Mirjam Blokker – 18 April 2023

Applications to managing distribution networks

Mixing processes in pipes, sewers & the natural environment from theory to practice

KWR

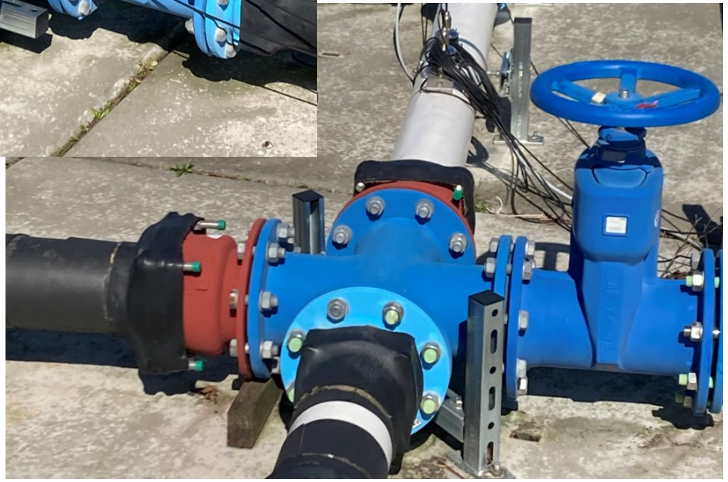
Bridging Science to Practice

In practice, in (Dutch) drinking water distribution networks …

demands are stochastic, and to a great extend unknown…

What is the effect if you assume deterministic demands (in your model), which inadequate conclusions could you draw?

there are only T-junctions, no X-junctions



In practice demands are stochastic – effects on water quality modelling

- SIMDEUM is a stochastic demand model that produces realistic demands
- SIMDEUM was used to show what the effect is if you assume deterministic demands, which inadequate conclusions could you draw

	dispersion / diffusion	bulk interactions	wall interactions	water age	resuspension	temperature	CL decay	contaminant back tracing
hydraulic path		x		x		x	x	x
Stagnant %	x		x			x	x	x
Laminar %	x		x			x	x	x
Turbulent %	x		x		x	x	x	x
Q_{max}					x			
flow direction reversals		x	x	x	x			x
mixing		x				x	x	x

Comparing models with stochastic and deterministic demands, and effect on water quality models

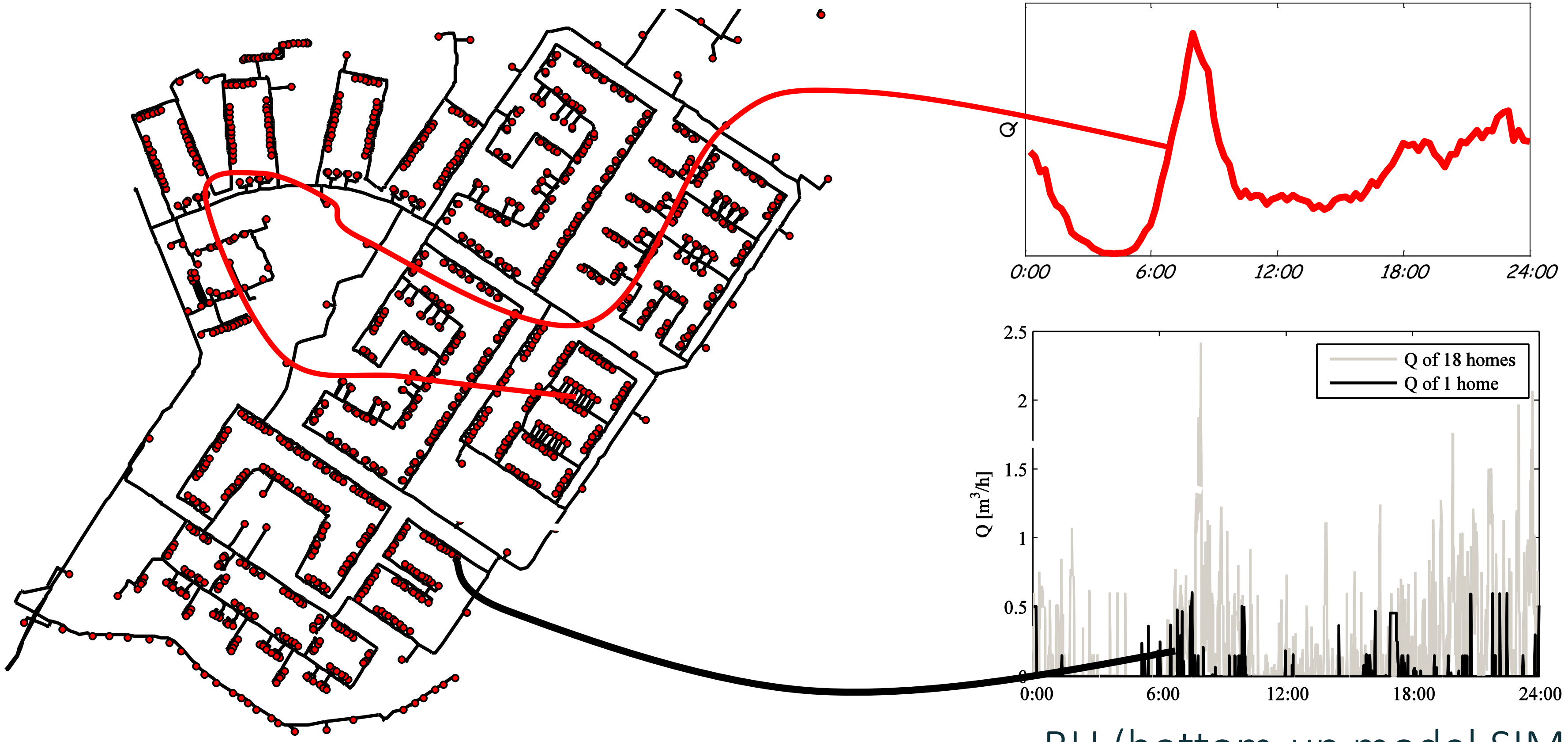
Figure 8-3. DWDS of area A in Purmerend. The colours indicate diameter.

Hydraulic model of neighbourhood in Purmerend that is used to show the influence of stochastic (also called BU, bottom up) versus deterministic (or TD, top down) demand allocation

Blokker, E. J. M. (2010). "Stochastic water demand modelling for a better understanding of hydraulics in water distribution networks," Delft University of Technology. http://resolver.tudelft.nl/uuid:82f6a988-2cef-4eba-aef2-d9790e283f95

Demand allocation – two methods

TD (top-down model) - deterministic



BU (bottom-up model,SIMDEUM) - stochastic

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Turbulent %	x		x		x	x	x	x
Q_{max}					x			
flow direction reversals		x	x	x	x			x
mixing		x				x	x	x

Effect of stochastic versus deterministic demand model – duration of stagnant water

Figure 8-5. Percentage of time that pipe flow is stagnant pipes (0.01 h time step).

In model with deterministic demands there are no stagnant times (demand multiplier is never 0)

In model with stochastic demands flows in smaller pipe diameters are stagnant most of the day

Effect of stochastic versus deterministic demand model – duration of laminar flows

Figure 8-6. Percentage of time that pipe flow is laminar pipes (0.01 h time step).

Re < 2000

In model with deterministic demands all flows are laminar most of the time

In model with stochastic demands, only flows in average pipe diameters are laminar most of the time; in larger and smaller pipe diameters only small part of the day

Effect of stochastic versus deterministic demand model – duration of turbulent flows

Figure 8-7. Percentage of time that pipe flow is turbulent pipes (0.01 h time step).

