White Paper: Development of Methods for Tracking Exposures to Contaminants in Drinking Water

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1. INTRODUCTION

After three and a half years of work developing the foundations for an Environmental Public Health Tracking Network (EPHTN), several states have found themselves facing similar, specific technical problems in the development of methods to track population exposures to contaminants in drinking water. Rather than each state trying to solve these problems on their own and share their results after their work has been completed, a number of states worked together to develop a proposal to the Centers for Disease Control (CDC) to support their efforts to jointly develop methods and identify needs. This proposal was funded and the states (WI, WA, NM, NJ and CA) formed the Drinking Water Exposure Group (DWEG). This group worked on a number of these issues, coordinated the assessment of different potential methods, and shared the use of specialized technical resources. The group solicited the input of two prominent epidemiologists who have conducted epidemiological studies of the risks associated with contaminants in drinking water: Dr. Ken Cantor of the National Cancer Institute, and Dr. Jay Nuckols of Colorado State University. The other members of the DWEG are listed in Appendix A.

The purpose of this paper is to describe the issues, new information, methods, limitations, and possible solutions for estimating exposure to drinking water, as a means of improving and standardizing methods used by EPHT states. The paper is meant to provide the CDC Tracking Branch, the Drinking Water Content Workgroup, and the states funded to implement the EPHTN with an outline of what the relevant drinking water exposure assessment and surveillance issues are and provide insight into potential next steps and projects for the national EPHTN to take. These lessons learned and recommendations may serve as a foundation for the drinking water content workgroup and for use by tracking and non-tracking states to develop and implement drinking water surveillance and exposure assessment methods.

By providing this guidance to the EPHT community, this report also serves to inform several other audiences about the need for improved surveillance capacity and enhanced tools and methodologies for EPHT in the area of drinking water and related exposure assessment. State environmental agencies (e.g. primacy agencies) drinking water programs, the United States Environmental Protection Agency (USEPA), the United States Geological Survey (USGS), and public utilities may find these results useful for understanding the importance of routinely collecting drinking water data beyond regulatory monitoring and compliance. Researchers and other environmental health practitioners may find this document useful for highlighting and communicating the difficulties and obstacles faced in tracking drinking water exposures for use in epidemiologic investigations or routine public health assessments.

1.a. Environmental Public Health Tracking

Environmental public health tracking is the systematic, coordinated public health surveillance of hazards, exposure and potentially related health outcomes. The overall goals of tracking are to improve our understanding of the relationship between environmental exposures and public health outcomes. In January 2001, the Pew Environmental Health Commission identified core functions needed to enhance environmental health surveillance capacity in the United States through the development of the EPHTN. Information, methods, tools and infrastructure developed to support a tracking network should advance

the environmental public health communities ability to perform the following surveillance functions (Pew 2000).

- identify populations at risk;
- respond to outbreaks, clusters and emerging threats;
- establish the relationship between environmental hazards and disease;
- guide intervention and prevention strategies;
- identify, reduce and prevent harmful environmental risks;
- improve the public health basis for policy making;
- enable the public's right to know about health and the environment;
- and track progress towards achieving a healthier nation and environment.

Recent studies have shown potentially adverse health effects from exposure to contaminants in drinking water slightly above or below the Maximum Contaminant Level (MCL). Epidemiologic studies have reported associations between consumption of contaminated drinking water and incidence of cancer (Hildesheim et al. 1998; King and Marrett 1996; Koivusalo et al. 1997) and adverse reproductive effects (Aschengrau et al. 1998; Aschengrau et al. 2003; Bove et al. 2002; Bove et al. 1995; Cantor et al. 1998; Cantor et al. 1999; Dodds et al. 1999; Kanitz et al. 1996; Klotz and Pyrch 1999; Nieuwenhuijsen et al. 2000; Reif et al. 1996; Savitz et al. 1995; Waller et al. 1998). However, the methods used to assess exposure and endpoints in these studies vary and the results are difficult to synthesize. In a review of reproductive and developmental effects of disinfection by-products (DBPs) in drinking water, Reif et al. (1996) concluded, "Epidemiological studies have found associations between elevated levels of contaminants in drinking water with adverse health outcomes, such as increased cancer rates and adverse pregnancy outcomes. A major criticism of these studies is the inadequate characterization of exposure." Other reviews also suggest that the major difficulty in studying such epidemiological associations lies in the exposure assessment (Nieuwenhuijsen et al. 2000; Swan and Waller 1998).

The exposure assessment difficulties facing researchers also pose a challenge to public health practitioners at the state and federal level developing the EPHTN. Creating a meaningful EPHTN is dependent on having the appropriate data and estimation tools, and data needs for tracking measures go beyond simple measures of water quality. These needs have become apparent during the initial development of pilot projects for the development of the EPHTN, and were the impetus for this work.

1.b. Project objectives

To begin developing methods for overcoming these limitations, the DWEG focused on the following objectives:

1) Identify existing and potential methods for;

- characterizing variations in water quality in water supply and distribution systems over time and within a distribution system;

- linking individuals or small population groups to specific water supplies, and, if possible, hydraulically independent units within a distribution system;
- linking individuals or small population groups to small, unregulated water systems or private domestic wells; and
- estimating exposures to contaminants in water from these small systems when direct water quality observations are not available.

2) Assess the feasibility of incorporating the most promising methods into an EPHTN in terms of;

- cost and effort;
- hardware, software and IT infrastructure;
- availability of current and historical data sources;
- required level of expertise;
- accuracy;
- external factors which affect the ability to use a method or to acquire additional water supply information (e.g. cooperation of outside parties or regulations that limit reporting requirements); and
- characteristics of a situation or system which may make a method more or less appropriate.

3) Open communication lines with water systems to establish relationships, identify collaborative opportunities, and perform outreach/education in Environmental Public Health Tracking issues surrounding drinking water.

4) Disseminate the results to other states and other stakeholders through technical white paper.

The PI of the working group was from California; however, other states contributed technical input and oversight and fully participated in forming work agenda. A full-time research scientist with a background in environmental engineering was hired to assist in facilitating working group activities and to assist states in conducting a feasibility assessment. The overall work plan and regular input was provided by a designated individual from each participating state. Three face-to-face working group meetings, email, quarterly conference calls, and other conference calls when needed were used to facilitate the working group activities.

2. ISSUES AND FRAMEWORK

The United States has one of the most reliable systems of public water supplies, delivering generally high quality water to hundreds of millions of citizens. While the infrastructure and regulations help to assure the quality of this water, there are still areas of the US where existing contaminant levels may pose residual risks to the population. Further, there is a much lower level of assurance for those families served by small community water supplies not covered by the Safe Drinking Water Act (SDWA), or by private domestic wells which are virtually unregulated. As such, tracking hazards and exposures related to contaminants in drinking water remains an important aspect of an EPHTN, both at the state and national level.

2.a. Drinking water related measures for EPHT

One key function of EPHT is to collect data relevant to environmental public health, use those data to create useful information, and make those data and the resulting information available to end users. Within the context of EPHT, there are three types of information: information regarding hazards in the environment, information regarding exposures to individuals and populations, and information regarding health outcomes. Other environmental health indicator efforts have also identified the area of prevention efforts as an important aspect of data collection and interpretation.

There are several measures or conceptual constructs that may be of interest in the area of drinking water, depending on the specific application or use of an indicator. The quality of water delivered to consumers can be interpreted as both a measure of a hazard and of exposure. The proportion of systems meeting water quality regulations and goals can be a measure of the effectiveness of prevention efforts, as well as a measure of the hazard. The proportion of a population or demographic group receiving water of a certain quality is a measure of population exposure. The proportion of a population which is served by unregulated water systems or private domestic wells is a measure of the potential for exposure. Each of these measures can be interpreted as capturing some aspect of a hazard, exposure or intervention effort.

