Responses to comments from Anonymous Referee #1 on "The effect of a loss of model structural detail due to network skeletonization on contamination warning system design" by Michael J. Davis and Robert Janke

We appreciate the helpful comments from the referee. The comments are provided below and then the various points raised in the comments are repeated and addressed separately (italicized text).

Referee comments:

The reviewer read the manuscript thoroughly and decided accepted subject to a minor revision. This manuscript tried to evaluate the design effect of contaminant warning system (CWS) for the different levels of network details (e.g., all-pipes model vs. skeletonized model). The object and the content of this paper are appropriate for this journal. As the author reviewed in the manuscript, the researchers are still curious about the performance of the CWS from the impact of skeletonization of network model. The authors represented the influences on the performance of the CWS using the skeletonized models made from a commercial software (specific software was not revealed in the manuscript). However, it is unclear for the reviewer to understand the term of 'the quality of the network model' used in the manuscript (p.2 line 10). A network model is one of physical representation of infrastructures and has different purpose of usage as there exists different levels of representation of network models. For instance, the skeletonized model used typically in the planning purpose and the detailed model (e.g., all-pipes model) used for the operation. Also, the authors used four cases of trims (0 cm, 20 cm, 30 cm, and 40 cm) for each network model to show the performance influences on a CWS design, but didn't provide the hydraulic aspect of analysis. The reviewer recommends the authors to consider the hydraulic influences of skeletonization of network model in the manuscript. As the motivation of this study came from 'the uncertainties in the nature of the network itself (p.2 line 18)', it would be necessary to check the accuracy of the network model for the each skeletonized trim before the application of CWS design.

Responses:

"The authors represented the influences on the performance of the CWS using the skeletonized models made from a commercial software (specific software was not revealed in the manuscript)."

The commercial software that we used (InfoWater® Skeletonizer) will be identified in the manuscript. An appendix will be added that describes the use of the software to obtain skeletonized network models. A draft version of the appendix (Appendix A) is included at the end of these responses.

"However, it is unclear for the reviewer to understand the term of 'the quality of the network model' used in the manuscript (p.2 line 10). A network model is one of physical representation of infrastructures and has different purpose of usage as there exists different levels of representation of network models. For instance, the skeletonized model used typically in the planning purpose and the detailed model (e.g., all-pipes model) used for the operation."

By "quality" we mean the fidelity with which the network model represents the actual network and its operations for a given time. We will replace the sentence that uses the term "quality" with the following: "Although improvements in network models would be expected to result in improved CWS performance, the relationship between the degree to which the network model represents the actual distribution system and its operations and CWS performance has not been quantified. In this paper we examine quantitatively how lack of structural detail in the network model affects CWS *performance. We do not consider potential effects of inaccuracies in the representation of distribution system operations."*

A network model is both a physical representation of the water system infrastructure and its operations for a particular time. We suggest that the difference between planning versus operation models is in their ability to accurately represent either future operations (planning) versus a specific operational period (operation) and not their degree of infrastructure detail.

"Also, the authors used four cases of trims (0 cm, 20 cm, 30 cm, and 40 cm) for each network model to show the performance influences on a CWS design, but didn't provide the hydraulic aspect of analysis. The reviewer recommends the authors to consider the hydraulic influences of skeletonization of network model in the manuscript."

We will add an evaluation of the hydraulic influences of the skeletonization of the network models. In particular, we will examine the influence on flow velocities and water age. The following text will be added to the Methods section: "Network skeletonization affects the flow of water through the network, which in turn affects contaminant transport. The discussion here focuses on the implications of this change in contaminant transport for the design of warning systems. A discussion of the hydraulic effects of the skeletonization of the two networks considered here is provided in Appendix B." The evaluation will be included in an appendix, a draft version of which (Appendix B) is provided at the end of these responses.

"As the motivation of this study came from 'the uncertainties in the nature of the network itself (p.2 line 18)', it would be necessary to check the accuracy of the network model for the each skeletonized trim before the application of CWS design."