Re > 4000

In both models long durations of turbulent flows are mainly found in larger pipe diameters

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Stagnant %	x		x			x	x	x
Laminar %	x		x			x	x	x
Turbulent %	x		x		x	x	x	x
Q_{max}					x			
flow direction reversals		x	x	x	x			x
mixing		x				x	x	x

Effect of stochastic versus deterministic demand model – Q_{max}

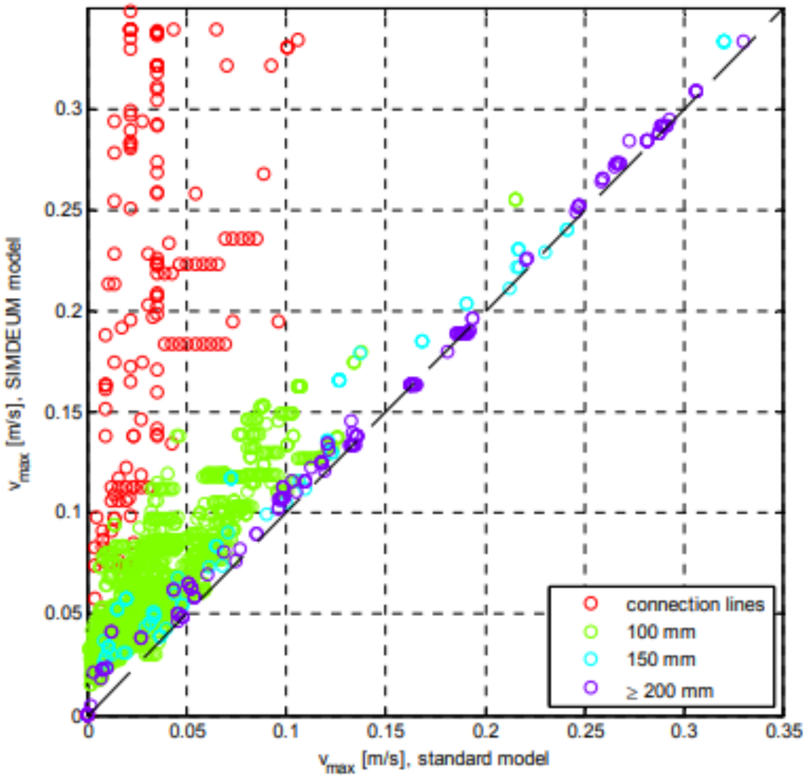

Figure 8-12. Maximum flow velocity (m/s) in all pipes in standard (TD) model and SIMDEUM (BU) model.

In larger pipe diameters – supplying a larger number of homes – the difference is relatively small

In smaller pipe diameters – supplying one to a few homes – the difference is quite significant: higher Q_{max} for stochastic demands

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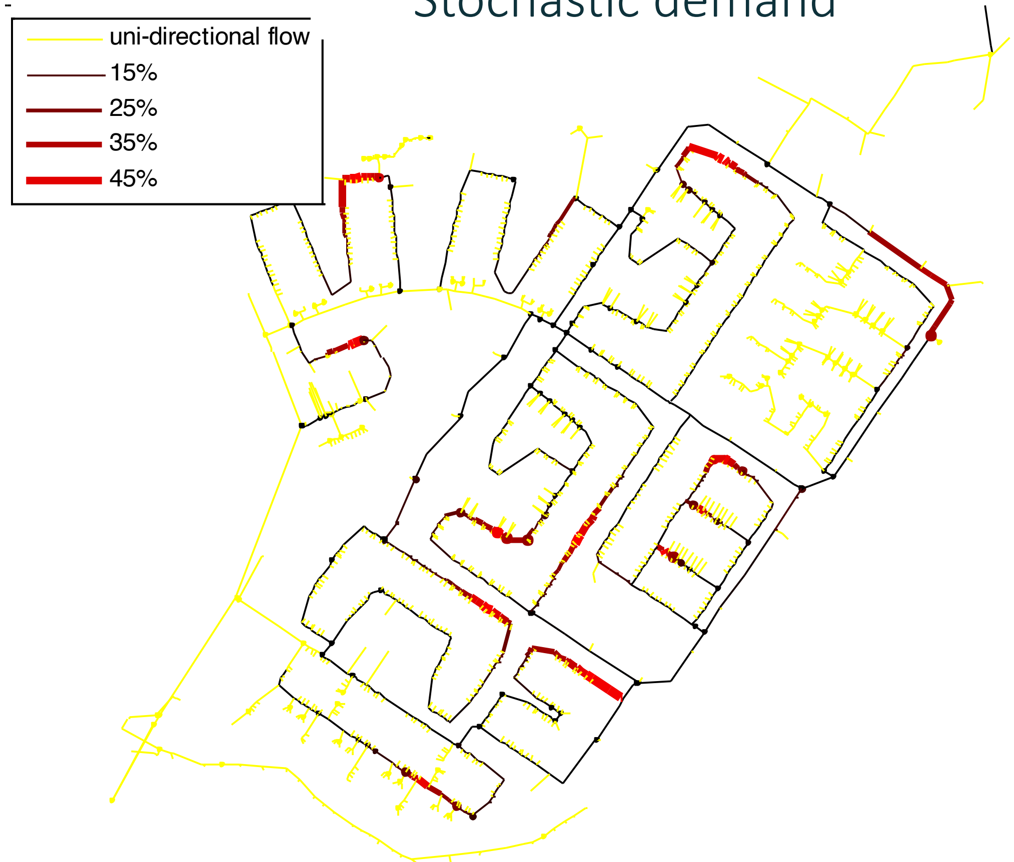
Turbulent %	x		x		x	x	x	x
Q_{max}					x			
flow direction reversals		x	x	x	x			x
mixing		x				x	x	x

Effect of stochastic versus deterministic demand model – flow direction reversals