Changes in the prevalence or incidence of health outcomes attributable to one or more contaminants in drinking water are a problematic indicator of public health impacts of drinking water quality for several reasons. First, many health outcomes associated with exposure to contaminants potentially in drinking water are relatively rare, in part because most regulated water supplies meet SDWA MCLs. As a result it would be expected that the residual risk associated with exposures for levels below the MCL, or from exposure to unregulated contaminants, would likely be subtle. In addition, there may be several routes of exposure to any specific contaminant, any one outcome is likely to have multiple risk factors and it is difficult to estimate precisely what fraction of the observed cases could be attributed to exposure to contaminants in drinking water, and multiple health outcomes may need to be assessed to estimate the full public health impact.

The main surveillance goal identified by the DWEG was to capture measures of population level exposures to contaminants in drinking water, recognizing that exposure to these contaminants may be through routes other than ingestion (i.e. inhalation and dermal absorption). This objective was felt to be the most appropriate for a tracking application as it captured not only the aspects of water quality, but the overall potential for a public health impact. A secondary focus was on estimating exposure for individuals or small groups in the context of epidemiological studies. In addition, and subsumed into these objectives, are measures of the quality of water delivered, and the effectiveness of efforts to provide drinking water quality which meets public health standards.

Estimating the level of exposure to a population is a meaningful measure that provides a public health context to measures of drinking water quality. While such measures are conceptually simple (e.g. the proportion of a population consuming water at or above some level of contamination), actually deriving such measures can be quite complex and involve gathering data which is not readily available. The purpose of this paper is to present the primary issues associated with deriving measures of population exposure to contaminants in drinking water, present and critique currently used methods, and offer recommendations for further research and enhanced data collection to improve these measures.

2.b. Determinants of exposure to contaminants in drinking water

There are three potential routes of exposure to contaminants in drinking water. First, contaminants may be ingested when water is ingested directly or as part of foods which are prepared using water. Second, compounds may be inhaled if it volatizes or aerosolizes, either during showering or from appliances such as dishwashers. Third, some compounds may be absorbed directly through the skin during bathing.

While the level of exposure depends on the concentration of contaminants in the water delivered to the home, business or school, personal behaviors are key determinants. Exposure via ingestion depends on the sources and patterns of drinking water consumed (i.e. tap vs. purchased), the methods of food preparation using water, and the use, type and maintenance of water filters. Inhalation exposures would depend on the frequency and duration of showering and use of appliances which can volatize or aerosolize contaminants. Absorption depends on the frequency and duration of water contact.

The quality[1] of water delivered to a consumer[2] is a function of the quality of water input to the distribution system and may be affected by complex physical, chemical and biological processes that occur in the distribution system. The impact of such processes can be affected by a number of factors, such as the length of time in the distribution system, the hydraulics and physical layout of the system, and the materials used in the distribution system.

There may be several inputs to a distribution system, and each input may have different levels of contaminants, temporal variability in the levels of contaminants, and temporal variability in the volume of water that was introduced to the distribution system. As such, the hydraulics of the distribution system may play a central role in determining the water quality that was delivered to any specific consumer. Many factors affect the level of mixing of each input during distribution and the proportion of water at each point in the distribution system. Having only one input source simplifies and reduces the effects of system hydraulics on delivered water quality.

The temporal variability in quality of an input source may be a complex result of several factors. Water treatment clearly impacts water quality; the quality of the finished water will depend to some extent on the quality of raw water sources. If, or when, more than one source of raw water is used, the quality of water at the beginning of the treatment train will depend on the quality and relative contribution of source waters to the treatment process. In many situations water enters the distribution system via a connection, or intertie, to another distribution system. Intertie inputs are the result of the source quality, relative source contributions, treatment, and distribution system effects up to the point where the water enters the distribution system.

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[1] Quality refers to the concentration of contaminants in the water and not to factors affecting only taste, color and/or odor.

[2] Consumer may refer to a home, a business or a school.

Finally, generating measures of exposure for populations and sub-populations based on geographic and/or demographic factors depends on knowing the characteristics of those individuals who live at a specific residence, and who spend time at a specific business or school.

2.c. Framework for estimating population exposures to contaminants in drinking water

Clearly, population exposures can be the result of extremely complex processes, and any practical method will generate only an estimate of population exposure. In some circumstances the situation will be relatively simple, such as a private well serving a single household or a small number of residences served by a single well via a single branch distribution system. Systems serving large populations are typically much more complex with multiple sources of raw water, treatment trains, points of entry, and hydraulic zones. In all these situations the general approach consists of four steps:

1) Estimate the quality and quantity of water input at each "Entry Point to the Distribution System" (EPTDS).

   This may be based on direct observations of water quality at the EPTDS and/or estimates of water quality based on source quality and treatment effects. For private wells this would be the measured or predicted quality delivered by the well.

2) Estimate the quality of water for each zone in the distribution system which would be expected to have similar water quality (water quality zone or WQZ).

   This would be based on the quality and quantity of the inputs to the distribution system, direct observations at the periphery of the distribution system, and information about the hydraulic characteristics of the distribution system. For private wells or simple water systems there would only be one water quality zone.

3) Estimate the population and the demographic characteristics of the population served by each water quality zone.

   There are several potential methods, such as using spatial overlays of demographic data onto distribution system extent layers, which are reviewed below.

4) Estimate exposures to contaminants in delivered water for populations and sub-populations based on their water use behaviors.

   This would be based on the estimated water quality delivered to the service connection (based on

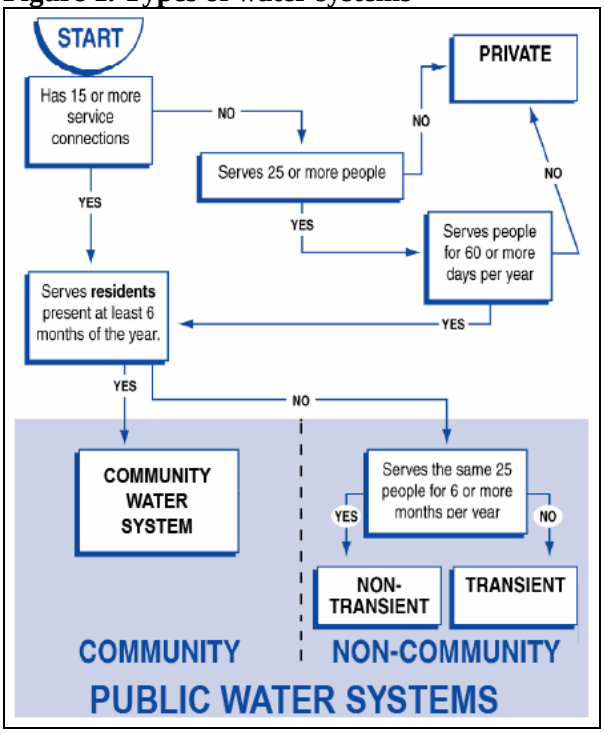
water quality zone) and observations and/or assumptions about water use behaviors. This is discussed in Section 5.

This document describes potential methods for completing these steps and the available and new data needs in order to use these methods.

2.d. Types of water systems

The specific methods and available data for carrying out these methods varies depending on the type of the system, the size of the system, and the level of federal, state and local regulation. The primary legislation regulating the operation of drinking water systems is the Safe Drinking Water Act (SDWA), first promulgated in 1972. The SDWA regulated PWS, which are defined as systems which have at least 15 connections or serve at least 25 people per day for 60 days of the year (see Figure 1 below and http://www.epa.gov/safewater/sdwa/30th/factsheets/understand.html). Systems that serve the same people year-round are Community Water Systems (CWS). Other systems are non-Community Water Systems and include systems such as schools that serve the same people but not year-round (i.e., Non-transient non-community or NTNC), or systems that do not serve the same people for more than six months (i.e. Transient non-community or TNC). The water quality monitoring requirements under the SDWA are different for each type of PWS, and also vary by the size of the system.

