Interactive comment on “Accumulation and modeling of particles in drinking water pipe fittings” by K. Neilands et al.

Reply to 2nd referee by K.Neilands and J. Rubulis

We thank the referee for the comments.

It should be noted that strong changes in the turbidity pattern of a pipe flushing may have also other important reasons beside the presence of pipe fittings. The most important one is that deposits are non-uniformly distributed within the network. If, for instance, two pipes with very different geometries or hydraulic conditions are connected with each other and are cleaned in a single flushing step, strong variation may occur around the pipe connection.

Agree, these factors are considered, different shear stresses in different diameters, pipe reduction and diameter change is also considered as fitting and need J coefficient.

Additionally, strong gradients in the distribution of deposits over the pipe length may be observed for pipes daily operated with low flow velocities. Potentially, deposit peaks due to fittings (especially T-pieces at pipe connections or crosses) and general deposit formation behavior may overlap respectively superpose.

Answer – we agree with the comment that strong changes in the turbidity pattern of a pipe flushing may have be theoretically due to significant increase of water consumption in upstream of hydrant. There are efforts to model effect of hydraulic transients (represented as the unsteady shear stress) by Asopou et al., 2010. Other factor which can be related with turbidity spikes is particles accumulated within standpipe of hydrant however executing flushing with care these particles can be withdrawn out from system and data can be discounted from online turbidity meter. While other factors which can influence logarithmic/non-logarithmic decreases of turbidity (i.e. uniform/non-uniform distribution of particles) within first turnover using the UDF principle is not known. Thus explanation of turbidity spikes is still indefinite.

To show logarithmic decreases of turbidity we added two examples (Fig.1-4) where no fittings within flushed section was observed.

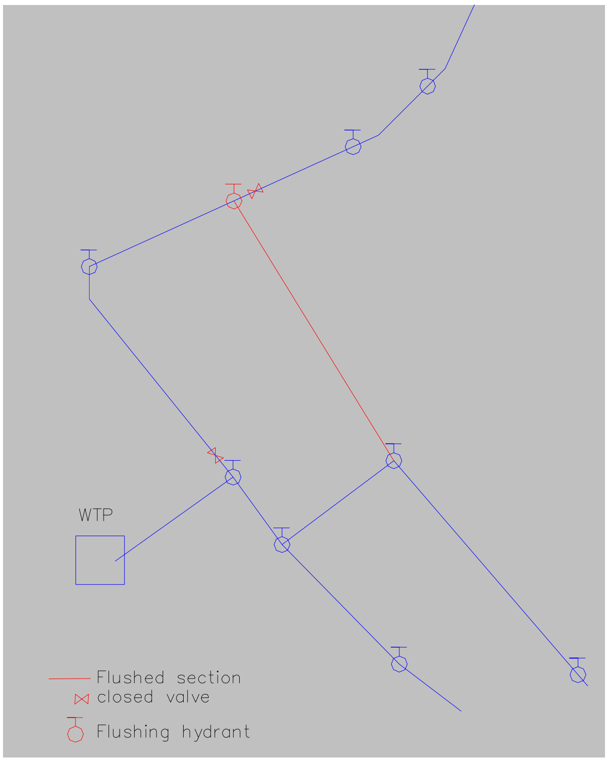

Figure 1. Simple system from PE pipes, red section is closed DN 100 mm, so its “dead end”, completely straight, without pipe fittings. In this situation pipes are 3 years old so cohesive layer should be already formed. Flushing is made by shears stress 2,4 N/m2.