Stochastic demand

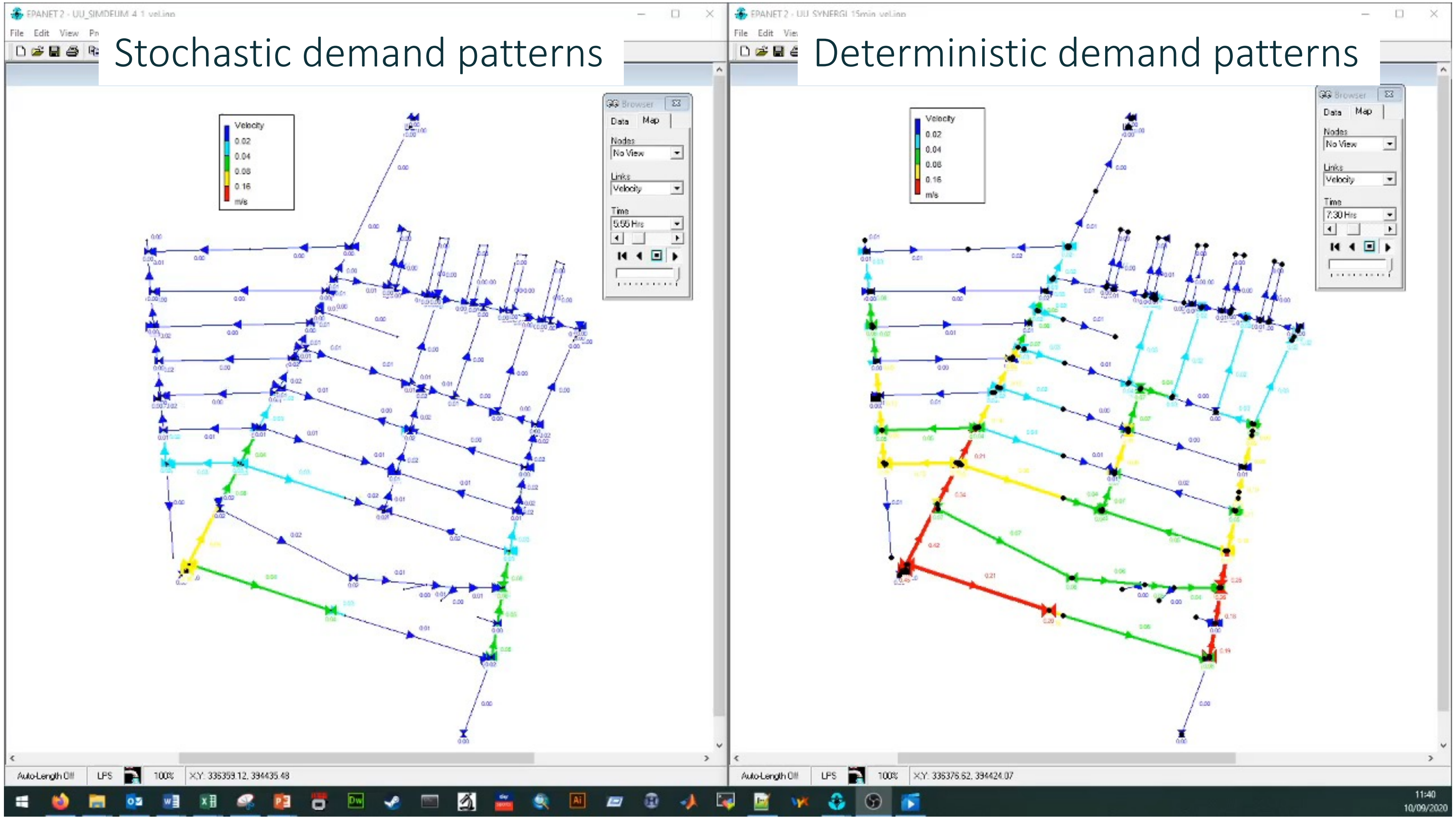


Deterministic demand

Flow direction reversals occur everywhere (except on branched pipes and some large pipe

Flow direction reversals occur almost nowhere (single source)

Effect of stochastic versus deterministic demand model – flow direction reversals (2)



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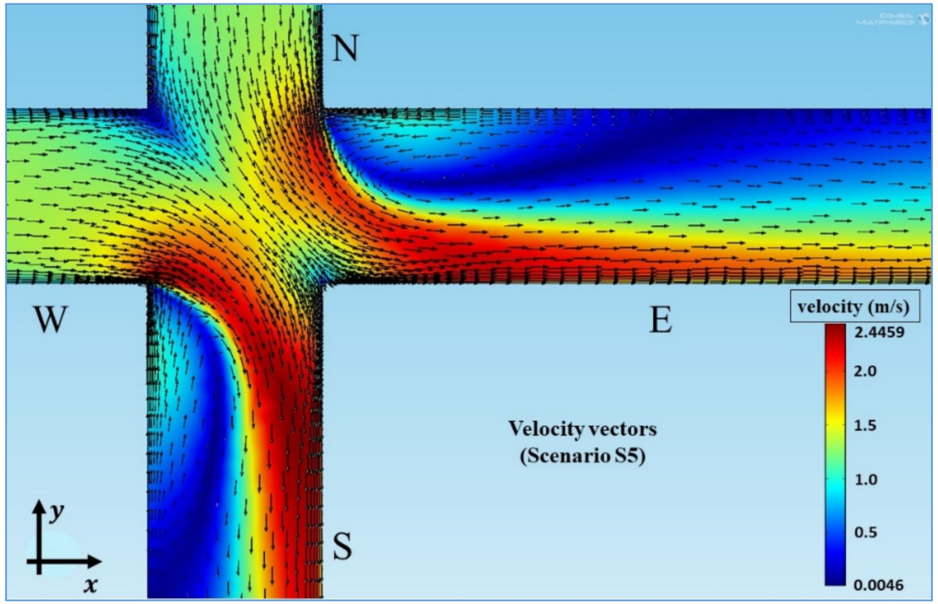
Turbulent %	x		x		x	x	x	x
Q_{max}					x			
flow direction reversals		x	x	x	x			x
mixing		x				x	x	x

Effect of stochastic versus deterministic demand model – mixing at junctions



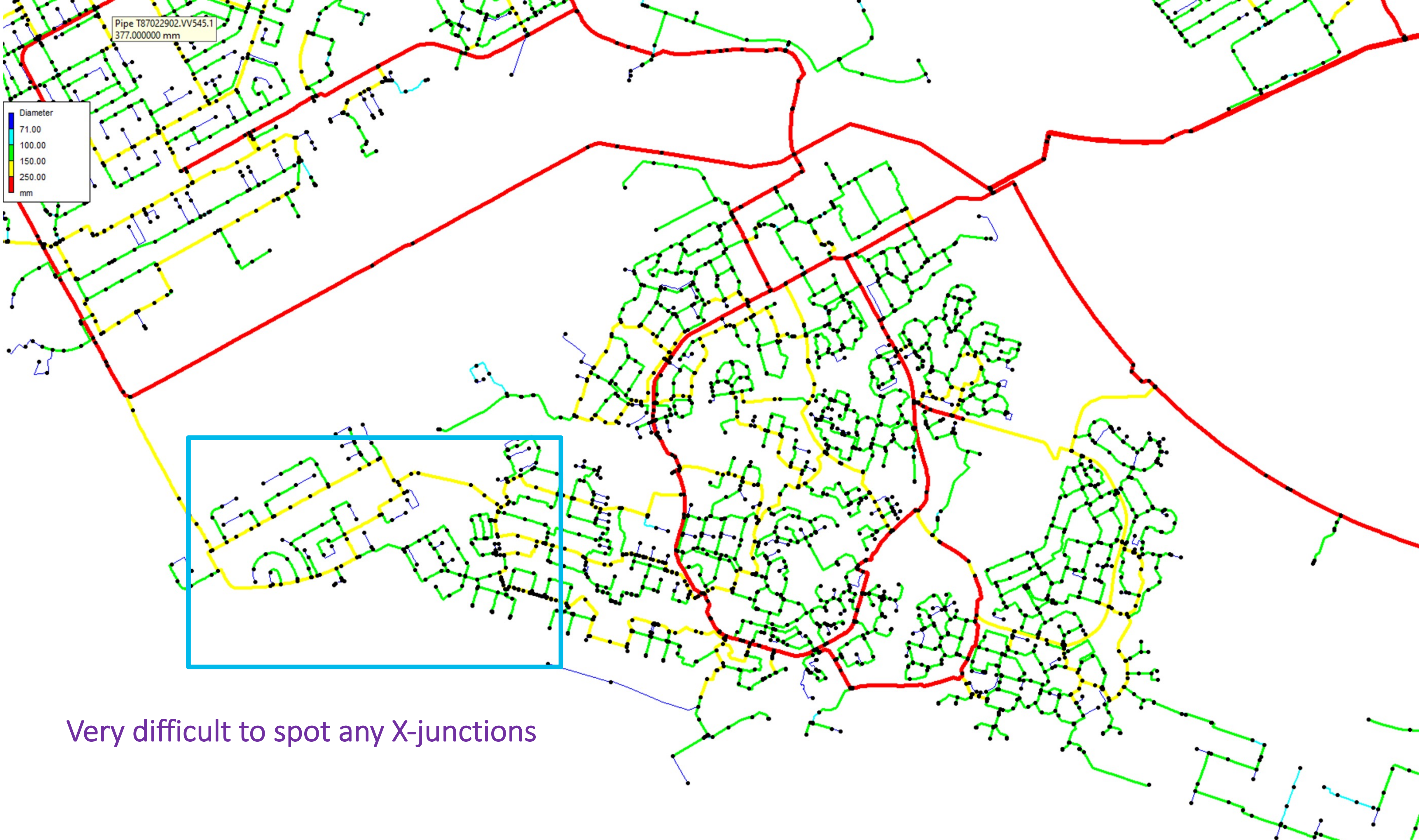
Hernández Cervantes, D., López-Jiménez, P. A., Arciniega Nevárez, J. A., Delgado Galván, X., Jiménez Magaña, M. R., Pérez-Sánchez, M., & Mora Rodríguez, J. D. J. (2021). Incomplete mixing model at cross-junctions in Epanet by polynomial equations. Water, 13(4), 453.

Graph shows (non-)mixing at X-junction when ratio between W and N (and between S and E) are constant, i.e. deterministic demands.