Figure 1. Types of water systems



Source: Adapted from WI DNR website, http://www.dnr.wi.gov/org/water/dwg.

Systems which serve more than one household, but less than 15 connection and 25 people, are not regulated under the SDWA, and are referred to in this document as “small community water systems” (SCWS). The monitoring and operational requirements vary by state. Systems that serve single households, or a few households are considered “private domestic water systems” (PDWS). The term “domestic well” refers to wells that provide water to either SCWS or PDWS. The distinction between a SCWS and private well is not legally defined in many states. The monitoring and reporting requirements for private wells and SCWS varies between states.

Estimates of the number of people served by CWS, SCWS and PDWS are not readily available, however, the USGS has generated estimates of the population of each state "self-served”, meaning not served by a CWS (see section 4). Overall in the US about 85% of the population is served by CWS. However, based on estimates derived by the USGS, private wells and SCWS are much more likely to have levels of pesticides, arsenic and nitrates that may be of concern. Thus, the high population makes estimating exposures for those on CWS important, while the potential for higher levels of contaminants makes estimating exposures for those on SCWS and private wells important.

Given the differences in monitoring requirements and system complexity between CWS, SCWS and PDWS, the methods and data needs for estimating population exposures are quiet different for each type of water system. Data and methods for estimating population level exposures for those served by CWS are presented in Section 3, while those related to PDWS are discussed in Section 4. SCWS share attributes of both CWS and PDWS; and as such the data and methods are addressed in both sections. Data and methods for taking behavioral and household factors into account in generating exposure estimates are covered in Section 5.

3. ESTIMATING EXPOSURES FROM CONTAMINANTS IN COMMUNITY WATER SYSTEMS

The most common type of water contaminant exposure assessment occurs in instances where traditional health surveillance data is linked in space and time with water quality data reported by CWS. This white paper uses the same definition of CWS as is used by the federal Safe Drinking Water Act (SDWA). The SDWA defines CWS as public water systems serving the same resident population 6 or more months per year and either having 15 or more service connections or serving 25 or more people. The SDWA covers other types of systems (i.e. non-community water systems with transient and non-transient populations), however, the linkage of these systems in space and time to traditional health surveillance data is more tenuous for exposure purposes and is not addressed in this assessment.

Some states (e.g. CA, NJ, and WA) have additional regulations that mandate monitoring and reporting for “small” community water systems which have fewer than 25 consumers or 15 connections. This paper refers to these types of water systems as "small" CWS or SCWS. Statewide water quality monitoring databases (e.g. CA and NJ) often include sampling records originating from SCWS. As defined by each state primacy agency, there is a lower limit on population size or number of connections for SCWS, and any entities falling under this limit are considered private domestic water sources or wells. Section 4 addresses SCWS and individual private domestic water sources/wells in more detail, including specific

issues related to SCWS, especially when data-related issues or exposure assessment methodologies are slightly different than those encountered with SDWA-regulated CWS.

The objective for exposure assessment in a CWS context is to systematically link individuals or small populations to relevant and representative water quality samples. There are, however, two factors that complicate this methodology. First, water quality often changes after it is sampled; concentrations of a contaminant can change before delivery to consumers due to dilution/mixing and chemical reactions in the distribution systems or filtering/treatment in the home. Second, existing CWS data do not typically describe where water flows after it is sampled, especially with respect to consumers or specific populations that come in contact with drinking water. Although a sampling station might have very accurate longitude/latitude coordinates, proximity to a sampling station does not always imply connectivity along a flow path.

Allowing for historical exposure reconstruction was outside the scope of this assessment. The following analysis assumes limited flexibility in estimating exposures for historical water quality information. Many of the methods take into account time-transient information about water system operations and water monitoring practices, however, collecting and characterizing very old information (>5-10 yrs) is considered a resource prohibitive task. Therefore, the focus of this section is on exposure estimation using current data.

This section is organized to first describe the types of relevant water quality information available and the conditions for its collection. The information is assessed with respect to estimating water quality information at key points within a community water system. Emphasis is primarily placed on establishing water quality estimates before the entry point to the distribution system (EPTDS) and then for estimating contaminant levels at service connections with the distribution system. There is an assessment of methods for linking water quality estimates and the estimated population which comes in contact to the drinking water. Methodologies and data needs for determining the population served by a water system are discussed. This is followed by a discussion of the features or special cases of different water systems that make this determination difficult, establishing a classification scheme to distinguish between water systems based on this complexity. In filling the data gaps that obstruct systematic water contaminant exposure estimation, the requirements for new information system applications and subsequent data elements are proposed and discussed. This section concludes with a consideration of issues in calculating exposure metrics and a summary of recommendations.

3.a. Water quality data for CWS

This paper places a large emphasis on water quality data for CWS, because they account for water delivery to the majority of the U.S. residential population and there are strict federal regulations that govern the ongoing monitoring and reporting of water quality information by CWS. State primacy agencies with jurisdiction over public water systems continuously compile water quality monitoring data into large state-level databases and report a subset of this data (typically just regulatory violations) to the USEPA Safe Drinking Water Information System (SDWIS).

The ability to generate estimates of exposures to contaminants in drinking water depends to a great extent on the availability and quality of water quality data. The available data are a combination of data collected to meet regulatory requirements, and that collected at the discretion of the utility to help with the operation of the utility. While the regulatory requirements are based on the SDWA, each state may have additional sampling requirements. Some states (e.g. CA, NJ, and WA) have additional regulations that mandate monitoring and reporting for “small” CWS, and these results are available from the same information system as the data collected to meet SDWA requirements.

Current SDWA monitoring regulations often require increased monitoring of larger CWS and less frequent monitoring of smaller CWS. Specific contaminants also have different monitoring schedules and these monitoring schedules often change over time as revisions to existing regulations are made. The majority of federal regulations require that sampling for maximum contaminant levels and treatment techniques are applied and monitored before the EPTDS. There are also federal regulations governing water quality monitoring within distribution systems for contaminant classes (disinfection by-products, lead, and copper). Individual states may have modified sampling requirements, but those are generally more stringent and often result in the reporting of water quality data at sampling locations situated before treatment and closer to source or intake locations.

The Standardized Monitoring Framework (SMF) is a federal framework established by USEPA in 1991 to standardize, simplify and consolidate monitoring requirements across contaminant groups by reducing the variability within monitoring requirements for chemical and biological contaminants across system sizes and types. Primacy agencies within states can issue waivers with EPA approval to account for regional and state specific characteristics and concerns. The framework is set within nine-year cycles, starting in 1993. The second cycle started in 2002. Contaminant groups that fall under SMF or newer federal regulations and are of exposure assessment interest include nitrates/nitrites, asbestos, lead/copper, other inorganic contaminants (IOCs), synthetic organic contaminants (SOCs), volatile organic contaminants (VOCs), disinfection by-products, and radionuclides. The monitoring requirements for each of these contaminant groups are described in greater detail in Appendix B.

Factors that influence monitoring frequency requirements are source water type, samples at or below the limits of detection, samples at or consistently and reliably below the MCL, and water system type and size. Monitoring requirements for IOCs, SOCs and VOCs are relatively similar. In general for each contaminant class, systems served by groundwater sources are required to monitor less frequently than surface water systems. Systems with waivers from the EPA or for which analytic samples are below detection limits are required to sample less frequently than systems without waivers or those with samples greater than detection limits. If a system has detections consistently at or below the MCL, they are required to monitor less often than systems with analytic samples greater than the MCL. Most often if an analytic sample is above an MCL, the system is required to take four quarterly samples at each EPTDS for one year, and continue for a time frame that is designated by its primacy agency.

3.b. Estimating water quality at the entry point to distribution system

The level of contaminants reaching the service connection of drinking water consumers depends on the quality entering the distribution system, and the changes in quality occurring during distribution. Most constituents are sampled at the EPTDS, providing information that can be used directly as an exposure estimate. There are, however, certain water quality conditions and exposure assessment objectives when source water sampling, combined with information about the effects of treatment, can provide additional detail for estimating levels at the EPTDS.