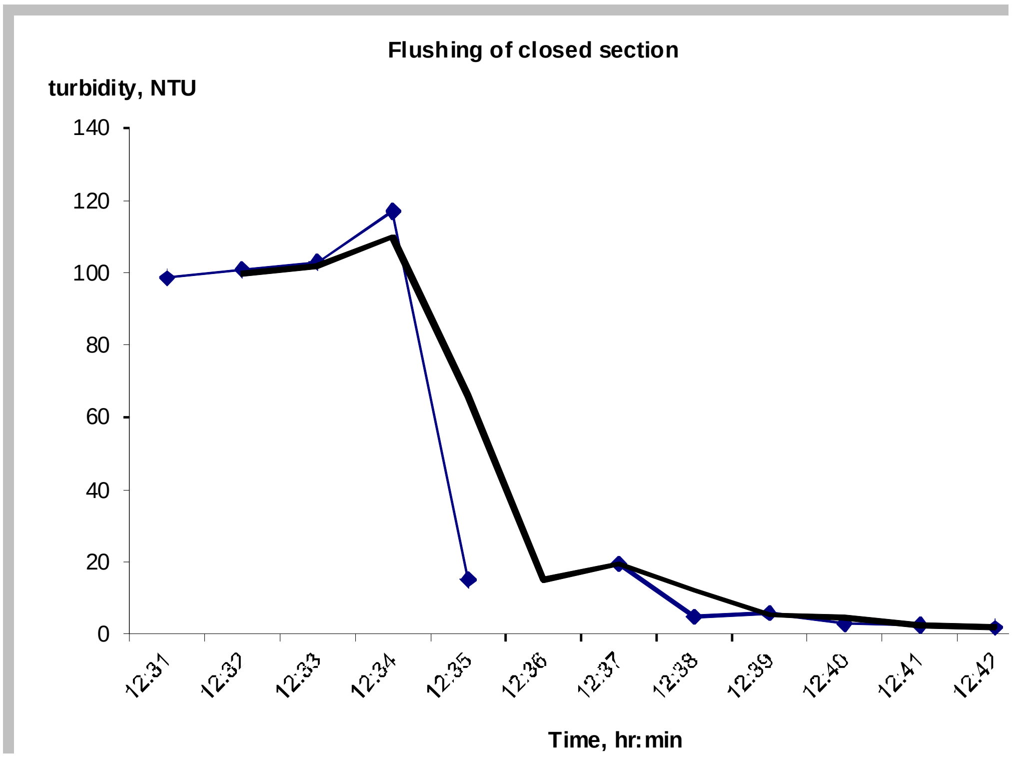

Figure 2. Turbidity curve of flushed closed section shows steady level until clear front is reached.

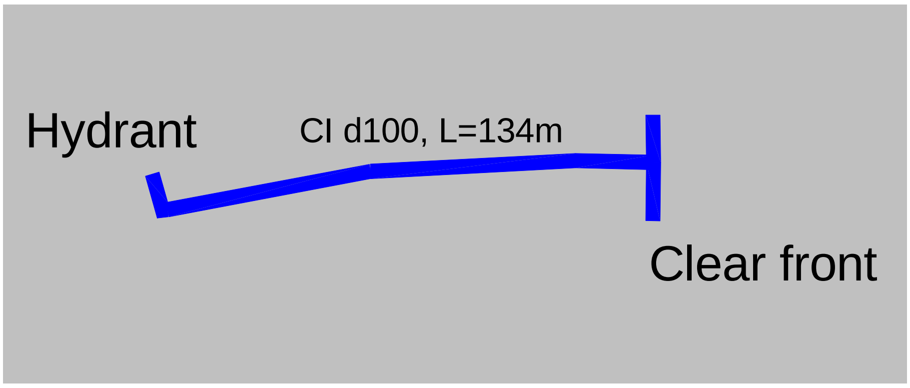

Figure 3. Case study from Adazi municipality (one of the 67 isolated sections mentioned paragraph 3.1in publication) Flushing hydrant is on complete dead-end section, about 20 years old cast iron DN100 pipe. Flushing performed with shear stress 1,84 N/m2. This section is without pipe fittings.

