 1.0
Apparent Conductivity (mS/m)
0
10
20
30
40
50
0.0
0.5
1.0
1.5
2.0
Ground Elevation (m)


Apparent Conductivity by Elevation, root Conductivity = 35 mS/m
HD, spacing = 1.0
VD, spacing = 1.0
Apparent Conductivity (mS/m)
0
10
20
30
40
50
0.0
0.5
1.0
1.5
2.0
Ground Elevation (m)



As the elevation of the EM 38 is raised from 0 to 2.0 m above the ground surface, the apparent conductivities measured in HD and VD orientation converge slightly, with greater differences in apparent conductivity between the two more visible when the conductivity of the root zone is significantly different from that of the lower soil zone (ie 45 and 5 mS/m being distinctly higher or lower than the 25 mS/m of the lower soil zone. The effect of the root zone being more or less conductive than the soil zone beneath is stronger in the HD orientation due to its greater sensitivity at shallow depths compared to VD orientation. When the root zone is more conductive than the soil zone, the apparent conductivity is higher than that of the lower soil zone, and when the root zone is less conductive than the soil zone, the apparent conductivity is less than that of the soil zone, due to the root zones conductivity making the subsurface appear either more or less conductive than the soil zone. When the root zone has conductivity of 25 mS/m, identical to that of the lower soil zone, the apparent conductivity is flat at 25 mS/m since the entire subsurface in this model has the same conductivity of 25 mS/m. Sadly the Earth contains more than 1 layer, but the differing apparent conductivity for VD and HD orientations, and their relative difference (ie the separation between the HD and VD lines on the graph) as the instrument is raised above the surface can be used to infer the presence and relative conductivity of layers in the subsurface, respectively.

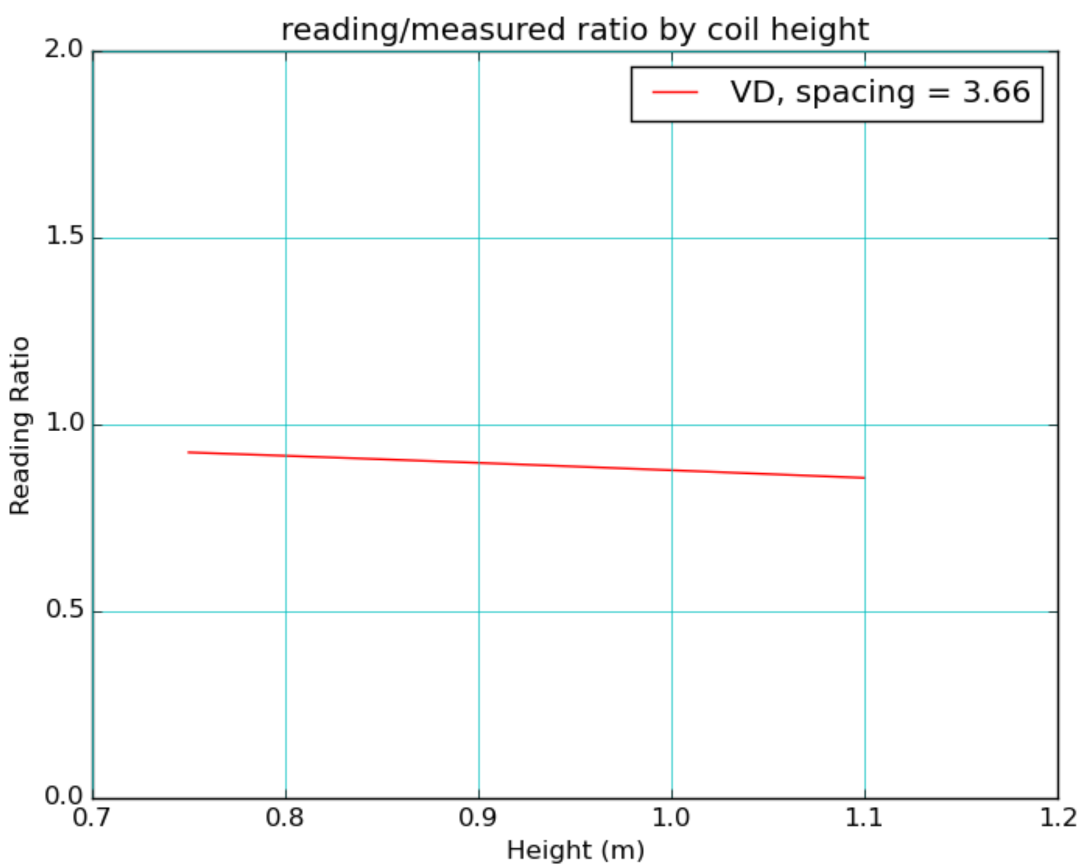
6a)