3.b.1. Using water quality measurements at source

A source sample can be one of two types of samples, raw or untreated. A raw sample, implying later treatment downstream, can be situated at a representative location within a surface water body (e.g. grab-sample in a reservoir or river), at the intake of a surface water body, at an import connection/intertie, at the wellhead of a groundwater source, or at a point just before treatment. Water systems frequently monitor raw water with known contaminants to inform blending and treatment operations downstream. Treatment plants always have a sampling location before raw water enters the plant, and sampling points are sometimes placed between specific treatment operations.

Untreated samples are situated after water is extracted from a groundwater source (e.g. pumped to wellhead or at a spring). There are very few instances of an untreated surface water sampling station, since very few surface water sources have treatment waivers. Some untreated groundwater sources can flow over relatively long transmission distances, while other untreated groundwater sources can be situated near the EPTDS. Untreated groundwater sources with known contaminant presence (e.g. nitrates), will perform frequent sampling to inform downstream blending practices.

According to USEPA's Standard Monitoring Framework (SMF), the majority of reportable water quality testing occurs at the EPTDS. Furthermore, in many situations, the frequency of sampling drops if previous samples demonstrate low levels of a contaminant. While this practice is more cost-effective when the sampling objective is to assure that the level of a contaminant is below the MCL, less frequent sampling makes it more difficult to generate good estimates of population exposures to low-levels of a contaminant (e.g., at levels below the MCL), and/or for shorter or more specific periods of exposure.

For example, consider a water system that has installed an aeration tower to volatilize an organic contaminant that is consistently and persistently present at a raw groundwater source. According to the SMF, the water system needs to test only for volatile organic compounds (VOCs) at the EPTDS once every 3 years, if the previous 3 annual samples were less than the MCL. For exposure assessment periods that are less than 3 years, EPTDS sampling is more likely to not overlap this period. Conversely, raw water sampling frequency during this period will likely continue at the same frequency and is more likely to overlap the exposure period. Moreover, though a EPTDS sample in this situation might overlap the exposure period, concentrations of contaminants in systems with monitoring waivers are often lower than the analytical method detection limit. A raw sample resulting in a detection that corresponds to a non-detect EPTDS sample provides additional relevant and detailed information to inform water quality

conditions entering the distribution system that would not have been possible using EPTDS sampling alone. Hence, for short exposure periods or low exposure concentrations, EPTDS samples alone are not as representative of water quality conditions in the distribution system, because EPTDS samples are less frequently administered than source samples and are more likely than source samples to result in a non-detect.

To assess whether EPTDS and raw sampling practices manifest in actual reported data, analytic results from raw sources were compared to corresponding post-treatment samples for water systems in California. The raw samples included in this analysis were those that had detectable levels of any regulated contaminant. As raw samples are not usually taken on the same schedule as the EPTDS samples, samples were matched if they were taken within 365 days of one another. Comparing samples in this manner provided an estimate of the differences between sampling practices observed at raw water sampling stations to post-treatment sampling practices for the same time interval. This analysis used samples taken between 1986 and 1996.

Seventy-two percent of the raw water samples having detectable levels did not have a corresponding EPTDS sample within 365 days. Ten percent of the raw water samples with detectable levels had a corresponding EPTDS sample, but with no detectable concentrations. In the context of time- and space-dependent exposure assessment, this indicates that raw water quality data may be able to provide a substantial amount of information not directly captured by EPTDS monitoring. Further, comparing raw water results with EPTDS sampling may provide some level of validation of the estimated effectiveness of a specific treatment process.

If these results reflect sampling practices in other states, this finding has important implications for exposure assessment and tracking methodologies. For source water contaminants (not, for example, THMs formed after treatment), raw water sampling may help to augment EPTDS sampling. This is particularly true for situations in which low contaminant levels (near the analytic detection limit) or short-duration exposure periods are of interest.

Ideally, raw water sampling results should be adjusted and factored into a final exposure metric to reflect the dominant conditions that might alter the contaminant concentration before reaching the EPTDS. Treatment and dilution/mixing were identified as the two most prominent factors that affect raw water contaminant concentrations after sampling. Section 3.b.2 below describes methods for adjusting raw water samples to take into account contaminant removals due to treatment. In accounting for dilution of raw water samples, the sequential connectivity and flow distance between raw sampling locations, through treatment, and to downstream EPTDS stations should be factored into an exposure metric. Next in importance is capturing temporal changes in sampling station configuration from source-to-treatment-to-EPTDS. For example, a drinking water tracking system should reflect whether a source provided flow to one EPTDS during a given time period, then was inactive during some other time period. In situations where the corresponding flow from multiple raw sampling stations contribute to a downstream EPTDS, the time-dependent absolute production (e.g. # gpm) or relative flow contribution (e.g. ##%) figures should be factored for each raw sample.

The advantage of being able to factor source water sampling into an exposure metric is clear, since these data constitute such a large portion of the water quality data relative to other sampling locations within a water system. The disadvantage is that treatment and mixing must be taken into account to adjust these

data to reflect expected quality at the EPTDS, and as such, additional data are needed to make such adjustments. The precision of these final estimates would only be as good as the precision of the input data.

3.b.2. Using water treatment information

Treatment information may be crucial for adjusting raw water quality observations to estimate concentration levels that would be seen at the EPTDS. Some state-based water quality monitoring databases maintain detail on the types of treatment operations for each water system. For other states such information may only be available in paper form from regional state engineers. Some states link specific treatment trains to specific water sampling locations after treatment.

Estimating post-treatment levels for a given contaminant using raw water sampling data requires modeling the removal of that contaminant based on the specific treatment train, or using existing estimates of the removal efficiency for that contaminant. The simplest model involves the use of a published effectiveness; for example, a literature review on reverse osmosis removal rates for arsenic might establish 5µg/L as the removal objective. In other cases a sequence of operations would lend to a removal rate; For example, coagulation-flocculation-sedimentation-filtration might be found in the literature to reduce mercury levels by 90%.

The advantage of this method is that, beyond understanding which raw sampling stations are affected by a specific treatment train and when specific operations went into effect, data about water treatment operations need to be compiled for a single point in time. The downside is that the estimated removal rate of a specific operation or sequence of operations will be the same for all treatment plants using those unit processes. This may limit the ability to generate accurate exposure estimates and differentiate exposure levels among populations in systems with similar treatment objectives but with specialized equipment that may have slightly varying removal rates.

Water systems may be able to provide information on actual removal rates based on raw and finished water results, or more sophisticated models may be developed specifically for that treatment train. These system-specific models would either require water systems to report treatment objective information on targeted contaminants and operation-specific removal rates or would require an analysis of variation in raw and treated samples taken during the same time frame. The latter method could establish a maximum or average removal rate that is approximated using existing sampling information. For example, if it is known that ion exchange is performed on a raw water source, and it is also known that arsenic levels decrease from 50µg/L at the raw water sampling location to 5µg/L at the EPTDS, and there are no other factors influencing arsenic concentrations before the EPTDS, then a 90% removal rate could be assumed. This method provides an ability to impute values for missing data and enables a way to incorporate the removal impact of treatment on source water quality that varies with time, water system (or sampling sequence), individual treatment operations, and specific contaminants.

Treatment information can also be useful for assessing potential for the formation of disinfection-byproducts (DBP) when distribution system sampling is felt to be inadequate. For the same reasons that a point-of-entry sample might be unrepresentative -- in studies of low concentration exposures over short

exposure periods -- distribution system samples might not provide the level of detail to estimate potential exposures. In these situations, knowing the type of disinfection performed at a treatment plant and analyzing with respect to other water quality parameters and operational configurations that are precursors to the formation of disinfection by-products (DBPs) could provide additional low intensity or time-sensitive resolution beyond that of typical distribution system sampling. For example, color, pH, temperature, and organic carbon measurements can be used in to predict the formation of DBPs using physio-chemical models.

