OFFICE OF RESEARCH AND DEVELOPMENT
National Homeland Security Research Center

TECHNICAL BRIEF

Assessing Potential Impacts Associated With Contamination Events in Water Distribution Systems: A Sensitivity Analysis

Purpose

This study examines the adverse effects of contamination events in water distribution systems using models for 12 actual systems that serve populations ranging from about 10^4 to over 10^6 persons. This study extends previous work (Davis and Janke 2010) and provides an improved understanding of the nature of the adverse effects that could be associated with contamination events. The results presented support water utilities, their consultants, and researchers in conducting contaminant vulnerability analyses and designing and implementing contamination warning systems.

Methodology

In this study, adverse effects are defined as the number of people who are exposed to a contaminant above some dose level (mass of contaminant in milligrams) due to ingestion of contaminated tap water. The number of people who receive a dose above a particular level defines the *impact* associated with an event. Impact refers to the number of people exposed above some level.

A wide range of dose levels are considered in order to accommodate a wide range of potential contaminants. For a particular contaminant, dose level can be related to a health effect level. For example, a dose level could correspond to the median lethal dose, i.e., the dose that would be fatal to 50% of the exposed population. The dose level required to reach a common endpoint can vary by orders of magnitude, depending on the toxicity of the contaminant. Highly toxic contaminants may be associated with a particular response at a very low dose level, whereas contaminants with low toxicity may only be associated with the same response at a much higher dose level.

This study examines how impacts depend on five factors that either define the nature of a contamination event or involve assumptions that are used in assessing exposure to the contaminant: (1) duration of contaminant injection, (2) time of contaminant injection, (3) quantity or mass of contaminant injected, (4) population distribution in the water distribution system, and (5) the ingestion pattern of the potentially exposed population. For each of these factors, the sensitivities of impacts to injection location and contaminant toxicity are also examined.

The sensitivity of impacts to the various factors studied is determined by comparing the impacts associated with different cases of a factor, for example, comparing 1-h versus 24-h injection durations. Impacts are estimated for injections at all non-zero demand nodes in a particular model. For the 12 networks considered in this study, the comparisons involve simulation of injections at thousands of nodes. In order to facilitate comparisons, locations of contaminant injection, which consist of network model nodes, are identified in terms of the ranking of the associated impact. The n^{th} percentile injection node is the node associated with the n^{th} percentile impact. Two types of sensitivities are examined with respect to the various factors: sensitivity that results in variations in the magnitude of the n^{th} percentile impact and sensitivity that results in changes in the injection locations that are associated with the n^{th} percentile and higher impacts.

Results

Impacts were found to be sensitive to all the factors examined. The degree of sensitivity is dependent on the particular water system, the location of contaminant injection, and the dose level or toxicity level of the contaminant considered. Sensitivity of impacts to all the factors considered tends to increase with decreasing toxicity of the contaminant, with considerable inter-network variability. With the exception of the population distribution, sensitivity to the various factors tends to be highest at lower impact levels (e.g., impacts below the 80^{th} percentile). Conversely, for the population distribution factor, sensitivity is lowest at the lower impact levels. For injection duration, impacts generally are higher for longer duration injections. Definite patterns are present in the sensitivity of impacts to injection time, but these vary substantially across the networks. As would be expected, impacts are larger for larger mass injections, but the sensitivity can vary dramatically depending on the contaminant toxicity level and the network. Estimated impacts can be sensitive to assumptions about how population is distributed in a network, particularly at high impact levels and low toxicity levels, again with considerable variability across networks. Finally, impacts can be sensitive to assumptions about ingestion patterns in the potentially exposed population, with sensitivities varying across networks and tending to be highest for low toxicity levels.

When the various factors are considered together (not including the ingestion model) and depending on the contaminant toxicity level, the magnitudes of impacts are most sensitive to injection mass or duration:

- At high toxicity levels, impacts are most sensitive to injection duration, although the relative changes in impacts due to changes in duration may not be large for high percentile impacts. Impacts are larger for longer duration injections and the increases tend to be more important for lower percentile impacts.
- At high toxicity levels, impacts are not particularly sensitive to injection mass, given a likely range in injection masses.
- At low toxicity levels, impacts are most sensitive to injection mass, with impacts increasing for larger injection mass.

The influence of the various factors on the location of high percentile injection locations can be as important or more important than their influence on the magnitudes of impacts. In addition, the choice of contaminant has a major influence on which nodes are high impact injection locations. The sharing (overlap) of the same high-percentile injection nodes for different values of a factor can vary substantially by contaminant and impact level (percentile of impact). Overlap tends to decrease with decreasing toxicity of the contaminant and increasing impact level for all the factors considered, with considerable variability among the networks.

Applications

The results of this sensitivity analysis can be applied in the design of CWSs and in the analysis of vulnerabilities of water distribution systems. CWSs are designed to minimize the adverse effects associated with a contamination event. Therefore, estimating such adverse effects is an important part of any CWS design. This sensitivity analysis should encourage designers of vulnerability studies and CWSs to consider (1) the factors that define a contamination event, (2) the possible uncertainties associated with establishing the distribution of the population within a network and estimating ingestion doses, (3) the contaminant used in determining adverse effects, and (4) network-to-network variability.

For more information: Visit the NHSRC Web site at www.epa.gov/nhsrc

Technical Contact: Robert Janke (513) 569-7160, janke.robert@epa.gov

Reference: Davis, M. J., and Janke, R. (2010). "Patterns in potential impacts associated with contamination events in water distribution systems." Journal of Water Resources Planning and Management, (16 March 2010), 10.1061/(ASCE)WR.1943-5452.0000084

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