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

Response to Anonymous Referee #1

First of all, thank you for your comments to the discussion of our manuscript.
The suggestions made by the reviewer were considered, and the respective changes were applied to the manuscript as follows:

Abstract

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 on the one hand be favorable in the improvement of the water quality mainly due to the strengthening of cake filtration and deep bed filtration processes. On the other hand, the formed cake layer must be balanced by scouring in order for an RBF system to be sustainable without loss of hydraulic capacity. 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. RBF may be considered as a feasible option to solve water quality changes at a larger scale. 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.

Introduction

- P2, 16 authors ought to give examples of the 'mutagenic compounds' and 'certain organic and inorganic micropollutants' being referred to here. This is a review article, there is no need to speculate. What are the reported removal efficiencies of the 'mutagenic compounds' and 'certain organic and inorganic micropollutants' by riverbank filtration?
R/ "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)."

- P2, 17 which are some of these 'specific micropollutants that remain mobile, and why?

R/ "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)."

- P2, 20-21 what is the feasibility of using riverbank filtration as a pretreatment method considering rate of productivity and travel time of water along flow paths?

R/ "Although RBF has shown to be highly effective in the removal of many contaminants, it must mainly be considered as a pre-treatment method, which needs to be combined with a certain post-treatment (Cady et al., 2013; Dash et al., 2008; Kuehn and Mueller, 2000; Singh et al., 2010). A balance between the water quality and the production capacity must be considered, where greater removal efficiencies are achieved by increasing travel distances, but decreasing the rate of productivity."

- P2, 24-25 how high were the reported turbidity values? There is need for actual figures here. What do authors mean by 'contamination events'?

R/ "However, in the last decades, turbidity and contamination events in surface waters have become a serious concern in Colombia for guaranteeing safe drinking water (Gutiérrez et al., 2016; Universidad del Valle and UNESCO-IHE, 2008). Fast urbanization, the lack of integration between water management and spatial planning, and inappropriate land use are identified as the main causes for the progressive deterioration of the surface water (IDEAM, 2015; van der Kerk, 2011; Universidad del Valle and UNESCO-IHE, 2008). Figure 2 illustrates the monthly turbidity variation in percentiles in the Cauca River (Cali, Colombia) for years 2008-2013 (EMCALI, personal communication, August 21, 2015). High turbidity events in the Cauca River lead to the intake shutdowns in the main water treatment plant (Puerto Mallarino WTP) of the city of Cali, reporting turbidity peaks up to 10,000 NTU (Figure 2). The decrease in the DO concentrations in the Cauca River is used as an indicator of high pollution peaks. It typically drops after heavy rainfalls with the increase of organic matter concentrations (CVC and Universidad del Valle, 2004)."