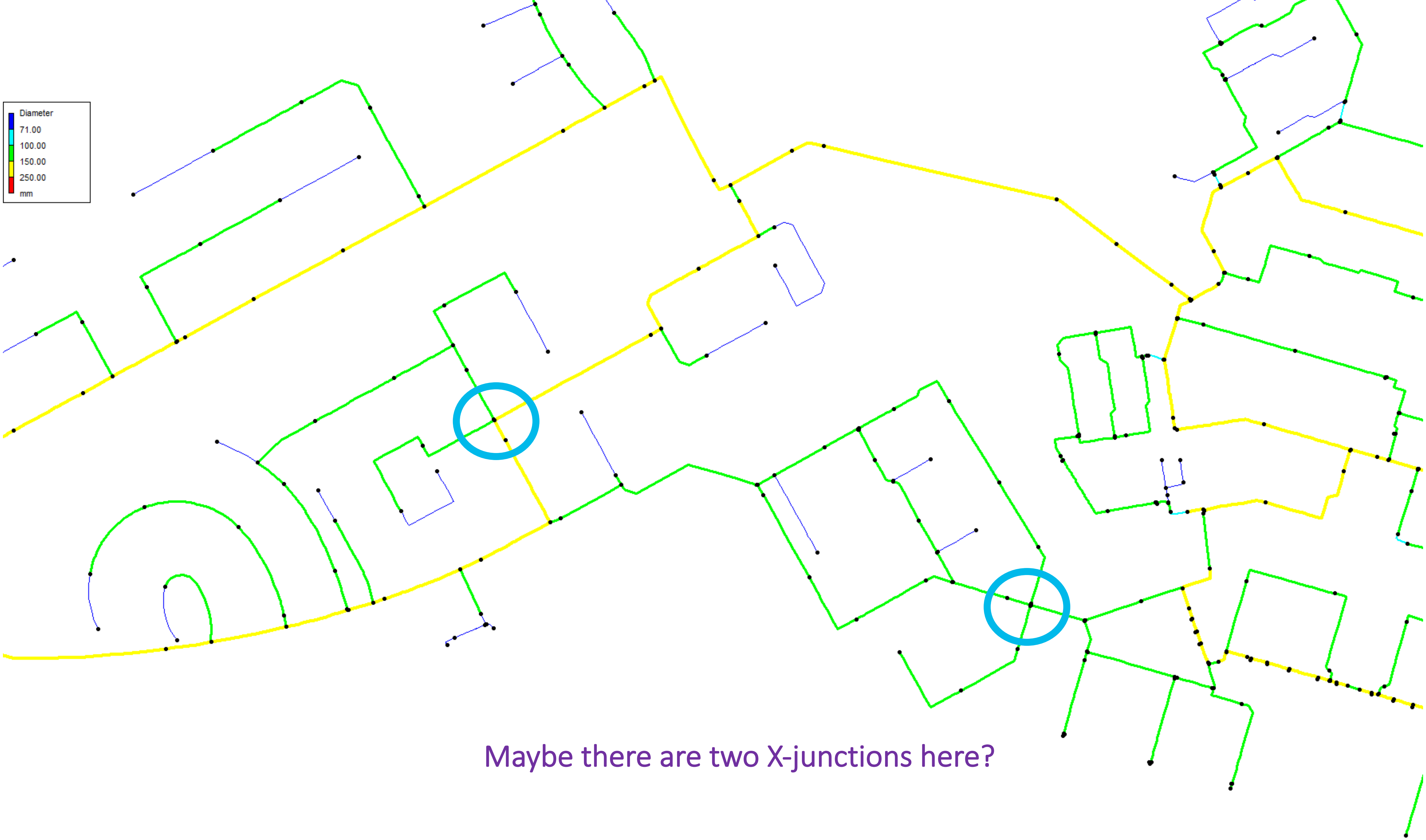
What would occur in model with stochastic demands?

And are these junctions found in real drinking water distribution networks?

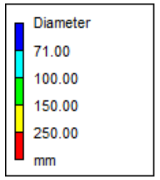
Looking for X-junctions

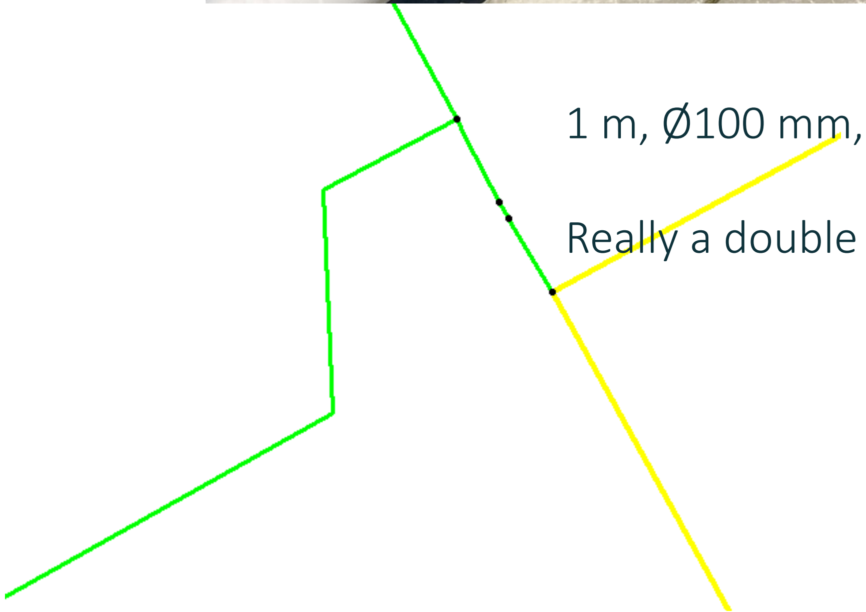


Very difficult to spot any X-junctions



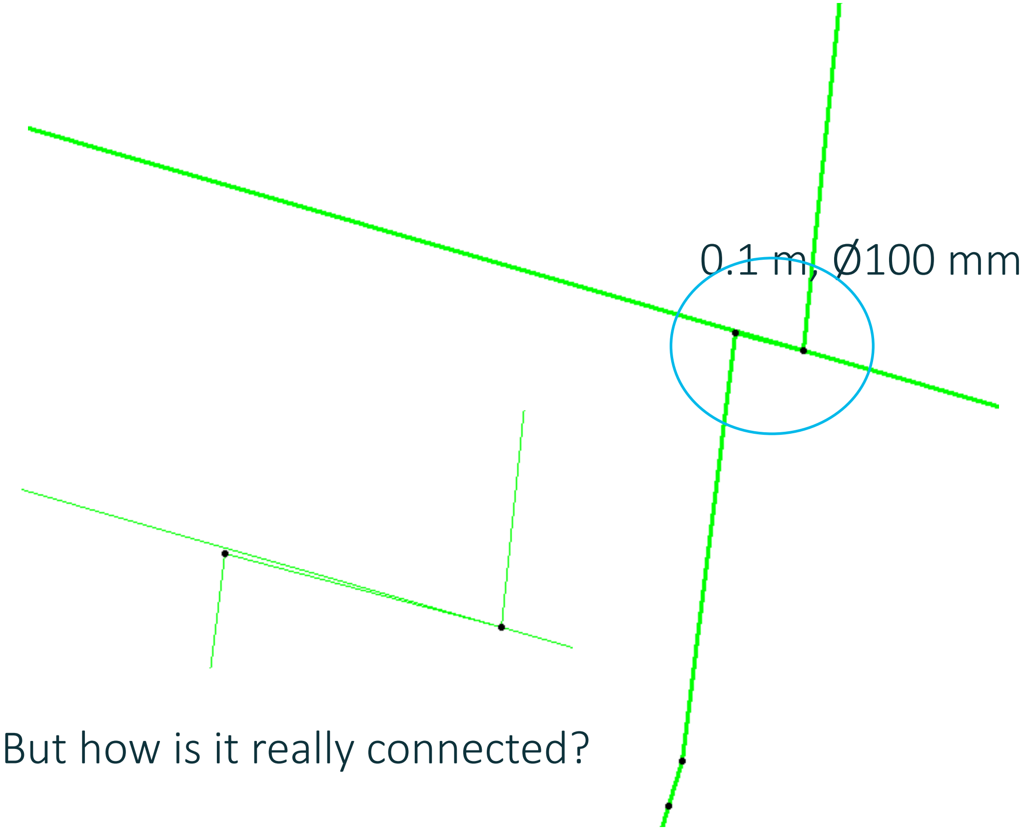
Maybe there are two X-junctions here?