3.b.3. Using water quality measurements at EPTDS

The EPTDS is where potable water is added or introduced to distribution mains for delivery to customers; water quality measurements at this point may be used directly to estimate levels of contamination entering the distribution system. The ‘source’ of that input may be the finished water from a water treatment plant, water from a storage tank, untreated water from a single source, or blended water from several sources, or water provided from another water system via an intertie. For a water system having treatment facilities, the location of an EPTDS typically follows treatment. With treatment and blending of source water occurring upstream, and, given the variety of water system configurations, the EPTDS sampling point is consistently the most representative monitoring location for estimating downstream exposures within the distribution system.

For sources that undergo treatment, this sampling point is commonly coded as “treated” in state water quality monitoring databases. There are, however, other instances where an entry point sample cannot be systematically queried from a monitoring database. For example, groundwater that does not undergo any treatment is often coded as “untreated”. Untreated water can either be introduced directly to the distribution system or be combined with other sources (raw, treated, or untreated) prior to the EPTDS. In the first instance an untreated sample is as representative as any other EPTDS sample, while in the second case, it is not representative of water quality entering the distribution system. For this reason, it is very important that there be a comprehensive method for identifying and coding sampling stations so it is clear if they represent conditions at the EPTDS.

There are other special cases where the definition of an EPTDS is ambiguous. This is particularly true in cases where finished water is sampled and then subsequently routed to a storage facility whose input to distribution mains can be considered an entry point. If flow stemming from the storage facility is not sampled prior to entry to distribution system, and the storage facility has a residence time that exceeds the period by which a contaminant level can significantly change (e.g., DBPs and short-lived radioisotopes, like radium-224), the finished water sample is not necessarily indicative of the levels entering the distribution system from the storage facility. In these situations, having pre-storage sampling and knowing the average residence time of a storage facility and time-dependent flow rates in and out of a storage facility, provides enough input information to estimate contaminant levels exiting the storage facility. This calculation is not necessary for contaminants whose levels are stable relative to the storage residence time.

3.c. Estimating water quality at the customer service connection

The second step is to estimate the quality of water being supplied to the residence. Only a few constituents are sampled within and/or at the periphery of the distribution system, and in general there are relatively few sampling points that can be used to characterize water quality at all service connections. As such, providing estimates of water quality for all service connections will require adopting assumptions and/or modeling of the relationship between water quality measurements in the distribution system and/or at each EPTDS, and the quality at each customer service connection. Such 'models' may be as simple as assuming that the quality of water in the entire distribution system is homogenous. The relationship between EPTDS contaminant levels and service connection levels may be simple or very complex and will depend on the hydraulic complexity of the distribution system, chemical of concern, and the chemical and physical characteristics of the distribution system.

3.c.1. Using EPTDS water quality estimates

The degree to which EPTDS samples represent the quality delivered to a service connection depends on three primary factors: the number of inputs (i.e. the number of EPTDS) to the distribution system, the hydraulic complexity of the distribution system, and, for constituents whose concentration may be affected during residence in the distribution system, the effects of those processes.

If water is input to the distribution system from a single EPTDS, then EPTDS data can be used directly to represent the quality of water delivered to a service connection, at least for conservative contaminants (i.e., not subject to reactive decay or increase between the point of sampling and the point of consumption).

In cases where multiple EPTDS serve a distribution system, data from one EPTDS may be used to represent a part of the overall distribution system if the water in that part of the distribution system comes from only one of the inputs. In such cases water quality would be expected to be relatively uniform within that part of the distribution system. Such areas will be referred to as "water quality zones" or WQZ in this paper. A water quality zone may be treated as if it were a simple distribution system with a single EPTDS. In many instances pressure zones in a distribution system may be used to delineate such WQZ as pressure zones often delineate areas of the distribution system which are hydraulically isolated from the rest of the distribution system. Sometimes, however, a pressure zone may have multiple points of interconnection with the rest of the system, and water quality within this area may not be homogeneous. Thus, it is crucial to determine whether an entire distribution system would be typically homogeneous for a conservative contaminant, and whether the pressure zones would similarly be homogeneous.

In cases where there are multiple EPTDS, but the configuration of the distribution system indicates that water from the inputs is mixed before reaching residential service connections, it is necessary to know the time-dependent relative flow contributions or absolute rates of input at each EPTDS to the distribution system or WQZ. These figures could be used to adjust the observed concentration levels seen at EPTDS sampling stations to reflect the probable degree of mixing during delivery to the distribution system/WQZ. Pump production information would be the best estimate, but pump capacity may be a

reasonable surrogate. There may be seasonal changes that could also be informative (e.g., “the well was only used at peak summer demand”) so that intermittently high contaminant levels could be captured. In the absence of pumping data, information describing when there was no input from an EPTDS, such as whether a well or surface water intake was off-line for repairs or maintenance, would be essential.

Much more rigorous flow modeling is required in cases where multiple EPTDS contribute flow to different parts of a distribution system, so that the relative volume of water from each input varies at different points in the distribution system or WQZ. This is typically the case for distribution systems with multiple EPTDS. An example of this situation is a groundwater well that pumps directly into a distribution system, which is also fed by other sources through other EPTDS. This problem can typically be solved with a time- and space-dependent hydraulic model (e.g., EPANET) that takes into account piping network configuration/operations and connection- or node-specific demand.

Such models require detailed information about the distribution system. In addition to the difficulty of collecting such detailed information for a large number of water systems, the centralization of this type of detailed water system configuration and operations information is also a security concern in the current climate of disaster planning. However, in some cases, especially in those where a groundwater source is situated in flat areas very proximate to consumers and where several EPTDS feed directly into a loop-type system, the nearest source location to a residential consumer may be the easiest and best approximation to a hypothetical exposure level at the tap. Aside from knowing an approximate location of the source sample and, perhaps, where a residential connection is situated along a street, exposure estimates in these situations can be quickly derived without knowing the location of detailed piping networks and time-dependent delivery operations. For all other cases, methods that estimate heterogeneous mixing within delivery units, with its concurrent detailed and sensitive data requirements, are outside the scope of this assessment. In either case, these types of systems should be identified and flagged for future assessment.

3.c.2. Using water quality measurements within distribution system

Samples taken within the distribution system can serve two purposes towards estimating water quality at service connections. First, the observed concentrations may be representative of water quality in that part of the distribution system, and can be used directly as the estimate of water quality at those service connections. Second, water quality observations of constituents that are not formed or introduced during distribution may be used to help estimate changes in water quality as a result of mixing and/or deposition, or to validate the results of hydraulic modeling.

For exposure assessment purposes, the major difficulty in utilizing these samples is determining the specific areas within a distribution system that are represented by the results at that sampling point. A large system might undertake distribution sampling in multiple locations, with widely varying results, but without additional reportable and centralized system architecture and EPTDS pumpage information, it would be difficult to identify the specific part of the distribution system that the specific sampling point would represent. For water systems where a constituent sampled within the distribution system might occur relatively homogeneously across a specific zone, knowing the boundaries of that zone and associating it with representative sampling points provides enough information to estimate the quality of water delivered to the customer.

3.d. Classifying water system complexity

In many instances the water quality information reported by SDWA-regulated water systems can be largely indicative of what consumers receive at the tap. For the purpose of epidemiologic investigation, and, especially in the case of conservative species, analyte concentrations at a sampling point can often be assumed equivalent to concentrations at the consumption point. However, there are other instances in which water system configurations/operations and contaminant-specific physiochemical properties give rise to drastically different concentrations at consumption points. Existing state-based water quality monitoring databases do not typically maintain information to definitively determine the instances where a system's water quality is indicative of concentrations that consumers receive.