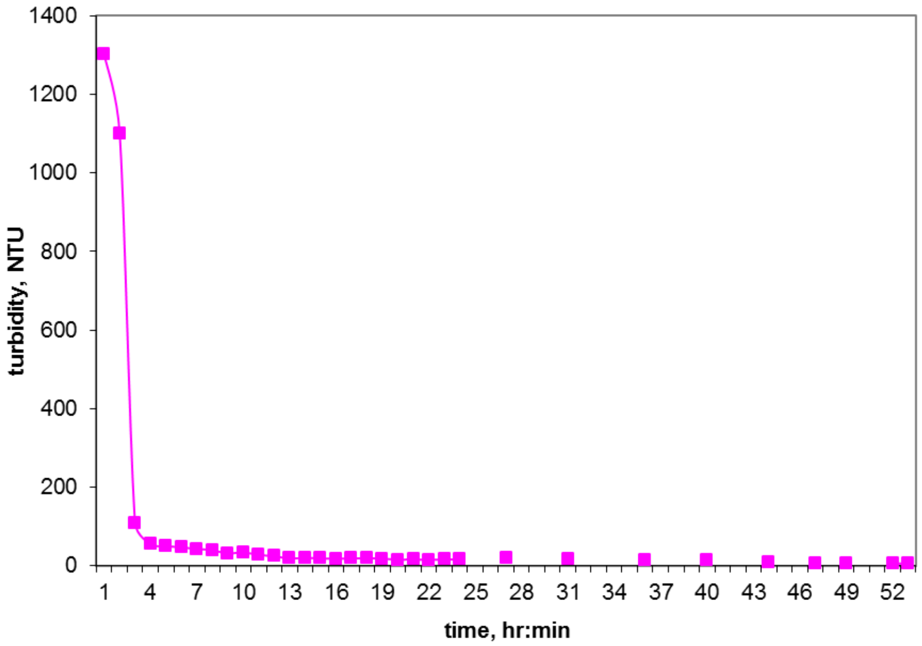

Figure 4. Turbidity curve for dead-end section. In the beginning turbidity is very high, but it drops when clear front is reached turbidity drops and after that stays steady without pikes, that means, although there is clear front, layer is not uniformly distributed

To show the obvious influence of pipe fittings on particle accumulation and to emphasize the reproducibility of the work we used results from (Rubulis and Neilands, 2010) flushing of one section (Figure 5.) twice within 6 months (Figure 6.-7.)

, where turbidity curve shows similar tendency only with lower NTU units.

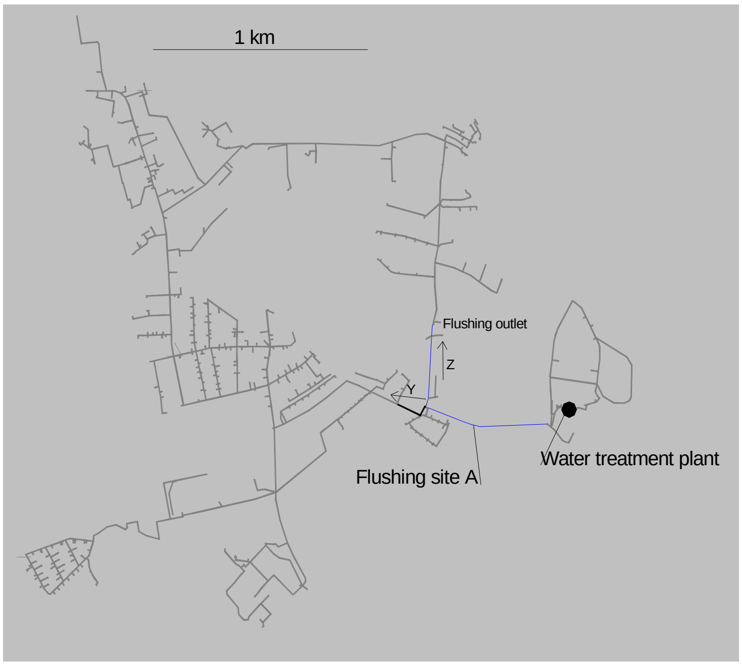

Figure 5. The part of drinking water distribution network Cases study Adazi municipality where relevant for further description, the section A appointed with bolder line (Reproduced from(Rubulis and Neilands, 2010) .

Flushing site A was examined twice in period of 5 months. The total length of cleaned section was of 1358 m and it consists from 300 and 200 mm of CI pipe. Turbidity curve (Figure 6.) showed three significant peaks where two of them corresponded to tee with reduction to outlet chamber (indicated as No 1) and straight tee with taper (No 2) where flushing stream turns from 300 to 200 mm of CI pipe (Figure 5). The last and insignificant peak corresponds to the clear water front (No 3). After clear front was reached the drop of turbidity was much slower. This can be explained with decrease in velocity (0.2 m/sec) or shear stress in 300 mm CI pipe compared to 200 mm (0.46 m/sec).

The same section was flushed after 5 months and the turbidity (Figure 7) was much lower (max 28 NTU) compared to first flushing trial (max 72 NTU), while the trend of curve is quite similar.