1 m, Ø100 mm,

Really a double T-junction



0.1 m, Ø100 mm

But how is it really connected?

Zooming in even further: double T, or X?

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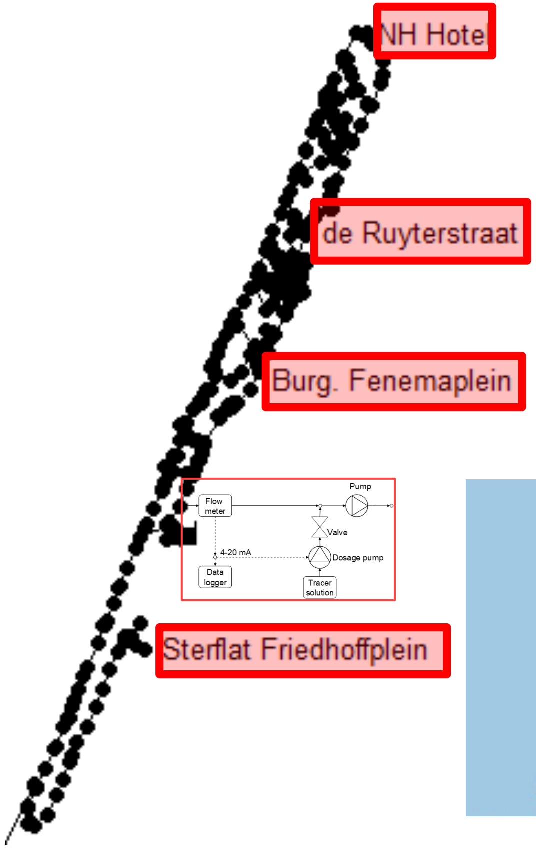
Laminar %	x		x			x	x	x
Turbulent %	x		x		x	x	x	x
Q_{max}					x			
flow direction reversals		x	x	x	x			x
mixing		x				x	x	x

Experimental Setup: Zandvoort Network


Burg. Fennemaplein



- ❖ Zandvoort (Netherlands)
- ❖ Ca. 10 km of pipes
- ❖ NaCl (tracer) dosage at booster location
- ❖ 4 measurement locations – electric conductivity
- ➔ pulse shape
- ➔ water age


NH Hotel

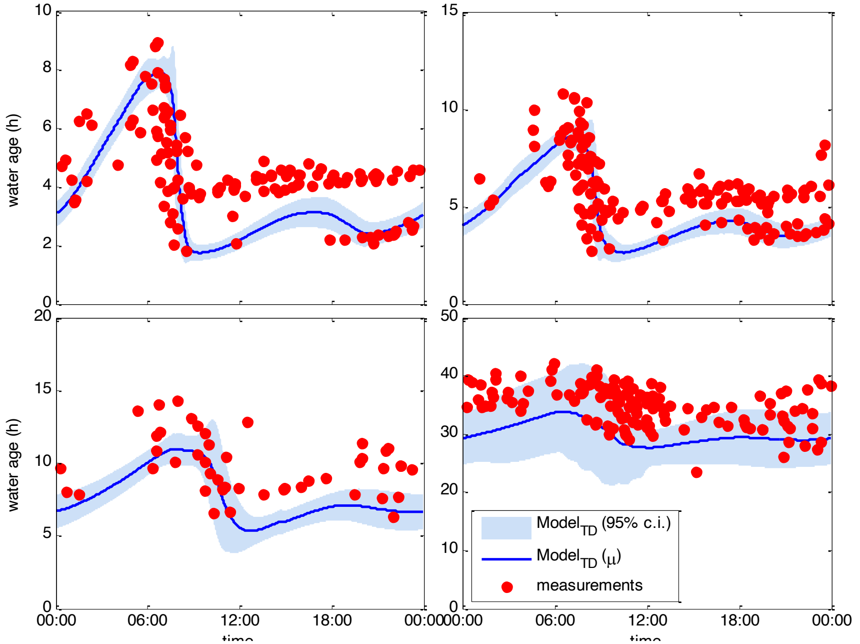

Sterflat Friedhoffplein


De Ruyterstraat

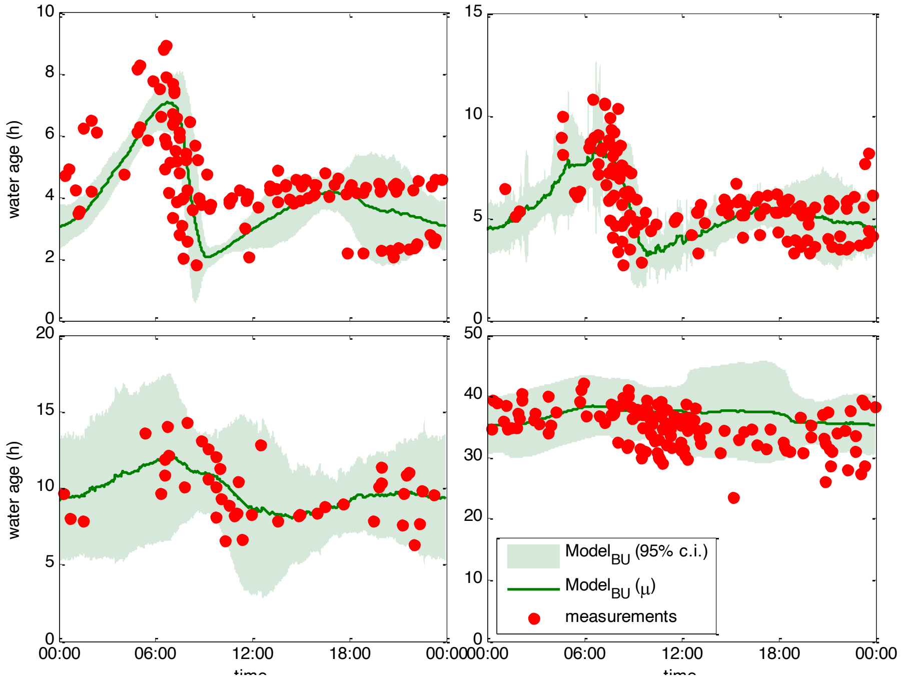
TU Delft

Effect of stochastic versus deterministic demand model – water age (2)

Red dots: measured
Blue: model results with deterministic demands
Green: model results stochastic demands