$$\frac{\sigma_{a\,groundlevel}}{\sigma_{a\,h=1}} = \frac{\sigma_1 * (1 - R(\frac{0}{s})) + \sigma_{hs} * (R(\frac{0}{s}))}{\sigma_1 * (1 - R(\frac{h}{s})) + \sigma_{hs} * (R(\frac{h}{s}))}$$

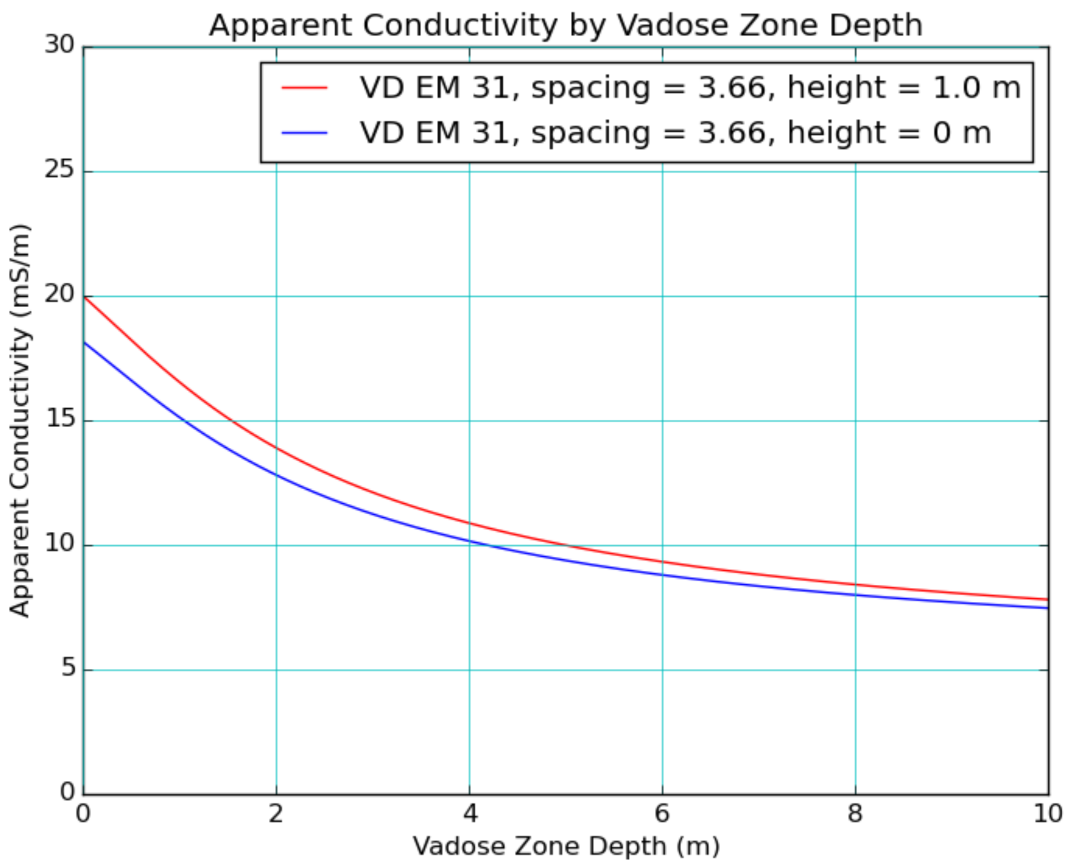
$$\frac{\sigma_{a\,groundlevel}}{\sigma_{a\,h=1}} = \frac{1}{\frac{1}{\sqrt{4*((\frac{1.0}{3.66})^2)+1}}} = 1.1396$$

The compensation used appears to be fairly close to the value derived, but slightly smaller. The reason for this may be to avoid overcompensating for a low conductivity air layer between the meter and the surface which was assumed to be 0 in the case that was used to derive the correctional factor for this question. In reality, the conductivity of this zone may be slightly higher due to the effects of conductive objects passing beneath the meter when moving horizontally (metal objects, humid air?)