We agree that the accuracy of a network model should be checked before being used to design a CWS. The paper is intended to quantify how inaccuracies in the network model can affect the performance of a CWS and, hopefully, motivate the use of better network models. The evaluation that will be added of the hydraulic influence of skeletonization will provide some perspective on the effect of skeletonization on hydraulics and, therefore, the accuracy of the skeletonized network models. Skeletonization has a substantial influence on flow velocities and water age. The changes in these quantities with skeletonization demonstrate the level of inaccuracies in the network models following skeletonization.

Material for Appendices A and B begins on the next page

Appendix A: Skeletonization

We skeletonized Networks N1 and N3 using a commercial software package, InfoWater® Skeletonizer (Innovyze, 2005). This package allows three methods to be used for skeletonization, namely branch trimming, parallel pipe merging, and series pipe merging. It maintains total network demand by recalculating and reallocating demands at all affected nodes. Pipes with check valves or controls are not included in the skeletonization process. Because the order in which trimming and merging are performed can affect the configuration of the skeletonized network (Innovyze, 2005), we followed a consistent process when skeletonizing networks.

We began the skeletonization process by specifying the pipe diameters to be considered (namely $\leq$ 20, 30, and 40 cm) using a query in the software's *domain manager*. Networks were then skeletonized; dead-end pipes were trimmed, series pipes were reduced, and equivalent pipes were obtained by merging parallel pipes and then series pipes. (The software has specific options for (1) dead-end trimming, (2) series pipe reduction, and (3) maintaining hydraulic equivalency.)

When we performed dead-end trimming, we did not use any secondary options. Therefore, maximum trimming reductions were carried out for each iteration of the trimming process. When series pipe reduction was carried out, we specified that the *pipe ID/attribute retain choice* be *large diameter* and that the *demand distribution method* be *nearest junction*. No additional options were used for series pipe reduction. Secondary options were specified for hydraulic equivalency: *larger diameter* was selected for the *pipe ID/attribute retain choice* as was the *equivalent diameter* check box. We performed parallel and series merges using the *merge parallel* and *merge series* options. The number of junctions was not affected by the former; there was some decrease in the number of pipes. The series merge reduced the number of both pipes and nodes.

We consistently and iteratively carried out trimming, reducing, and merging, both parallel and series, on each network. We first performed trimming, then reducing, and finally merging for each of the three trim levels used. Five iterations were carried out to achieve maximum reduction in the number of pipes and nodes. Parallel merging was always done before series merging and was executed immediately after using the reduction option.

Appendix B: Hydraulic effects of skeletonization

Skeletonization affects estimated flow velocities and, consequently, water ages. Table B1 provides mean and median flow velocities for the original and skeletonized versions of Networks N1 and N3. Mean and median velocities increase substantially with the first level (20 cm) of skeletonization and then plateau or decrease slightly with additional skeletonization, consistent with the results reported by Bahadur et al. (2008).

The skeletonization process removes pipes with diameters below a certain size. The process largely influences flow velocities in pipes having diameters that are affected by the trimming process. Tables B2 and B3 provide statistics on flow velocities for pipes in Networks N1 and N3 with diameters that are affected and unaffected by the trimming process. The table show results for both the original network models and for the skeletonized models with 20 and 40 cm trims. Mean flow velocities and velocities ranging from the 25th to the 95th percentiles in pipes with diameters less that or equal to the trim level are substantially increased by skeletonization for the two trim levels shown for both Networks N1 and N3. However, there is little

Table B1. Mean and median flow velocities, Networks N1 and N3.

	Flow velocity (m s^{-1})	
Network	Mean	Median
N1	0.08	0.04
N1 20 cm	0.13	0.09
N1 30 cm	0.14	0.09
N1 40 cm	0.14	0.09
N3	0.17	0.05
N3 20 cm	0.29	0.13
N3 30 cm	0.29	0.13
N3 40 cm	0.28	0.13

Note: Flow velocities were determined for the last 24 h of a 168 h simulation, using a 1 h hydraulic time step.