Better prediction with stochastic demands than with deterministic demands



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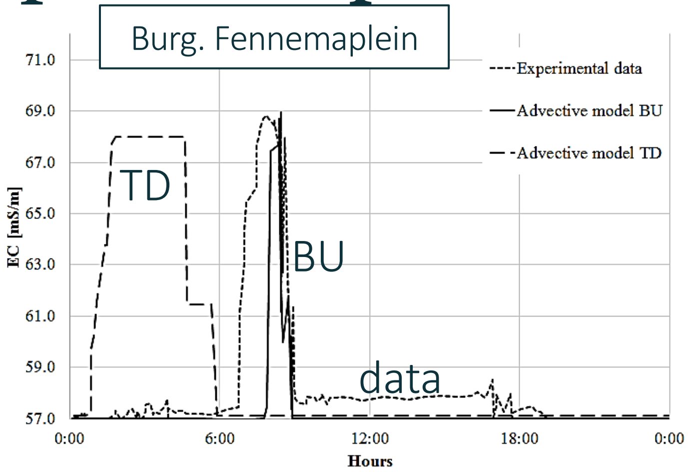
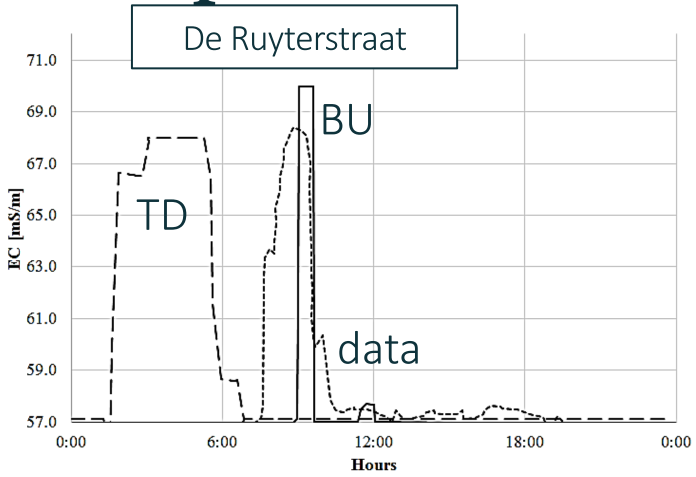
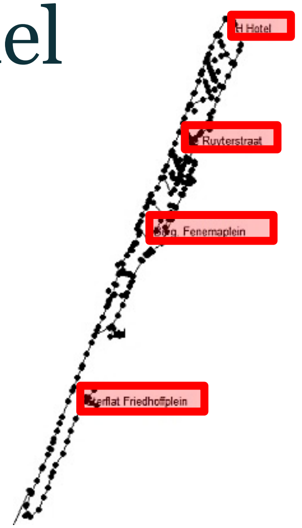
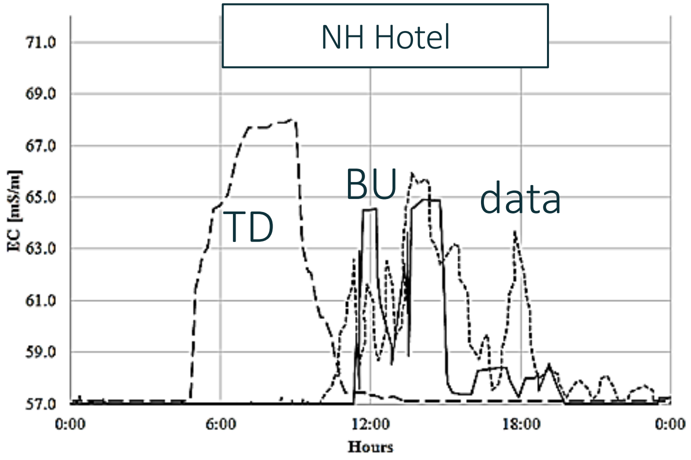
Laminar %	x		x			x	x	x
Turbulent %	x		x		x	x	x	x
Q_{max}					x			
flow direction reversals		x	x	x	x			x
mixing		x				x	x	x

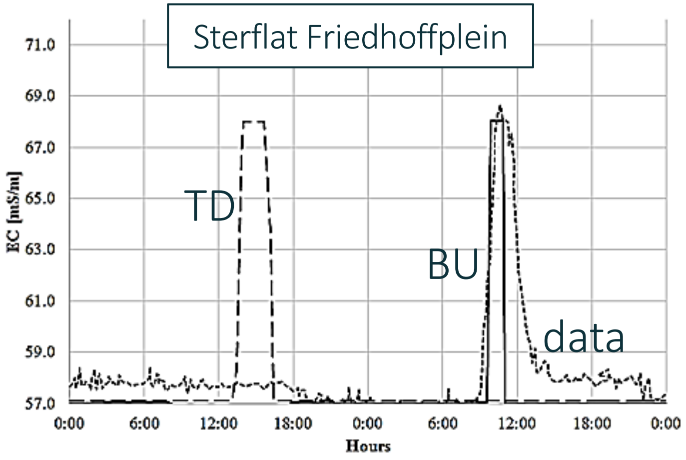
Effect of stochastic versus deterministic demand model – pulse shape (advective transport)







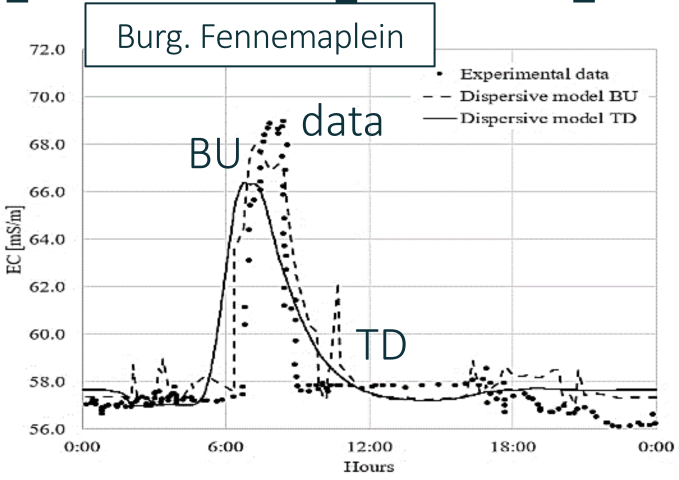


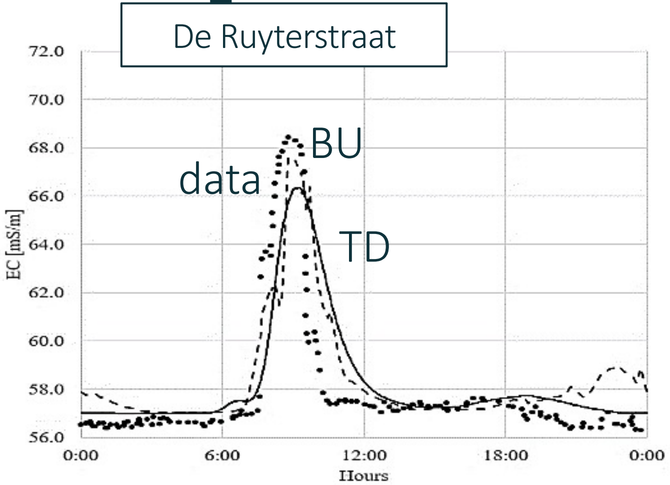


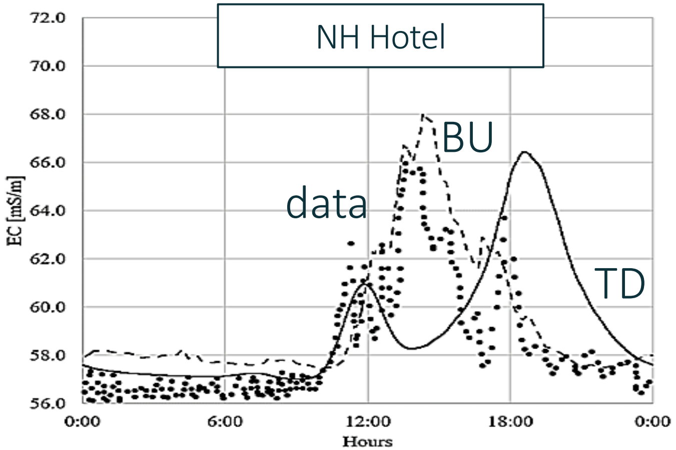
	Advective Approach			
	Burg. Fennemaplein	De Ruyterstraat	NH Hotel	Sterflat Friedhoffplein
Top-down N – S	-0.09	-0.12	-1.07	-0.50
Bottom-up N – S	0.28	0.24	0.22	0.50

