Responses to comments from Anonymous Referee #2 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 study is based on an integrated approach of contamination warning system (CWS) for water distribution system (WDS) for an incomplete network. It utilizes the TEVA-SPOT of EPA software for designing the CWS on the sensor placement. The CWS designs were developed by optimizing the sensor placement (5, 10, and 20 sensors) for worst-case and mean-case contamination events. The study reveals that further improvement in CWS designs network models to consider complete network or influence of uncertainty. However, a complete designs network was useful for CWS for water distribution system. The study is very useful for practicing water managers and academia. The utility of article will be increased if the authors would add/clarify some of the points in their manuscript. Authors have presented it as a case study but they only refer to Network N1 and N3 from Davis and Janke (2014). It would be better for any reader to follow the article if the authors provide/reproduce the details of the said network. The section 2 (Methods) forms the basis of any study and the authors have based their study on earlier reference work. The authors should explain their methodology and they may like to add more details about it as supplementary material. There is no mention of the improvement in the design network of CWS at what level (of performance level indicators). The performance should also factor in the hydraulic aspects of network. As mentioned in the results and conclusion that more network are needed for arriving at broader conclusion. The effect of number of sensors in different networks also needs more investigation. The present study will add to the understanding of the subject provided the authors add more details to their manuscript.

Responses:

“The utility of article will be increased if the authors would add/clarify some of the points in their manuscript. Authors have presented it as a case study but they only refer to Network N1 and N3 from Davis and Janke (2014). It would be better for any reader to follow the article if the authors provide/reproduce the details of the said network.”

To provide more detail on the networks we will include the following revised text to the Methods section: “The characteristics of the utility-developed network models used are summarized in Table 1, which provides the populations and areas served, numbers of nodes and pipes in the network models, the number of tanks, reservoirs, pumps, and valves in the models, as well as mean and median nodal populations. Network N1 is a looped system; N3 is a branched system. The WDS represented by Network N1 is located in a relatively flat area, with only a few pressure zones. N3 represents a WDS located in a substantially more complicated environment and has about 10 pressure zones.” The Supplement to the manuscript provides the complete .inp file for Network N1. Networks N1 and N3 have over 10,000 nodes each; showing maps at the scale that can be used in a journal publication would provide little information other than the general shapes of the networks. Therefore, we decided not to include any maps. Also, including a map for N3 could allow the system to be identified, which we cannot do.

“The section 2 (Methods) forms the basis of any study and the authors have based their study on earlier reference work. The authors should explain their methodology and they may like to add more details about it as supplementary material."

The approach used in the manuscript requires methods for network skeletonization, simulation of responses to an injection of contaminant, design of CWSs, and evaluation of results. The descriptions of the evaluation of results and the design of CWSs that are currently in the manuscript are complete. To expand the description of how network skeletonization was done we will add an appendix that provides the details of the process used. The description that will be added is included at the end of these responses (Appendix A). To provide more detail on the simulation approach, we will add the following paragraph to the Methods section:

> *"Determining impacts, which the CWSs considered in this paper were designed to minimize, requires estimating nodal populations and the quantity of contaminant ingested by each of the individuals in those populations during a contamination event. Nodal population is not provided in the network models; it was assumed to be proportional to nodal water demand. We also assumed that all persons served by a WDS could potentially be exposed to contaminated water. Contaminant concentrations in a network vary both temporally and spatially following injection of a contaminant. Estimating ingestion doses, which are required to determine impacts, therefore requires estimating when each individual in the network will be ingesting tap water. The quantity of water ingested for each ingestion event also needs to be estimated. Ingestion times were obtained with a probabilistic model developed based on time-use studies (Davis and Janke, 2008, 2009), which assumes that there are five daily ingestion events for each individual. A probabilistic model was also used for daily ingestion volume. An empirical distribution for daily water volume was developed using estimated per capita water volumes ingested by consumers of community water in the United States (U.S. EPA, 2000, 2004). Random values for daily water volumes for each individual at each node in a network were then obtained from this distribution by inverse transform sampling. These daily volumes were then divided equally among an individual's five daily ingestion events. Individuals were assumed to ingest the same volume of tap water each day during the simulation. The methodology used in carrying out these simulations is the same as that discussed in Davis et al. (2014) and is incorporated in TEVA-SPOT."*

"There is no mention of the improvement in the design network of CWS at what level (of performance level indicators). The performance should also factor in the hydraulic aspects of network."

We will include an evaluation of the influence of network skeletonization on network hydraulics, specifically flow velocities and water age. The evaluation will be included in an appendix. 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 material that will be added as an appendix is provided at the end of these responses (Appendix B). The manuscript has a substantial discussion of how network skeletonization affects CWS performance. It is not clear what additional discussion the referee is requesting in the statement "There is no mention of the improvement in the design network of CWS at what level (of performance level indicators).”

“As mentioned in the results and conclusion that more network are needed for arriving at broader conclusion. The effect of number of sensors in different networks also needs more investigation. The present study will add to the understanding of the subject provided the authors add more details to their manuscript.”

Broader conclusions will require the evaluation of more networks. Such an evaluation should also allow the effect of the number of sensors to be better understood. As stated in our responses above, we have added more details to the manuscript, as suggested.

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.

			Flow velocity (m s^{-1})				
	Pipes			Percentile			
Network	Dia.[a] (cm)	Fraction[b]	Mean	25th	50th	75th	95th
N1	≤ 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	≤ 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	≤ 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	≤ 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.

			Flow velocity (m s^{-1})				
	Pipes			Percentile			
Network	Dia.[a] (cm)	Fraction[b]	Mean	25th	50th	75th	95th
N3	≤ 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	≤ 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	≤ 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	≤ 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.