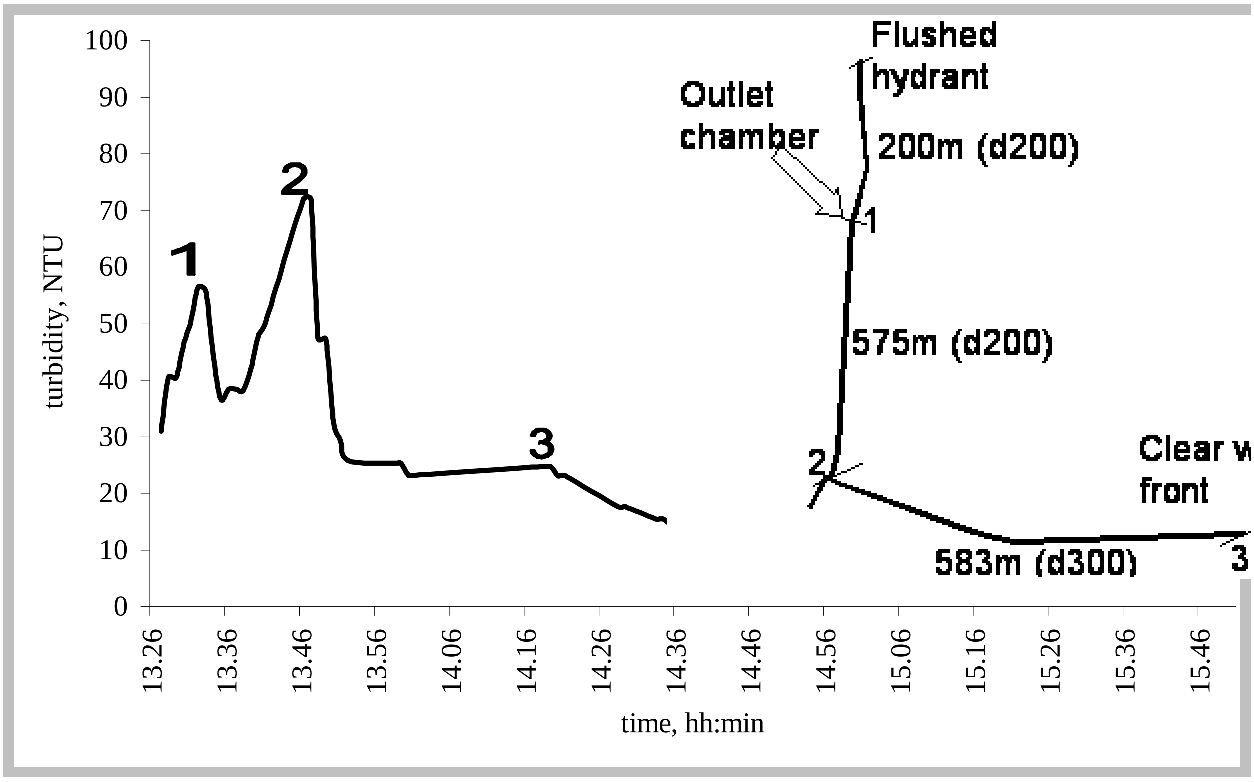

Figure 6. Turbidity curve for flushing site A and the CI pipe layout with indicated clear water front (Nr.3.), flushed hydrant where the measurements were made and the length of each section. With No 1 is the tee with reduction for outlet chamber and No 2 is the straight tee of 300 mm with taper on left to 200 mm. In brackets the diameters in mm is shown.