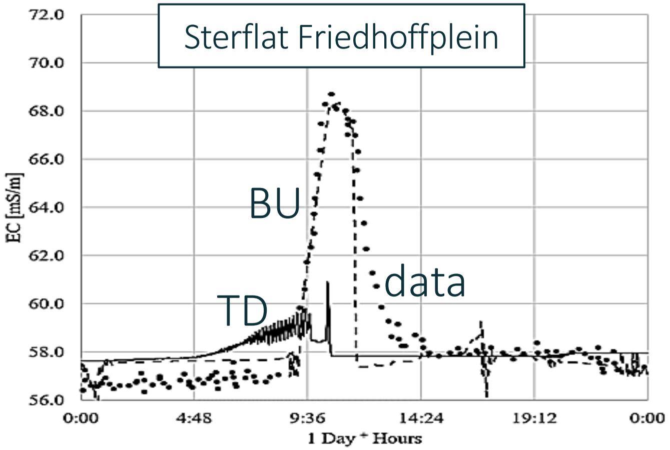
Comparison between advective model and experimental data (Top-Down and Bottom-Up for 3/09/2008)

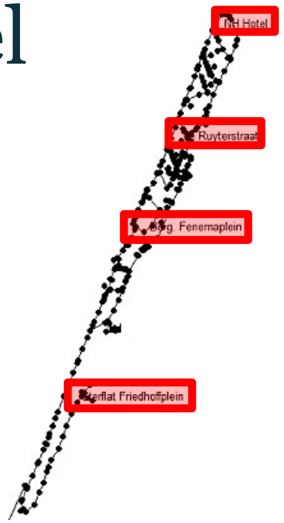
Effect of stochastic versus deterministic demand model – pulse shape (dispersive transport)











	Advective – Dispersive – Diffusive Approach			
	Burg. Fennemaplein	De Ruyterstraat	NH Hotel	Sterflat Friedhoffplein
Top-down N – S	-0.04	0.78	-0.62	-0.44
Bottom-up N – S	0.79	0.88	0.68	0.71

Comparison between dispersive model and experimental data (Top-Down and Bottom-Up for 3/09/2008 backward dispersion coefficient=0.05 m^2/s and forward dispersion coefficient=0.30 m^2/s)

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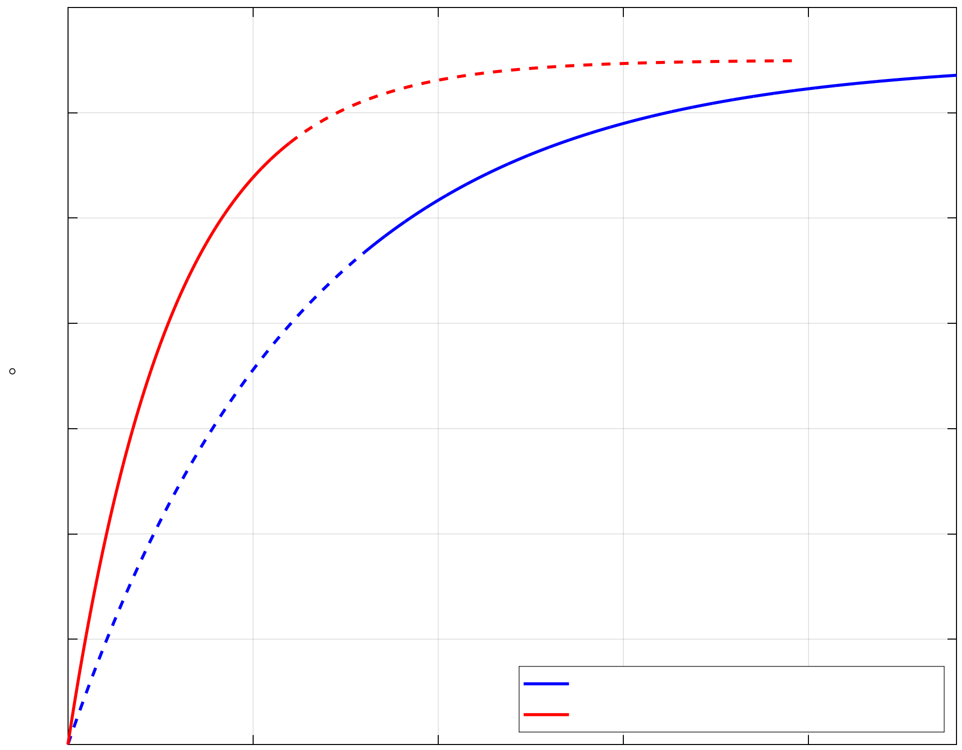
hydraulic path		x		x		x	x	x
Stagnant %	x		x			x	x	x
Laminar %	x		x			x	x	x
Turbulent %	x		x		x	x	x	x
Q_{max}					x			
flow direction reversals		x	x	x	x			x
mixing		x				x	x	x

Effect of flow regime on interaction with wall - temperature



Much faster heat exchange with turbulent flows (includes convective heat transfer), than with laminar flows (only conductive heat transfer)

160 mm PVC: drinking water temperature versus time
Re > 5000: turbulent flows

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Turbulent %	x		x		x	x	x	x
Q_{max}					x			
flow direction reversals		x	x	x	x			x
mixing		x				x	x	x

Effect of flow regime and Q_{max} on discolouration risk

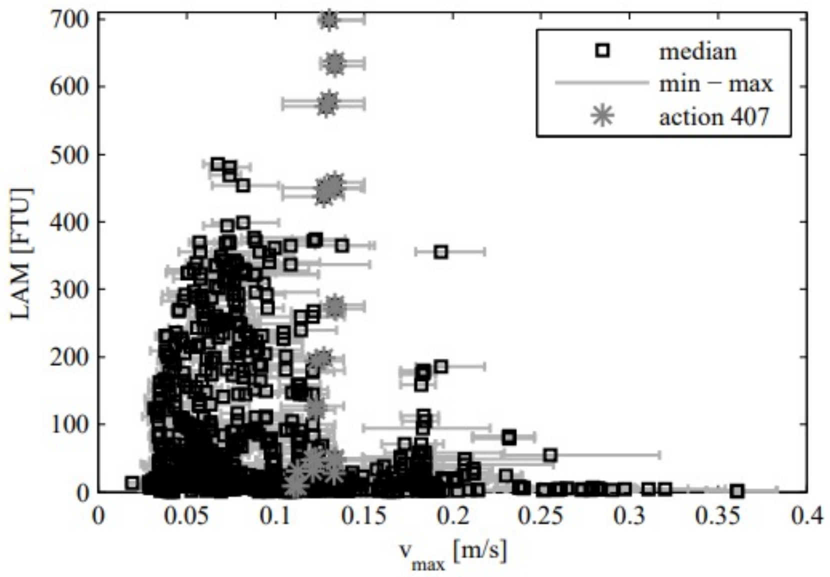

Figure 7-8. Locally accumulated material [FTU] versus maximum velocity [m/s] in areas A and B. The median, minimum and maximum values of ten simulated maximum velocities are shown.

In pipes which experience Q_{max} > 0.2-0.25 m/s on a daily basis: no accumulation of discolouration material ➔ self-cleaning.

Impossible to measure all the velocities ➔ stochastic model allows research that can't be done otherwise.

Effect of flow direction reversals on wall shear stresses

S.L. Weston, R.P. Collins and J.B. Boxall

Water Research 194 (2021) 116890

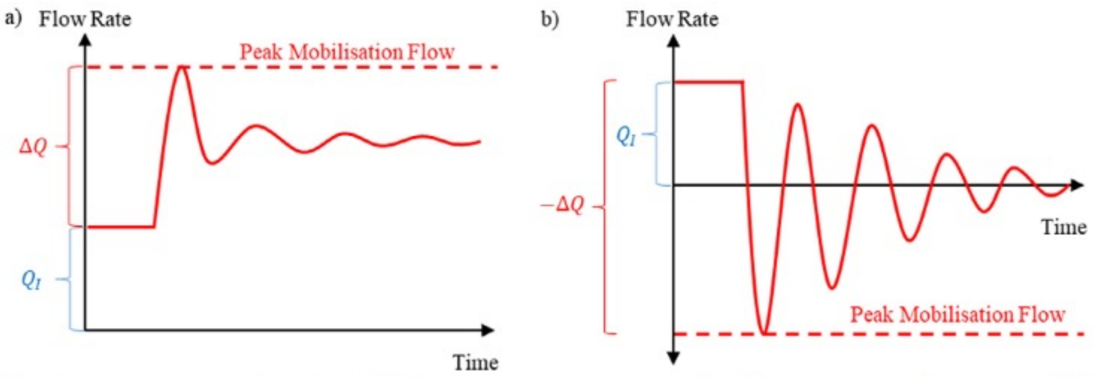

Fig. 8. Idealised flow rate schematic for a) accelerating and b) decelerating flow transients at pipeline mid-length showing the peak mobilisation flow as the absolute sum of the pre-transient steady state flow rate, $Q_{pre-transient}$, and the pseudo instantaneous change in flow rate, ΔQ.