In light of this ambiguity and limited resources for primary data collection, it is useful to define criteria (see Table 1 below) for identifying the complexity of the water system, and thus the data needed to accurately characterize water quality being delivered to the users. This information could then be gathered from purveyors (i.e. a survey) and state databases to identify the specific systems where existing information is all that would be needed to assign water quality information to specific populations. In doing so, water utilities whose sampling information require much less extra reported information to perform exposure assessment can be separated from those that require more intensive data collection efforts. Then, having the ability to distinguish between these systems, the stage will be set for prioritizing and allocating resources to develop early Tracking products for less complex systems. For more complex systems, survey results would inform methodologies for reporting and integrating newly centralized information and provide a basis for estimating the amount of required resources to implement them.

Table 1: Classification of the complexity and data needs of water systems

Complexity Category	Distribution System Characteristics	Data and analyses
A	Single EPTDS; EPTDS samples accurately characterize the concentration(s) of the constituent(s) of interest entering the distribution system; simple distribution system (small variation in travel time).	Assume EPTDS samples reflect delivered water quality.
B	Single EPTDS; EPTDS samples DO NOT accurately characterize the concentration(s) of the constituent(s) of interest entering the distribution system; simple distribution system	Estimate EPTDS water quality incorporating source water quality data, weighted average of relative source contributions, and treatment removals, if needed. Assume estimated EPTDS water quality reflects delivered water quality
C	Multiple EPTDS; isolated hydraulic zones to each EPTDS	Estimate overall water quality as weighted average of relative source contributions. Use EPTDS sampling or estimated quality at EPTDS.

D	Multiple EPTDS; complex distribution system with interconnected zones of blended water.	Use EPTDS sampling or estimated quality at EPTDS. Need knowledge of hydraulics of distribution system from purveyor, modeling and/or distribution system samples to define water quality zones.

In all cases, temporal variability needs to be assessed. The degree that temporal variability needs to be incorporated depends on the metric of exposure being used (see section 3.h) which depends on the purpose of the metric (e.g., short term vs. chronic exposure; yearly vs. monthly indicator). In all cases, spatial information or assumptions about the extent of the water distribution system is still needed.

3.e. Determining population served

In order to generate population estimates of exposure, or to estimate exposures for specific individuals for epidemiologic studies, water quality estimates need to be assigned to these groups/individuals based on the quality at their service connection. Conceptually, there are two ways to make this linkage: 1) based on the location of the population, or individual, and the location of the water distribution system, and 2) based on existing databases of who is served by a specific water system (e.g., billing databases). While the number of households, and perhaps the number of residents, would be known, it is not likely that any other demographic characteristics would be available from such databases; this information would need to be estimated using Census data for that area, which would then require the geographic linkage of each household in the distribution system to an area where the demographic characteristics area known.

Clearly, knowing the spatial extent of the distribution system, and perhaps sub-zones within a distribution system, is a key factor for assigning water quality levels to populations or individuals. As this information is not required by SDWA regulation, it is also not routinely collected. In fact only a few state environmental health agencies (e.g. NJ, NY, and PA) have compiled information about the extent of water distribution systems, and created geographic information systems (GIS) coverages of the system boundaries. A variety of methods were used by these states to generate these coverages, and they are reportedly quite time-intensive. Generally through intensive efforts of direct communications with water purveyors, digitizing multiple paper maps, importing GIS files, and using customer databases and cadastral coverages.

In some instances, particularly in rural areas, distribution system boundaries can be assumed to be approximately congruent with the boundaries of incorporated areas. This can be verified from the utility or the municipality.

Such efforts result in a spatial description of the extent of the distribution system. As described above, water quality being delivered to service connections may vary across the distribution system at any point in time. In such cases, the extent of each sub-zone of the distribution system which has different water quality must also be collected in order to capture the within-system variations in water quality.

Distribution system and sub-zone coverages provide a snapshot in time of distribution system extents, and thus, of the potential exposures due to contaminants in drinking water. Water system customer delivery areas can be dynamic over time, some consolidating with and spinning off from other water systems, and others expanding outward through new residential development. To take into account the transient nature of water systems, regular reporting/collecting of distribution system data would also be required. Proposals for mechanisms for collecting such data are discussed in section 3.g.1.

There are additional governmental and non-governmental entities that might warehouse drinking water distribution system coverages for collections of water systems. For example, counties, regional government associations, and wholesale water districts often maintain GIS files for water district boundaries within their jurisdiction. These entities should be approached first to establish baseline coverage before water utilities are contacted directly.

Having the ability to systematically overlay an individual residence or a polygonal unit describing a small population onto a water system polygon and then assigning those individuals the level of water quality estimated for that service connection is essential to enhancing regulatory water quality data for exposure assessment purposes. To the extent feasible, collecting this type of information should be coordinated with existing governmental and non-governmental organizations that regulate and provide oversight and support to water purveyors. The most important partner will be state drinking water primacy agencies. Secondarily it may be useful to partner with local/county health agencies, USEPA Office of Groundwater and Drinking Water, and water utility associations, like the American Waterworks Association (AWWA) or the Association of Metropolitan Water Authorities (AMWA). In addition, there may be state-based water utility drinking water security and preparedness task forces (e.g., under state homeland security groups), whose involvement in assembling (and protecting) this information may be useful.

Disciplines and stakeholders beyond the customary environmental health tracking community might also find benefit in analyzing information that links populations to water quality sampling information. Certainly, state acute health surveillance and preparedness activities could find the information useful for understanding the population served by particular sources of water and the possible extent of affected areas. If collected comprehensively and on an ongoing basis, public health personnel would find greatly increased analytical capacity by combining this information with morbidity and mortality records to rapidly identify and respond to waterborne illnesses. The detection and analysis of widespread acute illness through emergency department reporting with respect to drinking water delivery may very well precede the detection and analysis of actual water contaminant parameters.

3.f. EPA surveys of water systems

The USEPA Office of Ground Water and Drinking Water has undertaken two types of surveys of public drinking water systems: Drinking Water Needs Surveys and Community Water System Surveys. EPA has completed three Drinking Water Needs Surveys (1997, 2001, and 2003), and uses the data from these surveys to conduct an assessment of drinking water infrastructure needs every 4 years. Though the breadth of coverage and response rate among large and medium-sized water systems has been very high, the content of the Needs Survey does not assist in distinguishing between simple and complex systems for

exposure assessment purposes. *(Source: USEPA website, http://www.epa.gov/safewater/needssurvey, accessed Sep, 2006)*

The Community Water System Survey, on the other hand, does provide a significant level of detail that would assist in determining which water systems are simple or complex, and could potentially directly assist in adjusting water quality sampling data for exposure assessment purposes. For example, respondent water systems provide information on treatment operations, cross-connections (import/export relationships), the types of source water, absolute production contributions of water sources, and the number of points-of-entry to the distribution system. The downside to these surveys is that a stratified random sampling design of only about 3% of water systems was undertaken for systems serving under 100,000 people, and the response rate averaged around 70%. Fortunately, a census of all large water systems (about 400 CWS) serving over 100,000 people was undertaken, however, the response rate for large systems was 63%. EPA has completed five Community Water System Surveys (1976, 1982, 1986, 1995, and 2000) and is scheduled to administer another survey in 2007. *(Source: USEPA website, http://www.epa.gov/safewater/cwssvr.html, accessed Sep, 2006)*

3.g. Collecting additional water system information

Generating estimates of exposure to contaminants in drinking water for sub-populations clearly requires more information than is typically available from state or federal agencies. In this section we describe possible methods and requirements for collecting additional information needed to make such population exposure estimates.

