

Interactive comment on “Importance of demand modelling in network water quality models: a review” by E. J. M. Blokker et al.

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Received and published: 16 June 2008

We would like to thank the referee for the thorough reading of the paper and his valuable comments. A reply to those comments follows.

1) Providing mathematical formulations and critical comparisons of the demand models (PRP, NSRP and end-use model)

This requires a full paper on its own. Authors are preparing this paper.

2) Evidence of statement on auto and cross correlation
Authors will add figures plus some explanatory text.

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Figure 1 Cross correlation of measured patterns (Milford, OH) on different temporal scales and spatial scales: 1 home, 10 homes and 20 homes.

Figure 2 Auto correlation of measured patterns (Milford, OH) on different temporal scales and spatial scales: 1 home, 10 homes and 20 homes. Higher auto correlation at short time steps is due to high number of times with zero flow.

3) Evidence of statement on influence of time step on WQ analysis

A graph of the relation between Reynolds number and probability of stagnation is suggested by the reviewer. Authors will add a graph which shows for some typical (Dutch) flow patterns at different time steps and different number of downstream homes (with pipe diameter chosen accordingly) what the probability of stagnation, probability of laminar flow ($Re < 2000$) and probability of turbulent flow ($Re > 4000$) are. Above ca. 50 homes the time step becomes less important. Small time step (< 1 min) is mainly of interest in the end of the pipe system.

Figure 3 Probability of stagnation, laminar flow and turbulent flow for different time steps and number of homes (1, 5 homes: $\varnothing 59$ mm; 10 homes: $\varnothing 10$ mm; 20, 50, 100, 150 homes: $\varnothing 150$ mm; 200: $\varnothing 300$ mm). The influence of time step on particulate and dissolved substances needs to be investigated further. Authors will discuss more elaborate on how this can be done.

4) Bottom-up versus top-down approach

Authors will refrain from drawing conclusions on which approach is best as such conclusions cannot be drawn at the moment. Authors will add some extra information on what has been done: Initial network simulations (1990s era) tended to use skeletonized distribution systems with top-down demand allocation and an AR water quality model (Rossman et al 1994 is the classic example). More recent analyses (since 2000) attempt finer resolution simulations using all-pipe networks with bottom-up demand allocation and an ADR water quality model (Tzatchkov et al., 2002; Li, 2006). Here top-down demand allocation means that the measured demand multiplier pattern of the

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pumping station is allocated to the demand nodes with a correction factor to account for total demand on that node. A bottom-up demand allocation means that the demands per individual home are modelled and subsequently these individual demands are summed to obtain the demands at larger demand nodes.

5) Typical values of dispersion coefficients

Typical values follow from the following equations which will be added.

$$\frac{\delta C}{\delta t} + u \frac{\delta C}{\delta x} = E \frac{\delta^2 C}{\delta x^2} + f(C) \quad (1)$$

E represents the mixing (dispersion) coefficient in one-dimensional flow.

Suppose a solute with molecular diffusivity D is transported in fully-developed steady laminar flow at an average velocity u through a pipe of diameter d . Gill and Sankarasubramanian (1970) derived an exact but cumbersome expression showing that the instantaneous rate of dispersion in steady laminar flow grows with time and asymptotically approaches the equilibrium dispersion rate E_T given by Taylor (1953),

$$E_T = \frac{d^2 u^2}{192D} \quad (2)$$

Lee (2004) simplified the 1970 G&S result and provided a theoretical approximation for the time-averaged unsteady rate of dispersion, $\overline{E(t)}$, for a solute moving in steady laminar flow through a pipe,

$$\overline{E(t)} = E_T \left[1 - \frac{1 - \exp[-16T(t)]}{16T(t)} \right] \quad (3)$$

Here $T(t) = 4Dt/d^2$ is dimensionless Taylor time and t represents the mean travel time through the pipe. When Taylor time is large, Eq (3) reduces to Eq (2). For nearly

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all networks links, however, Taylor time is very small [e.g., $T(t) < 0.01$]. In this case, the expression in (3) can be further simplified,

$$\overline{E(t)} \approx \frac{u^2 t}{6} = \frac{uL}{6} \quad (4)$$

where L is the length of the pipe. To illustrate, consider a solute with diffusivity $D = 10^{-5} \text{ cm}^2/\text{s}$ transported in steady fully-developed laminar flow (say $\text{Re}=1000$) at 20°C through a pipe with $d=15 \text{ cm}$ and $L=100 \text{ m}$. The corresponding average velocity is $u=0.67 \text{ cm/s}$. Hence, the mean travel time through the pipe link is $t = L/u = 250 \text{ min}$ and the corresponding dimensionless Taylor time is $T(t=250 \text{ min}) = 0.0027$.

For this condition, Eqs (3) and (4) give similar results, namely, $\overline{E(t)} = 1,105 \text{ cm}^2/\text{s}$ and $1,117 \text{ cm}^2/\text{s}$, respectively. These estimates of the dispersion rate are eight orders of magnitude greater than the rate of molecular diffusivity. However, they are only two percent of the equilibrium value given by Taylor's formula in Eq (2), $E_T = 52,600 \text{ cm}^2/\text{s}$. Owing to small molecular diffusivity and relatively large pipe diameters, it is virtually impossible in real water distribution systems for the time-averaged rate of laminar dispersion to attain the equilibrium value given in Eq (2).

Recent preliminary experimental evidence indicates that Eqs (3) and (4) tend to slightly over-estimate the actual time-averaged rate of dispersion observed in controlled laboratory runs (Romero-Gomez et al 2008). The reason(s) for this discrepancy are not clear and this is the subject of ongoing research investigations.

Additional References

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