Hydrol. Earth Syst. Sci. Discuss., 12, C126–C132, 2015
www.hydrol-earth-syst-sci-discuss.net/12/C126/2015/

Hydrology and Earth System Sciences
Discussions

Interactive comment on "How effective is river restoration in re-establishing groundwater – surface water interactions? – A case study" *by* A.-M. Kurth et al.

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Received and published: 11 February 2015

Dear Dr. Walther Thank you for your thorough review and your interesting comments. In the following I will address your remarks according to your list. General Comments 1) The manuscript was checked by a native speaker. However, we'll ask him to specifically check the grammar of the manuscript again. 2) In the revised version of the manuscript we'll include a definition of what we mean by the term "temperature profile". It might be helpful if we changed the term to "longitudinal/horizontal temperature profile". Specific Comments Abstract 3) P 1094, line 1: the sentence seems to be misleading and, consequently, will be shortened to "In this study, we investigated whether

river restoration was successful in re-establishing groundwater-surface water interactions in a degraded urban stream." 4) P. 1094, line 7: the term "(near-) natural" will be omitted from this sentence: "... and in two reference streams.", as the nature of the reference streams is described in more detail in the Materials and Methods section of the manuscript. Introduction 5) P. 1095, line 29: Groundwater-surface water interactions may only be re-established in streams in which groundwater and surface water were originally connected prior to anthropogenic interference. In naturally occurring disconnected streams river restoration might shortly connect the stream by e.g. removing clogging layers from the stream bed. The sentence will be adapted to read "We define hydrogeological success as an increase in vertical connectivity along the restored site of the stream. This will be indicated by an increase in groundwater-surface water interactions, provided that groundwater and surface water were connected prior to anthropogenic interference.", or something to that effect. Materials and Methods 6) Page 1096, line 23: a line break will be inserted 7) Page 1096, line 25: In spite of the hydropower production 5 km upstream the investigated section of the Urbach has a near-natural flow- and sediment transport regime and a natural river morphology. This is due to the extensive intermediate catchment (Zwischeneinzugsgebiet) between the retaining lake and the investigated section of the Urbach. 8) Page 1097, line 3: the sentence will be changed to "Although having been lowered and straightened has led to a rather uniform stream width, the Röthenbach still has a naturally varying water depth and flow velocities." 9) Page 1097, line 7: Hydrogeology unites surface water and groundwater bodies, as they cannot be viewed as separate entities, except in disconnected settings. However, the sentence seems to be misleading and therefore will be changed to "Nevertheless, due to initial investigations of the water temperature distribution in the stream, groundwater-surface water interaction in the Röthenbach were assumed to be near-natural in winter." 10) Page 1097, line 9: the Chriesbach was widened and restructured. Nonetheless, a map would not show these alterations. However, there are sketches of a small section of the investigated Chriesbach section before and after restoration. They will be added to the manuscript. 11) Page 1097, section 2.2: The accuracies of the DTS instruments in our experiments were 0.5 °C for the Agilent DTS instrument and 0.1 °C for the Oryx DTS instrument. Post-measurement calibration with reference temperature measurements improved the accuracy of the Agilent DTS measurements to 0.1 °C. The Agilent DTS instrument shows a very slight drift, which was corrected in the post-measurement corrections as well. As is stated in line 13, a very narrow temperature range was selected to remove any temperature effects, such as a comparably faster cooling in colder sections of the cable (presumably due to the colder temperature of the subsurface surrounding the cable). DTS method and experimental set-up were separated, to make a clear distinction between the introduction to DTS technology and the DTS settings employed in the field. However, the description of the cooling rate calculation belongs into the experimental section and will be moved accordingly. 12) Page 1098, section 2.3: a detailed description of the Rn measurements is provided in the experimental section (page 1100, line 6 ff). 13) Page 1099, section 2.4: The blue marking of the test locations on the map was the optimum highlighting of the test sites, as a clearer highlighting, e.g. by encircling the test sites, covered too much of the map and rendered it difficult to read. However, we will experiment with the colour of the marking. The water flow velocities in all investigated streams were too high to allow for sediment settling on the cable. However, in the Chriesbach, algae accumulated at the section of the cable where a reference logger was affixed to the cable. As the cable was regularly checked during the measurement, accumulating debris was noticed. If it should go unnoticed, it would be noticed at the latest during the removal of the cable. 14) Page 1099, line 24: the voltage applied was 48 V, the amperage 10 A; with a resistivity of 4.58 Ohm per 203 m the power applied was 2.48 W/m. For clarification, the power applied will be stated in the experimental section as well. 15) Page 1099/1100: The meadows surrounding the drainage ditch were waterlogged at the day of the measurement. The drainage ditch drained these waterlogged meadows, and thus it was concluded that the water temperature of the drainage ditch was similar to the local groundwater temperature (unless the drainage ditch was in full sunshine). As the water depth in the drainage ditch was below 5 cm, full exposure