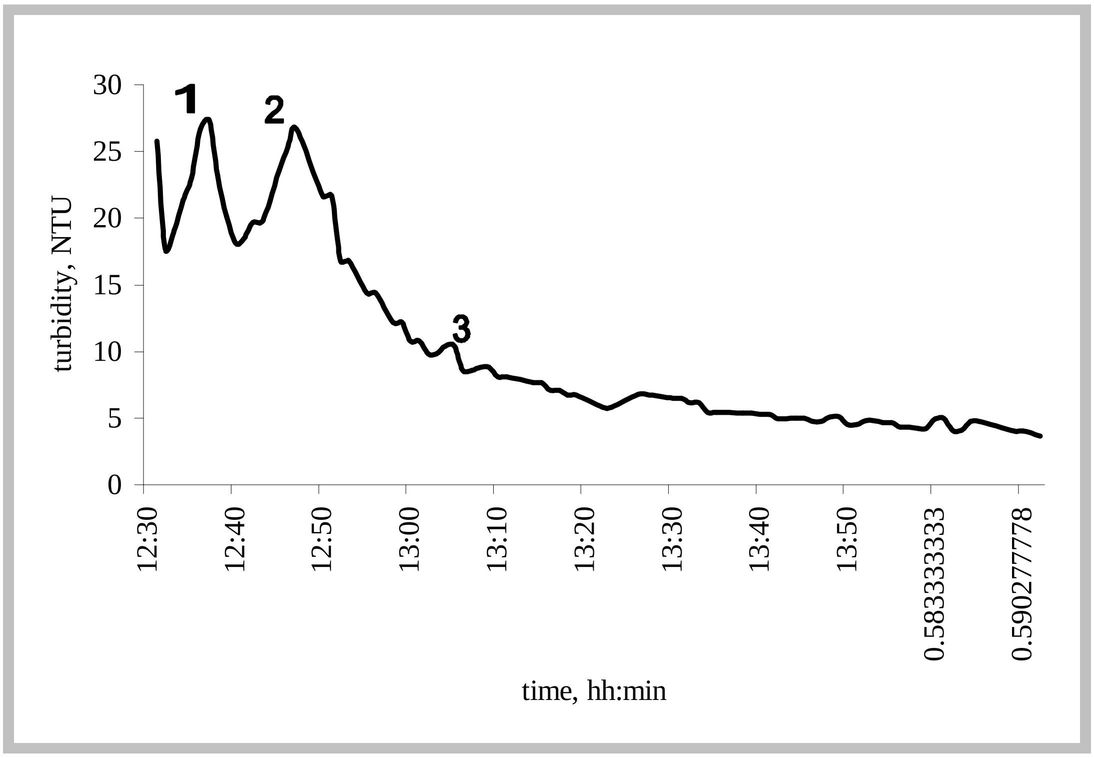

Figure 7. Turbidity curve for flushing site A after 5 months period

In current situation from validated hydraulic model maximum potential flow was section Z (Figure 5) was 15.15 m3/h; if flushing demand is added in the same section the total flow was 70 m3/h. In other branch (Y, in Figure 5) which goes to city demand at 13:26 was 12.67 m3/h. The maximum possible capacity of WTP was 74 m3/h. This suggests that only possible theoretical reason for sudden increases of turbidity due to significant increase of water consumption in upstream of hydrant was not possible.

The POODS approach itself (as far as I know from Boxall & Saul, 2005) is an empirical (let’s say phenomenological) modelling approach to predict the mobilization of deposits. Therefore, the deposits have to be in a steady state, as far as I know. For me it sounds as if in the paper from Boxall, Skipworth and Saul (2001) (which I’ve not read!) additional equations are presented compared to the paper from 2005 named above, describing the deposit formation. Is this correct?

In period of flushing flow conditions must be in a steady state so the shear stress must not vary to cause turbidity curve rapid changes. In our cases flow varies less than 5% of total, so it should not cause rapid turbidity changes and spikes in the curve.

In the paper from Boxall, Skipworth and Saul (2001) representation of layer strength versus stored turbidity volume is presented, based on empirical equation. In “Modeling Discoloration in Potable water distribution system” Boxall & Saul, 2005; case studies are analysed based on previous equation made model PODDS.

In the equation I understood, there were simple mistakes I list below. Please self-check the bigger empirical equations (3b, 6), which I could not prove.