6b)



6c)



For an EM 31 meter in VD orientation, readings taken at a height of 1.0m above the ground are slightly higher than those taken on the ground surface, the difference being the greatest when the vadose zone is the most shallow (Vadose Zone depth close to 0m). This difference decreases as the Vadose zone becomes deeper, since the effect of the extra 1m beneath the elevated meter is less when dealing with a significant conductivity contrast in the subsurface which causes the apparent conductivities measured by both meters to be lower than when the aquifer was near the surface.

7)

$$2 * \int_0^\infty \sigma\left(\frac{z}{40}\right) * \varphi_h\left(\frac{z}{40}\right)\frac{dz}{40} - \int_0^\infty \sigma\left(\frac{z}{20}\right) * \varphi_h\left(\frac{z}{20}\right)\frac{dz}{20}$$

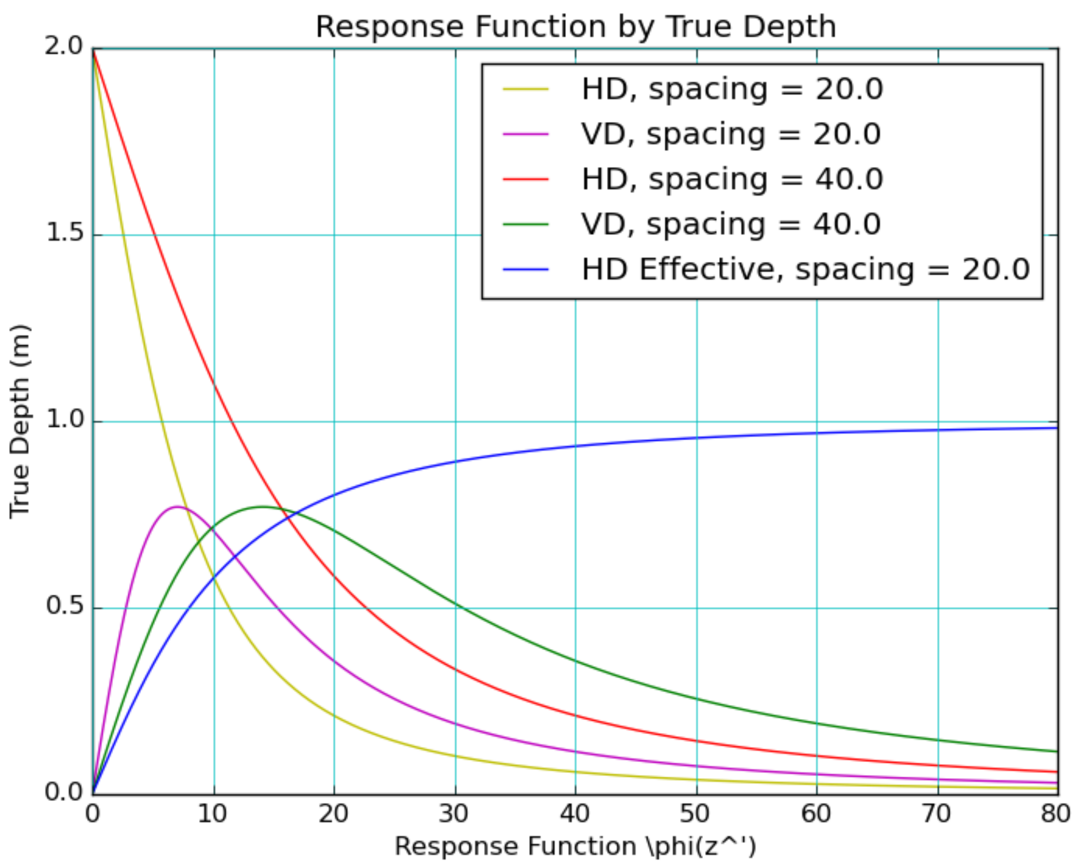
$$\frac{1}{20} * \int_0^\infty \left[\sigma\left(\frac{z}{40}\right) * \varphi_h\left(\frac{z}{40}\right) - \sigma\left(\frac{z}{40}\right) * \varphi_h\left(\frac{z}{40}\right)\right] dz$$

$$\int_0^\infty \frac{\sigma\left(\frac{z}{40}, \frac{z}{20}\right)}{20} * \left(\varphi_h\left(\frac{z}{40}\right) - \varphi_h\left(\frac{z}{20}\right)\right) dz$$

$$\varphi_{\mathrm{effective}_{VD}} = \varphi_h\left(\frac{z}{40}\right) - \varphi_h\left(\frac{z}{20}\right)$$

$$\varphi_h(z') = 2 - \frac{z'}{\sqrt{4 * z'^2 + 1}}$$

7)