to sunshine might have a significant effect on the water temperature. Here, the effect was about 3.5 °C around noon, warming the water from 8 °C to about 10.5 °C. The mentioned 11.4 °C refers to the groundwater temperature in the piezometers next to the Chriesbach, not the Urbach. Results 16) Page 1101, line 7ff: the cable was regularly checked during measurements (at daytime), i.e. exposure to sunlight or air was noticed and, if possible, the issue removed. The measurements in the Urbach are, with exception of (as stated) the side channel (exposure to sunlight), still significant. The exposure to sunlight is already visible in the data plots as warmer water temperatures. Unfortunately, all outdoor (and indoor) experiments are affected by climatic conditions. The data is, nevertheless, conclusive. 17) Page 1101, line 26ff: The "anomaly" was a slightly lower water temperature, which might have been caused by a locally lower water depth, i.e. shallower water. 18) Page 1102, line 10: the variations in subsurface temperature mainly correlate with the cable depth. Here, a greater depth causes a larger dampening of the temperature signal (conduction), and higher advection causes a lower dampening of the temperature signal. In order to circumvent the issue with cable depth, and therefore variations in the cable temperature (correlating to the cooling rates), the cooling rates were compared in a narrow temperature range (please see above). 19) Page 1102, line 15: Heating data has shown, that the warmer the cable the stronger the heating. If this effect was due to higher advection, the water temperature would be warmer (i.e. closer to the surface water temperature), but, due to the higher advection the cable would heat more slowly. Hence, the effect would be high advection/high water temperature/slow heating, instead of high water temperature/faster heating. Yes, temperature changes are conventionally given in K. These temperature changes were accidentally overlooked. Discussion 20) Page 1103, line 5: "unfolding its full potential" describes a situation, in which the ecosystem can achieve as much as possible, i.e. ideally a near-natural state. 21) Page 1104, line 2: as stated in the results (page 1101, line 27ff) these zones refer to cable sections 199 m and 273 m. In the other sections groundwater infiltration might have occurred, but in volumes so low that the surface water temperature was not changed significantly (e.g. by 2 K). As stated above, this lower surface water temperature was induced by a shallower water depth. On the days of the measurement, the groundwater infiltration was visible (it could be seen bubbling up to the surface). As there is no piezometer close to the investigated section of the stream, no data with respect to groundwater levels are available. 22) Page 1104, line 29: the Chriesbach drains swampy meadows further upstream, i.e. it must be influent in these sections. Our Rn-data indicated that the section just upstream of the restored site may be influent, given that the groundwater level is high enough (i.e. there is a migration of the groundwater infiltration zone up and down the Chriesbach). However, as these results could not be verified in a second measurement campaign, this is just a speculation. Unfortunately, there are no data available with respect to water depth or flow velocities. With exception of the unrestored Chriesbach, the water depth varied strongly over the investigated sections of the various streams. 23) Page 1105, line 4ff: the Rn-activity in groundwater is generally significantly higher than in surface water, due to rapid degassing of Rn in the surface water. Hence, a very low activity in the surface water indicates that no groundwater is infiltrating in the sample locations. The increase of Rn activity in the groundwater with increasing distance from the Chriesbach indicates that the Chriesbach is a losing stream. The higher Rn activity further upstream in the unrestored section indicates that, at the time of the measurement, groundwater was infiltrating at this section. However, the results could not be verified in the second measurement campaign. This might have been due to higher groundwater levels during the first sampling campaign (influent conditions), and lower groundwater levels during the second sampling campaign (effluent conditions) (please see above). At the cable section 195 m in the Chriesbach the cooling rate of the cable was significantly higher than in the other sections. This indicates a significantly higher flow over the cable compared to the other sections. As the Chriesbach is effluent in this section a significantly higher volume of surface water seems to be infiltrating there. The elevated subsurface temperatures were due to the gravel bank being exposed to the sun all day (it was a very sunny and hot day). However, this has no effect as to the cooling rates, as these were investigated at night and the cooling rates were compared

