Interactive comment on “Riverbank filtration for treatment of highly turbid Colombian rivers” by J. P. Gutiérrez et al.

Response to Anonymous Referee #3

Thank you for your comments to improve our manuscript.
The suggestions made by the reviewer were considered, and the respective changes were applied to the manuscript as follows:

1. The abstract needs to be revised to give brief highlights of all the findings discussed in this review not just limited to suspended solid removal.

The abstract was modified as suggested by the reviewer.

The poor water quality of many Colombian surface waters, forces for seeking alternative, sustainable treatment solutions with the ability to manage peak pollution events and to guarantee an uninterrupted provision of safe drinking water to the population. This review assesses the potential of using riverbank filtration (RBF) for the highly turbid and contaminated waters in Colombia emphasizing on water quality improvement and the influence of clogging by suspended solids. The suspended sediments may be favorable in the improvement of the water quality, but may reduce the production yield capacity. The cake layer must be balanced by scouring in order for an RBF system to be sustainable. The infiltration rate must remain high enough throughout the river-aquifer interface in order to provide the water quantity needed, and the residence time of the contaminants must be enough to ensure an adequate water quality. In general, RBF seems to be a technology appropriate for use in highly turbid and contaminated surface rivers in Colombia, where improvements due to the removal of turbidity, and pathogens, and to a lesser extent inorganics, organic matter and micro-pollutants are expected. RBF has the potential to mitigate shock loads thus leading to the prevention of shutdowns of surface water treatment plants. In addition, RBF, as an alternative pre-treatment step, may provide an important reduction of chemicals’ consumption, considerably simplifying the operation of the existing treatment processes. However, clogging and self-cleansing issues must be studied deeper in the context of these highly turbid waters, evaluating the potential loss of abstraction capacity yield as well as the development of different redox zones for efficient contaminant removal.

2. P4, 11-15 the sentence reports that heavy metals are mainly removed through ion exchange, is it that extensive as reported and what exactly could be possible for this property (which part of the filter bed does this occurs). I understand the bed is mainly made of sand which mainly utilizes size exclusion as a removal mechanism.

R/ Additional information was included in order to make it clearer to the reader. Therefore, the modified paragraph reads as follows:
“The removal of heavy metals from source water during subsurface passage mainly occurs by sorption, precipitation and ion exchange processes, which depend on the content of inorganic and organic compounds in the aquifer and contact time (Bourg et al., 1989; Hülshoff et al., 2009). Under aerobic conditions, heavy metals removal is mainly attributed to ion exchange processes

at negatively loaded surfaces (Schmidt et al., 2003). The presence of negatively charged surfaces (e.g. clayey and/or organic sediments) and amorphous ferric and alumina oxides provide exchange sites for binding trace heavy metals (Foster and Charlesworth, 1996; Salomons and Förstner, 1984). As contact time is a critical parameter affecting the fate of most heavy metals, the removal of such compounds by ion exchange processes mainly occurs in the hyporheic zone and the flow path between the river and the abstraction well (Hülshoff et al., 2009; Stuyfzand, 2011)."

3. How does variation in seasons influence the RBF performance and other influential factors such as clogging (due to high load of suspended solids). Do the authors have some information/comments on this?

R/ The paragraph in P7, lines 21-24 was completed in order to give a proper response to the reviewer´s question. Thus:
…Clogging has been identified as the major contributor to the long-term decay of RBF yield (Hubbs et al., 2007), but there is a lack of understanding of the exact factors that affect clogging (Caldwell, 2006; Hubbs et al., 2007; Schubert, 2006a; Stuyfzand et al., 2006). Hubbs et al. (2007) reported a decrease in the specific capacity of the wells up to 67% of its initial level in the first 4-year period of operation. Most of the reduction took place within the first year due to riverbed clogging in the vicinity of the well. Clogging is time dependent and is a function of bed material (Goldschneider et al., 2007; Rehg et al., 2005), content and composition of suspended load and transported bed load material (Bouwer, 2002; Holländer et al., 2005), and the shear forces (Hubbs, 2006b; Schubert, 2006b) scouring out the deposited material on the riverbed (Hubbs, 2006a; Mucha et al., 2006), which in turn are seasonally variable.