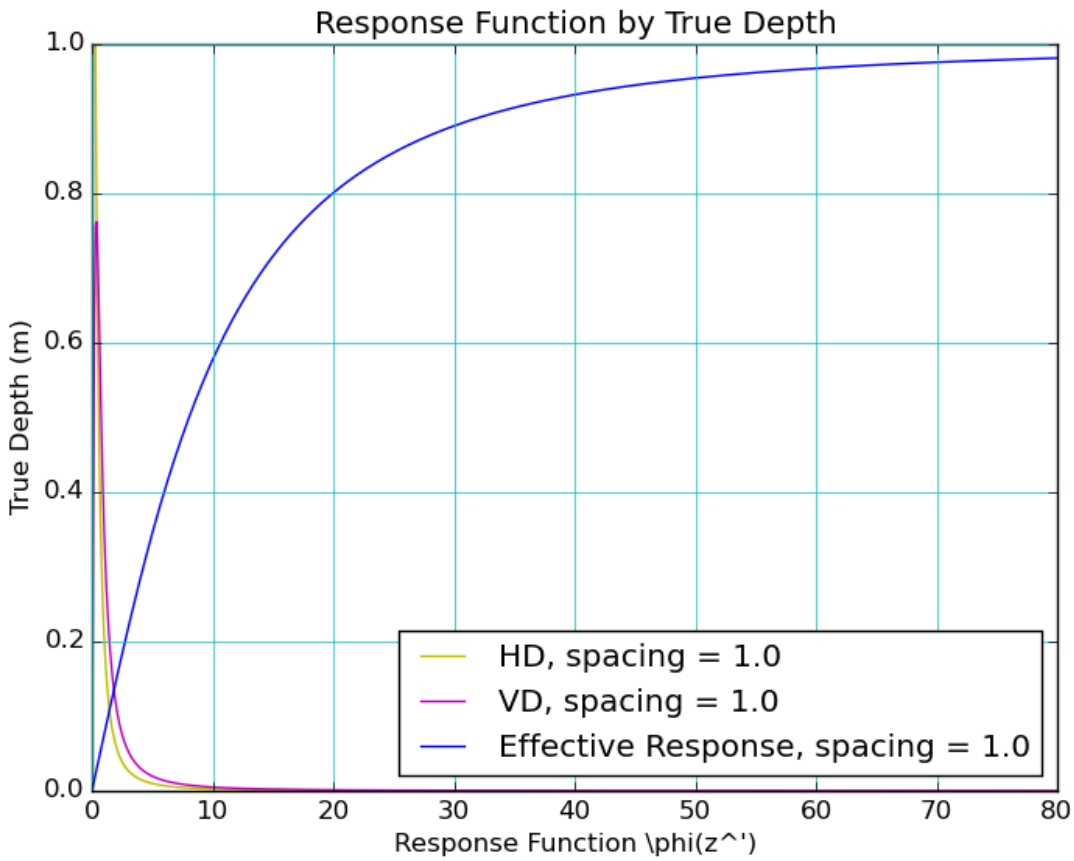
The effective response function for the combined measurements increases with depth, which makes it the best candidate for obtaining conductivity information for deeper layers when compared to the other options (all of which are significantly lower after normalized depths of ~40.

8)

$$\sigma_{a_{\text{effective}}} = 2 * (\sigma_a(1m\ \text{HD})) - \sigma_a(1m\ \text{VD})$$

$$\varphi_{\text{effective}}(z) = 2 * (\varphi_{\text{HD}}(z)) - \varphi_{\text{VD}}(z)$$

$$\varphi_{\text{Effective}}(z) = 4 - \left(\frac{8 * (z)}{\sqrt{4 * (z^2) + 1}}\right) - \left(\frac{4 * (z)}{[4 * (z^2) + 1]^{\frac{3}{2}}}\right)$$


Response Function by True Depth
True Depth (m)
Response Function \phi(z^')
HD, spacing = 1.0
VD, spacing = 1.0
Effective Response, spacing = 1.0
1.0
0.8
0.6
0.4
0.2
0.0
0
10
20
30
40
50
60
70
80