in a very narrow temperature range (see above). The cable was inserted into the gravel bank – from tip to end. The elevated subsurface temperatures were measured in the central part of the gravel bank, not the tip. 24) Section 4: As stated two sentences previously, this paragraph refers to the Chriesbach. All streams are dealt with consecutively, following the structure of the results part. Conclusions 25) Page 1105, line 17: the sentence will be split. 26) Page 1105, line 24: your interpretation is correct: the highest cooling rate was seen at the tip of the gravel island, which indicates the highest flow of water over the cable. Hence, the highest surface water infiltration (as the Chriesbach is effluent and the cable buried) occurs at the tip of the gravel island. No such high value was seen in any other section of the cable. Before the restoration of the Chriesbach there had been no gravel islands. During river restoration gravel islands were installed. After river restoration, the highest surface water infiltration was seen at the tip of the gravel island. Ergo, the installation of the gravel island has enhanced the surface water infiltration. This might be due to (1) the higher permeability of the gravel, compared to the fine sand of the stream bed, and (2) the water directly hitting the tip of the gravel island, pushing the water into it. 27) Page 1106, line 8ff: the cost of the system largely depends on the DTS instrument, which is the most expensive component of the ADTS system. 28) Table 1: further away from the stream is ca. 2.5 m. There is, of course, no "negative" Rn activity. The error is calculated based on the variance of the Rn activities. As they are based on natural decay products the variance can be higher than the actual Rn activity. 29) Figure 1: BAFU is the Swiss environment agency. Copyright is acknowledged. The map does not include a scale, but the size of Switzerland is about 220 km x 348 km. All maps are shown with North to the top. Unfortunately, the resolution of the figures is maximal and cannot be increased. 30) Figure 2: the cable is installed backwards, i.e. the end, e.g. 504 m, is pulled from the cable drum and installed at the far end of the investigated section. As the investigated sections may be shorter than the total cable length, a rest of the cable is on the cable drum. Hence, the section of the cable installed at the beginning of the investigated section of the stream might start with, e.g. 214 m. Unfortunately, I don't know to which grey shading you are referring. Maybe this was due to printing? The line diagram with the groundwater temperature is easier to interpret than one straight coloured line would be. The colour plot is formed by stacking the single measurements on top of each other. Thereby, each measurement is one straight line, with different colours defining the temperature. The damage to the cable only happened at a specific time. Hence, the damage was not there before. 31) Figure 4: yes, the side channel is connected to the drainage ditch, which is connected to the main channel. The sections between the black bars are proper measurements. However, as they are in the transition zones between the side and main channel and the drainage ditch, these sections were excluded. “Blacking out” these zones might clarify the data. 32) Figure 6: The second line is the groundwater temperature. The description was accidentally not included in the caption. 33) Figures 2 – 6: unfortunately, there is a maximum of 10 colours that are easily distinguishable. Thus, a uniform temperature scale would require a temperature resolution of about 2 °C, which is by far too large. However, the passive Chriesbach data has the same temperature scale. Plotting selected areas in the left-hand figure might be interesting, but would crowd the figure and render it confusing. Additionally, we wanted a clear distinction between the actual temperature measurements and the references. The DTS method (active/passive) will be added to the captions. The air temperature supports the understanding of the surface water temperature distribution. Unfortunately, for the interpretation of the exchange between ground- and surface water a normalised plot with the air/water temperature difference will not be conclusive.

I hope to have answered your questions to your full satisfaction. Kind regards Anne-Marie Kurth

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Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 12, 1093, 2015.