3.g.1. Distribution system reporting application

The requirements of a water distribution system reporting application, from an information technology perspective, are described here. In the past few years, advances in technology and spatial-related interoperability standards have set the stage to enable an enterprise reporting system that captures complex geographic features (i.e. distribution system polygons) with close collaboration and input by multiple reporting entities (i.e. water purveyors). For interoperability on the server-side, the Open Geospatial Consortium is in the final stages of receiving ISO approval for a Web Feature Service (WFS) (Open Geospatial Consortium, 2005) interface specification. WFS is a platform-neutral way of communicating XML-encapsulated geographic features over the Internet in read and write transactions. On the client side, multiple desktop GIS vendors have realized the benefit in supporting the ability to read from and write to WFS endpoints. However, the most vibrant and robust evolution is occurring in browser-based technologies. As has been increasingly demonstrated in applications that “mash-up” multiple technologies in a browser front-end, JavaScript, XML, DOM, and HTML provide standards for reading and displaying geographic feature content and writing to WFS endpoints through Remote Procedure Calls.

The capabilities of a water distribution system reporting application must be flexible to allow water system personnel to centrally input geographic and attribute information easily and securely. It must also take into account the various types of information water utilities may have that directly or indirectly assist in describing distribution system extents. Based on previous methodologies and preliminary discussions with water utility personnel, a list of possible functions or use cases have been described for the reporting application. An ongoing web-based methodology for allowing water purveyors to digitally report (uploading and editing) the boundaries of distribution systems would lead to the most flexible, accurate and time-dependent representation of water delivery areas.

The most important reporting function is allowing water utilities the ability to harness spatial information and/or GIS applications that they may already possess. If water purveyors maintain native GIS or Computer-aided Design (CAD) files, the application would allow these files to be securely uploaded to a central server, managing spatial reference (i.e. projection and datum) information, when necessary. Also, implementation of WFS on the server-side would allow water utilities the ability to interactively edit role-specific feature data within their own GIS applications. This is possible if the specific utility's GIS application platform supports the WFS Transaction (WFS-T) standard. So, for example, water utilities would be provided custom URL endpoints that include authentication information to enable role-based authorization to edit only their jurisdictional distribution system boundary areas. Moreover, utilities would have the choice of doing this within their preferred and locally installed GIS application/platform.

Additional functions for capturing water system distribution areas would involve browser-and role-based geographic feature editing within a dynamic map. The most basic function would allow the user to point-and-click each node comprising the distribution polygon. Also, known as "heads-up digitization", orientation layers, like street-level base map coverages and aerial/satellite imagery, would need to provide enough ground-level detail so that knowledgeable water system operators could identify coinciding landmarks on the dynamic map. Fortunately, much of this type of spatial data is free and easy (e.g. Web Map Services provided by TerraService, Google, Microsoft, etc.) to mash-up through standard interface specifications in a browser-based dynamic mapping client.

The reporting application should also offer the ability to use existing vector base map data (e.g. Census boundaries, Public Land Survey Sections, street centerlines, parcels, building footprints, etc.) information to either add to [or subtract from] an existing [or new] distribution system polygon. For example, a user would be given the ability to select one or many Census Block Groups that comprise the approximate distribution system boundary. The user could then use a selection of street centerlines to trim out areas that are serviced by nearby adjoining water utilities.

For water utilities that prefer using non-spatial data to infer boundaries of the distribution area, the reporting application should allow the secure upload of street address data elements from customer information databases. Water utilities bill their customers, and the residential connection address information included in customer information databases can be geocoded to geographic coordinates. The resulting point locations can be used to infer a polygon. This type of process would also be useful in reconciling areas that overlap near water system boundaries, in situations where multiple water utilities provide service to a single street block face, or in situations where a residential location [or service connection] is physically within the jurisdiction of a CWS, but does not currently provide drinking water service to that location.

For water utilities with pressure zones and multiple points-of-entry, the reporting application should provide the means for dividing a distribution system into smaller pressure zones. Interactively, the user would be assisted in creating common pressure zone boundaries within the distribution system. On a dynamic clickable map, these boundaries could be identified through heads-up digitization of a bisection line or through selection of one or more features from an existing layer, like street centerlines. The resulting segment could then be used to intersect the distribution system area or any other existing pressure zone polygons to form smaller contiguous pressure zones with edge-matched boundaries. Alternatively, in cases where a purveyor's customer information database includes identifiers for pressure zones, water utilities reporting connection addresses could report pressure zone identifiers in place of using a dynamic clickable map.

3.g.2. Sampling station sequence/connectivity

With the means for geographically overlaying individual residence or sub-population established for water systems, the next step in linking populations to relevant water quality sampling information is creating a reporting application that captures the time-dependent sequence of sampling from the distribution system upstream to sampling points near the point-of-entry and at source water locations. For water systems with pressure zones and multiple points-of-entry, the application should provide water systems with the means for identifying the EPTDS sampling stations relative to pressure zones that receive flow downstream, assign an absolute or relative flow contribution, and input a time period for which the recorded sampling connectivity and flow intensity is valid. A similar type of record can be created in instances when multiple raw sampling stations contribute flow to a treatment plant and/or a point-of-entry. These flow contribution records, when analyzed together, establish connectivity between upstream sampling stations, other downstream sampling stations, treatment plants, distribution systems, and pressure zones. The captured data structure is tree-based or hierarchical by relational database management system standards. The structure should simultaneously support the simplest and most complex water systems, and it should give water systems the flexibility to input a new flow contribution record for any transient operational change that is believed to significantly affect contaminant concentrations in the distribution system.

3.g.3. Survey content

Based on the data availability assessment activities of the DWEG, there is no single electronic and centralized source, where all CWS of all sizes can be definitively differentiated based on exposure assessment methodological complexity. The DWEG, therefore, proposed to implement a simple survey that would assist in making this distinction. In this section, the content of the survey is discussed and in the following section the web-based architecture for disseminating the survey and collecting questionnaire responses are described.

In the context of exposure assessment methodology, the primary objective of distinguishing the complexity of water delivery within water systems is in identifying the level of adjustment required for

assigning an exposure metric using regularly reported water quality sampling information. Less (or no) adjustments to sampling findings would be necessary for systems with less (or no) complexity.

The criteria for defining delivery complexity are based on two high-level aspects of water system configuration/operation: 1. water delivery after EPTDS and 2.water delivery before EPTDS. We aim to characterize systems relative to points-of-entry, because these are choke points where flow and water quality monitoring activities converge. At least for conservative contaminants introduced by source waters, the vast majority of Federal- and State-reportable monitoring occurs at or before the distribution point-of-entry. The questions that are presented below are not necessarily presented in the order that would be received by respondent water systems.

Looking downstream into the distribution system, the single most important piece of information is an accurate spatial picture of the delivery area in which customers receive drinking water service. The ability to quickly and efficiently assemble water system polygonal boundaries into a state- or nation-wide electronic GIS coverage is a representative indicator of how easily crude exposure assessment metrics can be generated in the short term. The DWEG developed the following question to inform this indicator:

> Do you have electronic files showing the customer service area boundary of your distribution system? (yes or no)
>
> If yes, check all that apply (GIS, CAD, Other____), click here to upload your electronic files through encrypted connection.
>
> If no, do you have paper drawings/maps of the boundary of the distribution system?

The response to this question not only has the potential for establishing an initial repository of distribution system coverages, it also results in an indicator of the level of effort required for inputting distribution system coordinates at water systems that do not currently maintain this information.

In assessing the distribution system after the point-of-entry, the complexity by which sampling information is handled increases if flow from one entry point is introduced to flow from other entry points. Point-of-entry sampling results for a system with one entry point are likely to be indicative of what customers receive at the tap. This is the simplest case. However, the ability to characterize the degree of mixing from multiple entry point flows increases if an area unit can be identified under which the intensity of a conservative species is essentially homogeneous. For small systems this might be the entire distribution system, and, for larger systems, this might be a single pressure zone. The time-dependent term that can be used in adjusting sampling results to account for mixing within the distribution system is absolute production or flow [or relative contribution] from EPTDS to this homogeneous unit(s). For instances where a homogeneous area unit cannot be identified, pressure-dependent modeling over a distribution network becomes necessary for estimating concentrations resulting from mixing.

