

## ***Interactive comment on “Groundwater flow and storage within an alpine meadow-talus complex” by A. F. McClymont et al.***

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### General comments

This is a very interesting contribution on the role of talus sediments for groundwater storage. This really is a current gap of knowledge regarding that talus slopes may be the primary groundwater reservoir within an alpine catchment. The aims of the contribution (subsurface structures, controlling factors of water-table dynamics, groundwater storage volume) are pointed out clearly, the references are relevant and up to date. The quantity of different data (GPR, ERT, seismic refraction, precipitation, snow, piezometers, soil moisture, runoff weir, infiltration, water chemistry) is quite impressive and valid for the targets of investigation. Data quality appears to be very good.

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However, there are some serious reservations about the validity of data interpretation, which may be summarised as follows:

GPR:

The pronounced reflection hyperbolas under the meadow should be removed by migration. It is somewhat mysterious that the occurrence of the hyperbolas should be exactly restricted to the meadow; I would suspect boulders on the lower parts of the talus, too. I suppose that the problem lies in scaling the GPR traces using their amplitude envelopes. Doing so, the weaker reflections under the meadow are amplified much stronger than those under the talus. Probably, that's why there seem to be no bouldertop reflections under the talus. If the "envelope" processing step would be left out, it might become clear that there is nothing much to see under the meadow because of strong attenuation. If this proves true, a "penetration depth of >20 m" would be nonsense.

The "average velocity [was] determined by analysing the normal moveout of reflections on several common-midpoint profiles". You should perform a semblance analysis instead to achieve a 1D profile of the velocity distribution at each CMP. This may (1) aid considerably in locating the talus base and (2) deliver surprisingly lower velocities in the deeper underground. A subsurface velocity of 0.12 m/ns is almost impossible under water-saturated conditions (p. 1551: "The water table observed in the soil pit was within 0.1–0.2m of the ground surface"). You assume a porosity of 0.6 (p. 1553); taking a fully saturated water content of 60% as a base, the dielectric constant would be c. 53.5 according to the Topp formula, which corresponds to a EM velocity of 0.041 m/ns (!!). 100 or 200 MHz antennas would have been the better choice regarding the shallow sediment depth (which is, of course, not a fair comment because you couldn't know in advance).

ERT:

The resistivities of > 20 k $\Omega$ m under the meadow (ERT2) are definitely too high for

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water-saturated bedrock. Furthermore, it is totally unclear why the bedrock should be high-resistive under the meadow (up to 60 k $\Omega$ m) and only 5-10 k $\Omega$ m under the talus. The 20-60 k $\Omega$ m zone is spatially restricted. I would suggest a boulder fall deposit with large interstices (which would also, partly, account for the strong hyperbolic GPR reflections). Or would relictic permafrost at the talus foot be an option? The position would be a typical one (see publications of Lambiel et al. and also the cited Sass 2006 paper).

#### Seismic refraction:

You mention two distinct velocity phases: "1) a slow shallow phase with velocities of around 500 m/s associated with the talus cover and 2) a faster deeper phase with velocities of around 3500 m/s indicating a change to higher velocity bedrock". From my point of view, these velocity phases are not "distinct" and I can't see the deeper phase with c. 3500 m/s. There are only few areas with such high velocities and these are at a depth of >10 m (!). Thus, if you say that "a layer of higher velocities predominantly between 2000 and 4000m/s [...] corresponds to the region of bedrock", this is not true. On p. 1549 line 19 you say that the model of sediment thickness was derived "by using our interpretations of the GPR and ERT profiles". You simply choose to leave out the seismic interpretation (which doesn't really fit) without giving an explanation. I don't see a reason to mistrust these data.

#### Combined interpretation:

Thus, all three geophysical methods point to a deeper position of the bedrock surface. If you used a considerably lower GPR wave velocity for the meadow (derived from full-fledged CMP analysis) and re-interpreted the ERT sections, it might turn out that the bedrock surface lies considerably deeper ( $\approx$ 10 m rather than  $\approx$ 3 m), which would match the seismic data. Please check the validity of your conclusions carefully considering these points. Maybe I'm wrong because I don't have the original data for further evaluation, but you should treat these points with caution.

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## Interactive Comment

The validity of the hydrology conclusions is not severely affected by the above reservations. The conceptual model is very good. Runoff is governed by drainage of the uppermost few decimeters of the subsurface, the deeper parts are partly dammed by the bedrock ridge. Thus, the meadow basin might well be much deeper without any effect on your hydrological data.

### Specific comments:

p. 1538, line 23: "the common occurrence of alpine meadows in the areas between talus and stream channels" - you should reword this section as this is probably a specific situation in your study area. Talus slopes may also verge directly on a stream, or can be totally decoupled and far away from the next channel.

### Technical comments:

Figure 2: Fig 2 a is the most informative sub-figure; if possible, it should be enlarged. Same is valid for 2 b which is definitely too small. Maybe you should split in two figures.

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