Generally, the suspended sediments load carried by the rivers during rainy season is higher than the found during dry season (Dunlop et al., 2008; Göransson et al., 2013); however, in regulated river systems seasonal variations in load does not always follow such a trend (Göransson et al., 2013). Shear forces are also seasonally variable, since these forces are a function of the water level (Hubbs, 2006b). As stated by Regnery et al. (2015), high discharge rates create higher flow velocities and shear stress, which usually result in higher infiltration rates indicating a lower degree of clogging. By contrast, low discharge rates commonly lead to an increase in pore clogging and then to a lower production yield of a RBF system.

4. P7, section 3.1. The reported clogging was is it only a function of the deposition of suspended colloidal matter? What about dissolved organic micro-molecules such as polysaccharides or extracellular polymeric substances?

R/ During the section 3.1 clogging has been attributed to several processes depending on the composition and size of the suspended matter. For instance, P7 line 25 to P8 line 4 reports clogging due to the presence of silt particles, biological growth (e.g. biomass and bacterially produced polysaccharides). The mentioned paragraph is cited below:

"Clogging can be caused by physical, chemical and biological processes, although physical clogging has been found to be the dominant mechanism over the other forms of clogging (Pavelic et al., 2011; Rinck-Pfeiffer et al., 2000). As water flows from the river and through the aquifer to the RBF system, the larger silt particles plug the pore channels to the aquifer in the riverbed and form a less permeable layer together with smaller particles (Grischek and Ray, 2009; Veličković, 2005). Tropical river conditions (temperature and nutrient loads) may be favorable for biological growth onto the riverbed, which might lead to biological clogging (Kim et al., 2010; Platzer and Mauch, 1997; Vandevivere et al., 1995). Rinck-Pfeiffer et al. (2000) reported biological clogging by biomass and bacterially produced polysaccharides in a simulated aquifer storage and recovery wells system, related to the high presence of nutrients. Hoffmann and Gunkel (2011) reported severe clogging mainly induced by biological processes in Lake Tegel reaching a depth of at least 10 cm"

5. Section 2.6 summarizes some interesting findings on micro pollutant removal, the discussion could have been clearer if the mechanisms of removal were also discussed because I don't believe size exclusion played a significant role in removal. Generally micro-pollutants are removed through three possible routes: charge interactions (electrostatic interactions), pollutant-substrate interactions (hydrophobic/hydrophilic interactions) and non-electrostatic interactions (acid-base interactions). Can the authors comment on this?

R/ The mechanisms of water quality improvement in RBF systems are described in section 2.1. In order to strengthen the information regarding to micro-pollutants removal, modifications in sections 1, 2.1 and 2.6 were conducted as follows:

Section 1, page 2, lines 15-18

"In addition, RBF has demonstrated an ability to decrease mutagenic compounds, including naproxen, gemfibrozil and ibuprofen (Hoppe-Jones et al., 2010; Schubert, 2003) and to remove organic and inorganic micro-pollutants, such as sulfamethoxazole and propranolol (Bertelkamp et al., 2014; Hamann et al., 2016; Schmidt et al., 2003). However, it has also been found that specific micro-pollutants such as carbamazepine and EDTA remain mobile, showing a persistent behavior even after 3.6 years of travel time (Hamann et al., 2016). The persistence is mainly driven by the very low reactive and sorptive characteristics of these compounds (Scheytt et al., 2006)."

Section 2.1, page 4, lines 19-22

"Micro-pollutants occur in most surface waters that run through heavily polluted regions or large industrial and agricultural areas. The fate of such substances in RBF systems is mainly determined by sorption mechanisms and biological transformations (Schmidt et al., 2003). During absorption, hydrophobic interactions occur between the aliphatic and aromatic groups of micro-pollutant and the membrane cells of the microorganisms. During adsorption, the negatively charged surfaces of the microorganisms and soil leads to electrostatic interactions of the positively charged micro-pollutants (Luo et al., 2014).