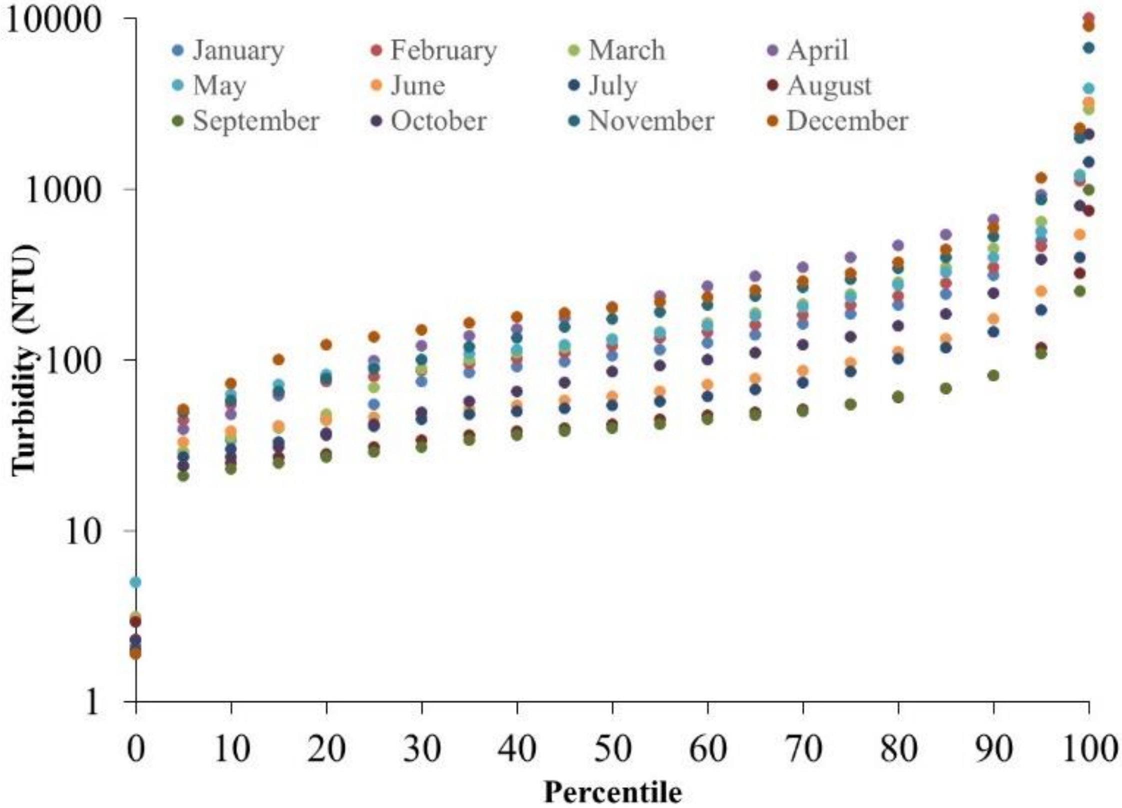

Figure 2. Turbidity percentile values in Cauca River, Colombia, during years 2008-2013

- P6, 23-25 out of 247 micro-pollutants only 14 were completely removed, what were the removal efficiencies of the remaining ones?. What were the chances of the 14 compounds reported to have been completely removed undergoing transformations and forming degradates? 3.6 years looks like a longer period considering increased demand for water of good quality and quantity? How about adsorption and complexation of the pollutants to the soil along flow paths which could result into soil pollution and groundwaters at the expense of purifying surface water using riverbank filtration. Consider investigating chances of creating another problem at the expense of solving other problems

R/ As stated by Hamann et al. (2016), 247 micro-pollutants were analyzed during 14 years, but only 29 were selected for the detailed fate analysis due to different reasons explained by the authors in the manuscript. Considering that, the sentence was reworded to make it clearer to the reader. All the comments made by the reviewer were considered and included, as follows: “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)."

Discussion

- Table 1-What were the chances of using one sample of water to compare the maximum turbidity levels in Source water and river bank filtration system? Was there any relationship between orientation, slope, type of soil within the riverbanks, travel time and turbidity removal percentages? What other factors need to be carefully considered in order to improve efficiency and productivity of the riverbank filtration systems.
R/ The Table 1 was built based on secondary information. The turbidity removal percentages presented were computed from the maximum turbidity values reported in both surface and bank filtered water, considering that the authors intended to show the behavior of RBF under critical conditions such as suspended sediments content (expressed as turbidity). In order to improve the Table 1, travel time and aquifer material were included. Other factors were considered such as slope and streambed material; however, that information was not reported in the cited articles.

Hence, the reviewer comments were considered in the Table 1 and the paragraph as follows:

"The RBF system configuration (i.e. vertical, horizontal) does not govern the suspended solids removal efficiency as observed in Table 1, since it is not a function of the travel/contact time. The texture of the streambed, however, influences the media clogging (Hubbs et al., 2007; Stuyfzand et al., 2006), where external clogging (cake layer formation) enhances the removal capacity of fine sediments contained in the water (Veličković, 2005). The removal efficiency of suspended solids is concentration dependent (Fallah et al., 2012; Thakur and Ojha, 2010); the higher the suspended solids concentration, the faster the cake formation and therefore the higher the turbidity removal capacity. Although, no studies have quantified the role of concentration on entrapment, the critical particle concentration where the porous media gets clogged has been determined to be dependent on the ratio of void size to particle size (Sen and Khilar, 2006). As reported by Sen and Khilar (2006), the critical particle concentration increased from 0.35% to 9% when the ratio of bead size to particle size was increased from 12 to 40. Therefore, the removal efficiency of suspended solids is a function of both the filtering media characteristics (streambed and particle sizes of the aquifer), and the water quality in terms of suspended particle size and concentration"

Table 1: Turbidity removal at bank filtration sites with highly turbid raw water sources

Bank filtration site	Pant Dweep Island at Haridwar, India (Dash et al., 2010) (Thakur and Ojha, 2010)	Indiana-American Water at Jeffersonville, USA (Weiss et al., 2005)	Indiana-American Water at Terre Haute, USA (Weiss et al., 2005)	Missouri-American Water at Parkville, USA (Weiss et al., 2005)	Louisville at Kentucky, USA (Wang, 2003)