change in the statistics for flow velocities for pipes with diameters greater than the trim level. For example, compare velocities in Table B2 for Networks N1 and N1 20 cm for pipes with diameters less than or equal to 20 cm. The skeletonized network has a considerably higher mean velocity (0.10 versus 0.06 m s^{-1}), as well as considerably higher velocities for the four percentiles shown. In the same table also compare velocities for Networks N1 and N1 40 cm for pipes with diameters greater than 40 cm. The mean velocities (0.33 and 0.32 m s^{-1}), as well as velocities for the four percentiles shown are similar for the original and skeletonized models. Note in Tables B2 and B3 that the fraction of pipes with diameters at or below the trim level is generally substantially larger than the portion with diameters above the trim level, even after skeletonization. especially for the 40 cm trim. For example, from Table B3, the fraction of pipes in Network N3 with diameters greater than 40 cm is only 0.04 and for N3 40 cm it is only 0.13.

Table B4 provides statistics on water ages for the original and trimmed models for Networks N1 and N3. Mean water age for the original and skeletonized models for Network N1 decreases with the level of skeletonization, as do the 25th, 50th, 75th, and 95th percentile water ages. Results are similar for Network N3, except for the median water age for the 30 and 40 cm trims, which has stabilized at 7.9 h. The effect of skeletonization on mean water age for the two networks is consistent with the findings of Bahadur et al. (2008).

Table B2. Network N1 flow velocities.

	Pipes		Flow velocity (m s^{-1})				
				Percentile			
Network	Dia.[a] (cm)	Fraction[b]	Mean	25th	50th	75th	95th
N1	$\leq$ 20	0.83	0.06	0.01	0.03	0.08	0.22
N1	> 20	0.17	0.17	0.05	0.12	0.25	0.55
N1 20 cm	$\leq$ 20	0.53	0.10	0.02	0.06	0.13	0.30
N1 20 cm	> 20	0.47	0.18	0.05	0.12	0.24	0.55
N1	$\leq$ 40	0.97	0.07	0.01	0.03	0.09	0.27
N1	> 40	0.03	0.33	0.13	0.32	0.50	0.67
N1 40 cm	$\leq$ 40	0.87	0.11	0.03	0.07	0.15	0.35
N1 40 cm	> 40	0.13	0.32	0.15	0.32	0.48	0.68

Note: Flow velocities were determined for the last 24 h of a 168 h simulation, using a 1 h hydraulic time step. [a]Pipe diameters considered. [b]Fraction of network pipes included.

Table B3. Network N3 flow velocities.

	Pipes		Flow velocity (m s^{-1})				
				Percentile			
Network	Dia.[a] (cm)	Fraction[b]	Mean	25th	50th	75th	95th
N3	$\leq$ 20	0.78	0.11	0.01	0.04	0.12	0.44
N3	> 20	0.22	0.41	0.06	0.24	0.60	1.33
N3 20 cm	$\leq$ 20	0.52	0.19	0.04	0.09	0.22	0.65
N3 20 cm	> 20	0.48	0.40	0.06	0.25	0.58	1.28
N3	$\leq$ 40	0.96	0.16	0.01	0.05	0.17	0.66
N3	> 40	0.04	0.60	0.19	0.50	0.89	1.72
N3 40 cm	$\leq$ 40	0.87	0.24	0.05	0.11	0.27	0.86
N3 40 cm	> 40	0.13	0.57	0.20	0.49	0.80	1.59

Note: Flow velocities were determined for the last 24 h of a 168 h simulation, using a 1 h hydraulic time step. [a]Pipe diameters considered. [b]Fraction of network pipes included.

Table B4. Water ages

	Water age (h)				
		Percentile			
Network	Mean	25th	50th	75th	95th
N1	29.3	11.0	18.1	33.7	105.4
N1 20 cm	23.5	8.8	14.5	27.7	70.0
N1 30 cm	19.6	8.5	13.5	25,2	53.5
N1 40 cm	18.0	8.2	12.8	23.7	49.3
N3	16.2	6.9	11.1	17.7	43.2
N3 20 cm	14.3	5.5	8.6	13.4	38.3
N3 30 cm	13.3	5.1	7.9	12.2	36.7
N3 40 cm	12.5	5.0	7.9	11.2	32.3

Note: Water ages were determined for the last 24 h of a 168 h simulation, using a 1 s water-quality time step and a 1 h hydraulic time step.