Extensive research in Germany has shown that these compounds may be removed to varying degrees, mainly depending on the properties of each compound (Schmidt et al., 2003). As stated by Schmidt et al. (2004), biodegradation of organic micro-pollutants is a function of the available organic carbon for energy production. The process of energy production is primarily based on redox reactions. The extent of biodegradation of an organic micro-pollutant is dependent on residence time and favorable redox conditions. Therefore, elimination rates of certain micro-pollutants vary depending on local geological and hydrochemical conditions and on organic loads of surface waters and infiltration zones (Schmidt et al., 2004)."

Section 2.6, page 6, lines 23-29

“Hamann et al. (2016) analyzed the fate of 29 micro-pollutant compounds in a RBF system considering a travel time up to 3.6 years, finding complete removal of 14 compounds (2-naphthalene sulfonate, 2,6-NDS, amidotrizoic acid, AMPA, aniline, bezafibrate, diclofenac, ibuprofen, iohexol, iomeprol, iopromide, ioxitalamic acid, metoprolol and sulfamethoxazol) due to retardation and degradation processes as supported from numerical modeling. In addition, some compounds were partially removed (triglyme, iopamidol, diglyme, 1,3,5-naphthalene trisulfonate, 1,3,6-naphthalene trisulfonate), with removal efficiencies ranging from approximately 60 to 90%, based on the highest concentrations measured in both the Lek River and observation well (906 m from river, 3.65 years travel time). Only 10 compounds were fully persistent during the subsurface passage in the RBF system (1,4-dioxan, 1,5-naphthalene disulfonate (1,5-NDS), 2-amino-1,5-NDS, 3-amino-1,5-NDS, AOX, carbamazepine, EDTA, MTBE, toluene and triphenylphosphine oxide). The authors do not differentiate between biodegradation and sorption; where adsorption, ion-pair formation and complexation of pollutants to the soil may lead to soil pollution (Bradl, 2004).”

6. The impressive removal of some micro-pollutants; could it have been due to the microbial degradation/microbial activity?

R/ Although Hamann et al. (2016) did not mention biodegradation processes, Bertelkamp et al. (2014) (page 7, line 1) and Schmidt et al. (2004) (added below in the response to question 7) stated the biodegradation as an important contributor to the removal of some micro-pollutants.

7. And if it is degradation, what intermediates/metabolites are formed? Did these studies determine the degradation products?

R/ The cited studies did not report any intermediate/metabolites formation. However, an additional reference is included at the end of section 2.6 (page 7, lines 1-7) reporting metabolites formation.

“…compounds listed before) were completely biodegraded. However, compounds such as atrazine and sulfamethoxazole were not removed in a 6-month period. Drewes et al. (2003) examined the fate of selected pharmaceuticals and personal care products during groundwater recharge, stating that the stimulants caffeine, diclofenac, ibuprofen, ketoprofen, naproxen, fenoproxen and gemfibrozil, were efficiently removed. However, the antiepilectics carbamazepine and primidone were not removed at all. Organic iodine was only partially removed. The formation of metabolites may be expected during organic micro-pollutant biodegradation, however, these have not been reported.

Schmidt et al. (2004) studied the fate of anthropogenic organic micro-pollutants comprising aminopolycarboxylates (EDTA, NTA, DTPA), aromatic sulfonates (2-aminonaphthalene-1,5-NDS, 1,3,6-naphthalene trisulfonate, 1,5-NDS, 1- naphthalene sulfonate, and 2-naphthalene sulfonate), pharmaceutical compounds (diclofenac, carbamazepine, bezafibrate and sulfamethoxazole), iodinated x-ray contrast media (iomeprol, amidotrizoic acid and iopamidol) and MTBE. Schmidt et al. (2004) found that sulfamethoxazole was primarily removed (20% removal efficiency) under anaerobic conditions (anaerobic aquifer), while only slightly reduced in the RBF system under aerobic conditions. The reduction in EDTA concentrations under aerobic conditions was higher than the achieved under denitrifying and anaerobic redox conditions. In addition, the EDTA concentrations in the filtrated water was higher than the measured in the surface water, concluding that the DTPA was partially biodegraded leading to the formation of EDTA as metabolite (Schmidt et al., 2004)."