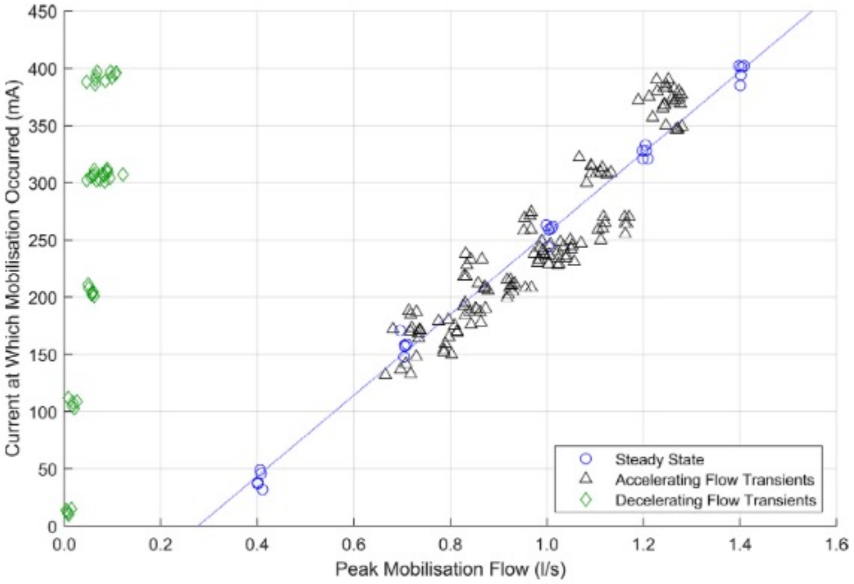

Fig. 9. Currents at which mobilisation occurred for peak mobilisation flow values for steady state, accelerating flow transients and decelerating flow transients.

Flow directional reversals can cause transients, that can cause mobilisation of discolouration material, typically cause by shear stresses

Weston, S. L., Collins, R. P. and Boxall, J. B. (2021). "An experimental study of how hydraulic transients cause mobilisation of material within drinking water distribution systems." *Water Research*, 194, 116890, https://doi.org/10.1016/j.watres.2021.116890.

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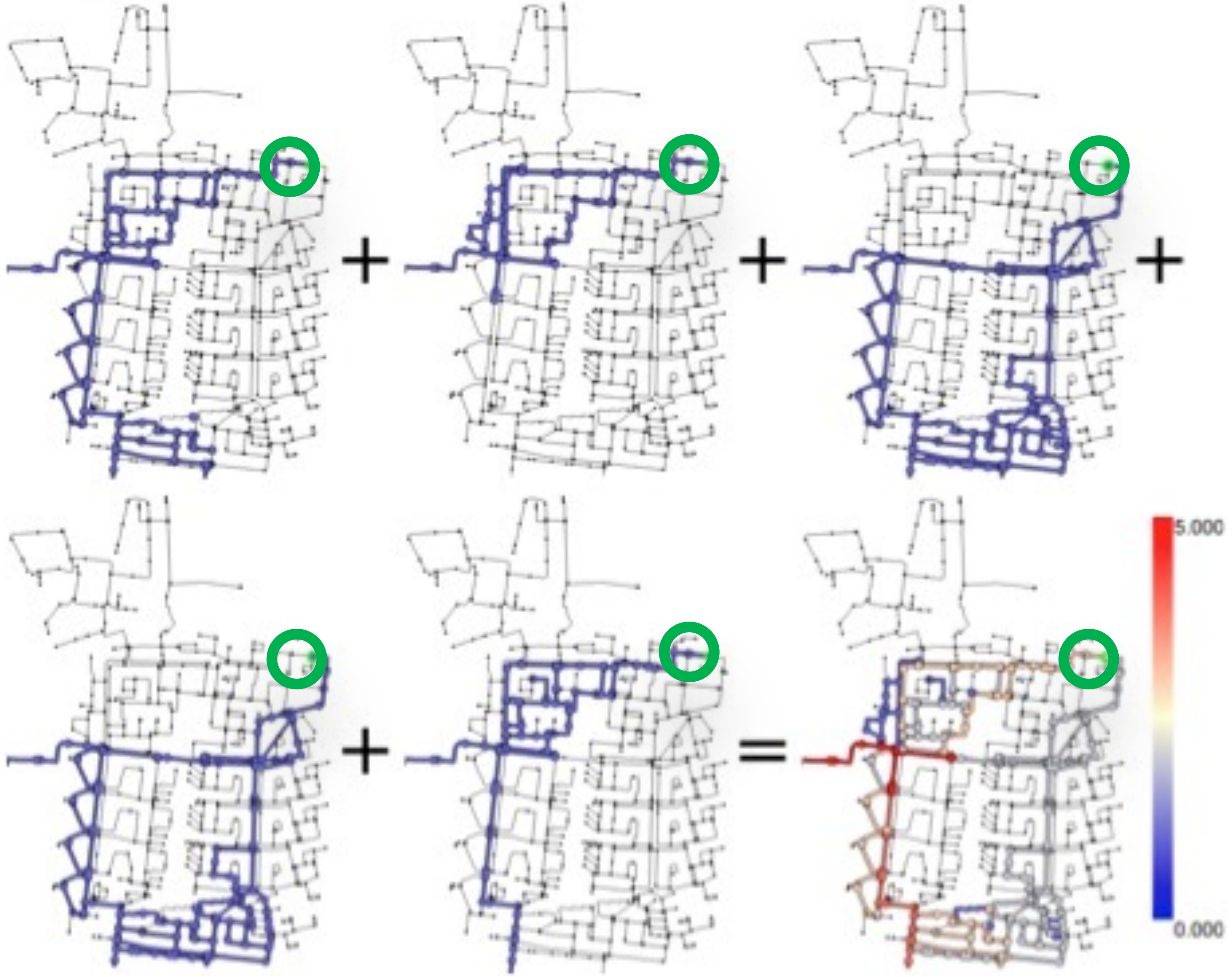
Laminar %	x		x			x	x	x
Turbulent %	x		x		x	x	x	x
Q_{max}					x			
flow direction reversals		x	x	x	x			x
mixing		x				x	x	x

Effect of water age + pulse shape + mixing on sensor interpretation

Backtracing with stochastic demands

Different sets of demand patterns would lead to a different path of the water towards the demand nodes and potential sensor locations.

Interpretation of the sensor reading depends on the "known" demands.



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Laminar %	x		x			x	x	x
Turbulent %	x		x		x	x	x	x
Q_{max}					x			
flow direction reversals		x	x	x	x			x
mixing		x				x	x	x

Concluding remarks: Practical implications for applications

- For understanding discolouration, a model with stochastic demands will (probably) give a better understanding of maximum flow rates, flow direction reversals and thus shear stresses
- For chlorine decay, a better understanding of temperature (heat exchange) is required, and maximum water age.
- For heat exchange, a better understanding of turbulent flows is required (Re > 5000?).
- For contaminant backtracing a model is needed with stochastic demands and improved dispersion/diffusion model.
- Incomplete mixing is not an issue, there are no X-junctions.

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