Distance from source water V: vertical H: horizontal	320 m (V) 108 m (V)	177 m (V) 30 m (V)	24 m (H) 122 m (V)	37 m (V) 37 m (V)	23 (V) 24 (H)
Travel time (d)	420-510 32.5	13-19 3-5	NA	NA	2-5
Source water (maximum turbidity, NTU)	200 2,500	661	1,761	1,521	599
Bank filtration system (maximum turbidity, NTU)	0.6 --	1.1 1.5	0.27 0.41	3.8 2.7	±0.8 0.69
Turbidity removal (%)	99.7 ±99.9	99.83 99.77	99.98 99.98	99.75 99.82	±99.8 99.88
Aquifer material	Sand, clayey and silty sands	Clay, fine and medium sands, coarse gravels	Medium and fine sands underlain by coarser sand and gravel	Fine to coarse sand, gravel, and boulder deposits with intermixed layers of clay and silt overlying consolidated shale and limestone	Sand and gravel with silt and clay

NA – Not available

- P10, 29 very good point, but are there any suggestions to that effect? What is the relationship between the removal period/residence time of contaminants by river bank filtration and sustainability considering the ever increasing demand for water worldwide? Is riverbank filtration a feasible option to solve water quality changes at a larger scale?
R/ To give response to the reviewer´s comments, the paragraph was reworded as follows: "Finally, in the design of a RBF system, a balance between the water quality and the production capacity must be sought. Greater removal efficiencies may be achieved with increased travel distances (residence time), yet there is an inevitable trade-off between the ability to supply large flows and the decreased water quality in the abstraction wells. The longer the travel distance the higher fraction of groundwater extracted from storage in the aquifer; and therefore, the lower the extraction capacity of the system (de Vet et al., 2010). For a 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. Nonetheless, even with shorter residence times, the abstracted water will have better characteristics than the raw water, making further treatment steps such as coagulation, flocculation and sedimentation redundant. Therefore, RBF may be considered as a feasible option to solve water quality changes at a larger scale."

- How does use of riverbank filtration (whose efficiency is site and substance specific) compare with other equally important methods of water purification such as use of sand filtration, activated carbon etc that are used in the treatment of highly turbid and polluted waters? There is need for a discussion and comparative assessment on the productivity/production capacity and performance of the riverbank filtration method versus other methods in removal of turbidity,

organic and inorganic compounds, otherwise making conclusions out of this consideration is somehow questionable.
R/ A paragraph describing the problem in using conventional WTPs in Colombia and a comparative assessment of combinations of trains has been included as follows:

As stated by Gutiérrez et al. (2016), in Colombian WTPs the operation and maintenance and sludge disposal are the main processes leading to costly water production. The costs are linked to chemical usage, sludge production and its treatment. A brief comparison of robust drinking water technologies in removal of turbidity, pathogens and the chemical contaminants discussed during this review is realized based on the analysis conducted by Hubbs et al. (2003) and Ray and Jain (2011). Slow sand filtration, with pre-treatment, is mainly suitable for small to medium sized communities, whereas RBF and conventional WTP can be suitable for small to very large communities (Ray and Jain, 2011). RBF is suitable for highly contaminated rivers, able to match conventional treatments including advanced technologies such as ozone, ultraviolet light or granular activated carbon for pesticides' removal. Although using a conventional train such as coagulation – sedimentation – filtration – activated carbon filtration – disinfection (O_3/UV/H_2O_2/Cl_2) and an alternative train such as RBF – aeration – filtration – activated carbon filtration – disinfection (O_3/UV/H_2O_2/Cl_2) may produce similar water qualities, there are differences in the production costs. The use of RBF leads to savings of chemical dosing, sludge handling and filter backwashing. As reported by Sharma and Amy (2009), the conversion from a conventional WTP to a process including a RBF system may reduce the operational costs up to 50%. Moreover, the sedimentation step may be skipped, and advanced removal of pathogens is no longer needed. As reported by Dusseldorp (2013), after anaerobic river bank filtrate is extracted in a WTP train in the Netherlands, water is pre-treated with reverse osmosis prior to conventional treatment steps of sand filtration, granular activated carbon and UV disinfection, in order to use in combination with membrane filtration avoiding ultrafiltration and biofouling. RBF has the advantage over the other assessed technologies of dampening shock loads and peaks, which is a need in rivers with extreme variable water qualities such as the Colombian rivers (e.g. Cauca River, Figure 2).