Answer formulas checked – $\Delta Cc(t=1)=P(\tau_a - \tau_s)^n * 2\pi rL$

(3a)

where P=gradient term [NTU/m2]

n=power term [-]

τ_a=applied shear stress [N/m2]

τ_s=current layer strength [N/m2]

r=radius of pipe [m]

L=length of link [m]

ΔCc(t>2)= ΔCc(t=1)x((1- P(τ_a- τ_s) * 2πrL) * t)/Cmax (3b)

where t = time [sec]

Accounting fittings (6):

$$\Delta C_c(t>2) = \Delta C_c(t=1)\times\left(1-\frac{R\times t}{C_{\max}/2\pi rL}\right)+\frac{C_{\max}/2\pi rL}{t}\times J\left(1-\frac{R\times t}{(Q\times t\times R\times 2\pi rL\times TSS\times 10^{-6}}\right)$$

where R = rate of supply [NTU/m2]

t = time [sec]

Cmax = is the total accumulated mass following a flushing event [m3 NTU]

r=radius of pipe [m]

L=length of link [m]

J = coefficient of a fitting [-]

Q = discharge [m3/s]

TSS = correlation coefficient between discoloration (NTU) and mass (kg).

Details =======

p. 140, L. 21: Rayan et al., 2008 –> Ryan et al., 2008 - Corrected

p. 144, L. 9: The standard deviation for measurements was − 30 s –> What does that mean? (I don't understand this.)

-This approximately duration when hydrant is fully opened from closed condition.

p. 145, L. 23: Remark: This is an application of the time-distance law. Agree.

p. 145, L. 25: Equation wrong. Should be V = q * t, V = pi/4 * D2 * L –> Q * t = pi/4 * D2

* L –> L = 4 * Q * t / (pi * D2) with t=0 at start of flushing

Corrected to L = 4 * Q * t / (pi * D2). Not clear what in above mentioned equation V = q * t "q" means.

p. 146, L. 13: "[...] The is a large number [...]" –> There is a large number ... - Corrected.

p. 146, L. 17: Suggestion: The stability of deposit layers is, according to the POODS model, based on the hydraulically induced shear of the bulk water on the deposit surfaces. The maximum (daily) occurring hydraulic wall shear stress is equivalent to the minimal shear stability of deposits.

Thanks for advice, corrected.

p. 146, L. 23: Equation wrong: If this shall be the equation for the wall shear (which is the maximum shear stress occurring in a pipe cross section in N/m2) the correct formulais ï *tau*= *ro* * g * D/4 * I . This energy gradient is I = h_f / L with the head loss h_f in metres as well as the pipe length L. The head loss is calculated with the Darcy-Weisbach

equation h_f = f * L/D * v2 /(2*g). Agree that should be used term energy gradient (I) and maximum shear stress in N/m2

p. 148, L. 15: "[...] The layers can have higher stored turbidity volume [...]" –> Weak layers (according to shear stability) can store more turbidity units than strong layers. Corrected.

p. 149, L. 9: I don’t understand the equation. if it is the objective to calculate the particle mass with eq. (7), the unit of the TSS should be NTU/(kg/m3), so Turb * TSS yields kg/m3 as unit. TSS should then be the correlation parameter of a (linear) relationship between turbidity and TSS (e.g. Turb = TSS * TS; TS = total solids in kg/m3). For the determination of the parameter TSS a wide range of samples have to be analyzed for TS and turbidity as stated correctly in line 13, p. 149.

– The objective of Eq.7 is to obtain total flushed deposit mass, kg/m3 multiplying with total flushed water amount which results in NTU kg in the end. However TSS was assumed constant from Boxall et al., 2003, and was not established from current flushing events.

p. 151, L. 4: "[...] namely the increase of the particle concentration towards the mains dead ends. [...]" –> the amount of deposits does not compulsorily increase at the end of pipe mains. If there are no suspended particles transported to the end of a pipe, which may settle, then there is also no deposit formation. – corrected.

p. 151, L. 14: "[...] which predicts that the particles on pipe walls are conditioned by the shear stress [...]" –> more accurate: " which predicts that the particulate deposits on pipe walls are conditioned by the shear stress" - corrected

p. 152, L. 15: What are the reasons for the introduction of the empirical relationship V/D? Is there a polynomial fit?

– The main reason for V/D parameter introduction was unification of all diameters for J values calculation in one trend, the second reason was that there was limited number of examples for each pipe diameter (one or two events for corresponding nominal diameter). The best fit of trend was found logarithmical.

References

Rubulis J. and K. Neilands (2010) Interpretation of loose deposits motion in drinking water distribution network, In: Proceedings of the Water Distribution System Analysis Conference. Tucson, Arizona. - ASCE Conf. Proc. doi:10.1061/41203(425)61