Since state water quality monitoring databases do not provide a consistent and systematic way for identifying EPTDS sampling stations, the DWEG developed the following survey question to identify scenarios where EPTDS sampling is indicative of contaminant levels delivered at residential connections:

How many points-of-entry are supplying your distribution system? A point-of-entry is where water is added or introduced to your distribution system. It can be from an intertie, a storage facility, a single source, or blended sources, such as from a well field

__ Number of points-of-entry

Moreover, state water quality monitoring databases do not consistently and systematically manage information describing the frequency and character of pressure zones. The DWEG developed the following question to differentiate the complexity of distribution systems relative to pressure zones and existing electronic spatial information.

Are there distinct pressure zones within your distribution system ? (yes or no).

If yes, how many? ___

If yes [and number EPTDS > 1], is each pressure zone isolated to a single point-of-entry? (yes or no)

If yes, do you have electronic files showing the boundary of pressure zones? (yes or no)

If yes, check all that apply (GIS, CAD, Other ____), click here to upload your electronic files through encrypted connection.

If no, do you have paper drawings/maps of your pressure zones? (yes or no)

The response to this question can potentially establish an initial spatial data repository of pressure zones, and it also results in an indicator of the level of effort required for inputting pressure zone coordinates at water systems that do not currently maintain this information. Additionally, having more than one point-of-entry is a factor that can increase the level of complexity, however, this question can identify an intermediate special case, in which each pressure zone is isolated and connected to only one point-of-entry. This situation is characteristic of larger water systems in which pressure zones behave as small, single point-of-entry distribution systems.

The effects of reactions within the distribution system are an important water system feature contributing to the complexity of exposure assessment methodology. This is especially true in situations when disinfection byproducts (DBP) form after a EPTDS sample is taken. Fortunately, DBP sampling is commonly undertaken within the distribution system and these sampling results are maintained within regulatory databases. However, the ability to trace the flow path from a distribution sample 1. upstream to EPTDS sampling, and 2. downstream to a connected pressure zone, are not captured data elements. Because of the high level of effort required in reporting distribution system sampling station connectivity to EPTDS and pressure zones, the DWEG concluded that this issue should be addressed in follow-up contact with water utilities.

Looking upstream from the point-of-entry, the ability to perform exposure assessment is complicated by regulations surrounding the sources of water to a distribution system, particularly in situations when there are interties (or cross-connections) between water systems. Treated water interties do not generally have monitoring requirements stipulated for the importing water system. Though health-affected populations might be linked to an importing water system, all of the relevant water quality sampling is associated with the exporting water system. Since state water quality monitoring databases do not always provide a systematic way of determining when a source of water is derived from an intertie, the DWEG developed the following question to assess this factor that complicates exposure assessment methodology:

> What types of water sources are regularly used to supply your distribution system? (Check all that apply)
>
> __ surface water,
>
> __ well/ground water,
>
> __ infiltration gallery,
>
> __ intertie/imported water,
>
> __ other _____ (please describe)

Though the response to this question does not provide the detail to link information between systems that are connected by an intertie, it does inform the level of effort required in making that determination across all CWS.

The ability to definitively determine whether a water system is an exporter and/or residential service provider is another water system attribute that is not sufficiently or systematically captured by regulatory databases. The DWEG developed the following question to identify those utilities that supply residential connections or interties.

> Do you currently provide water service directly to residential customers and/or do you currently export water to other water systems? (Check one box only)
>
> __ Only export water to other systems
>
> __ Export water and provide water service to residential consumers
>
> __ Do not export water and provide water service to residential consumers

Another important aspect of water systems upstream from the EPTDS is the potential unequal and time-transient contributions of sources feeding the distribution system. Since state water quality monitoring databases do not maintain information on source flow contributions, the DWEG developed the following question:

> Do you have records for the amount of water produced by each water source or

imported at each intertie? (check all that apply)

__ yes, on a daily basis

__ yes, on a monthly basis

__ yes, on a yearly basis

__ no

if yes, are these records in electronic format? (yes or no)

Another water system attribute that is situated upstream of the EPTDS and contributes to the complexity of exposure assessment methodology is the effects of treatment on raw water quality. In situations where raw water sampling is incorporated into an exposure assignment method, sample results should take into account any treatment operations that might reduce contaminant levels. Fortunately, state water quality monitoring databases maintain different treatment types utilized within a water system. However, tracing the flow path upstream from a treatment plant to raw water sampling sites is not a captured data element in monitoring databases. Because of the high level of effort required in reporting sampling station connectivity to treatment plants, the DWEG concluded that this issue should be addressed in follow-up contact with water utilities.

When a water system mixes or dilutes two or more water sources, there are important implications for exposure assessment. Whether the exposure assessment method uses sampling stations within the distribution system, at the point-of-entry, before treatment, or close to the source, the complexity of the method increases for each sampling point's results that must be adjusted for varying volumetric flow contributions. To characterize this level of complexity among water systems, the DWEG proposes the following question:

Do you combine two or more sources of water having substantially different quality? (check all that apply)

__ yes, before treatment

__ yes, between treatment and point-of-entry to distribution system

__ yes, after point-of-entry to distribution system

__ no

3.g.4. Survey information systems infrastructure

EPHTN-funded states might find it in their best interest to consolidate effort and resources by administering a survey of water systems as a coordinated national effort. To facilitate this cooperation, the

DWEG invested resources in defining the information technology requirements for a survey software application infrastructure. And rather than using an existing commercial survey software product (e.g. Zoomerang or SurveyMonkey), a custom product was developed to address the needs of different states. It takes into account the unique content and structure of state water quality monitoring databases and incorporates existing water quality monitoring information as part of the survey business rules. Firstly, each survey would be administered to a single water utility and authenticated against a regulatory contact at that water utility. State primacy agencies maintain this information internally, and also report it to SDWIS. Secondly, states expressed the desire to have the option to host at least the presentation component (not necessarily the database or business tier components) of the survey from State web portals. Managing and integrating information from thousands of water utilities and personnel into an enterprise survey application that is hosted at multiple portals is expensive and difficult, if not impossible, to procure as a single off-the-shelf product.

The custom product currently under development is based on an XML schema that provides instructions for accessing database content for and business rules concerning respondents, survey administrators, respondent-specific attributes (e.g. number of raw water sources within water system), questions, possible answers, dynamic (respondent-, answer-, and question-dependent) skip patterns for questions, and respondent answer entries. Though the server-side engine that hosts the survey content (outgoing or incoming) can be deployed at multiple gateways, the optimized deployment would have a single back-end database with multiple State clients interoperating with the survey engine through their web portal and in turn disseminating the survey to water utilities within their State.

The California IT/GIS team has completed an alpha version of the survey XML schema and server-side survey engine. A contractor is currently implementing a generalized HTML and JavaScript client that accesses the survey web service through remote procedure call.

3.h. Metric of exposure

The reporting applications described in the previous section allow individuals or small populations to be linked to water systems and water sampling stations. With the linkage of a sampling station to a population, individual and population level estimates of exposure to water quality estimates is possible. The accuracy and precision of these exposure estimates for tracking or an epidemiological investigation will depend on the aims and constraints of the specific study. There are, however, nuances in how water quality sampling information is gathered that should be generally considered in any investigation.

In many instances, an exposure metric will be derived from multiple samples, and an aggregation or summarization scheme will be required to characterize hypothetical exposure levels. This will be especially true for studies with long exposure periods or a complex water system with many sources, thereby capturing many sampling stations and potential sampling results. A flexible tracking system would allow the systematic aggregation of sample values to characterize peak exposures (maximum), low-level exposures (minimum), average contaminant levels, exposed-not-exposed populations, or degree of variation (standard deviation) in contaminant levels.

It is also important to consider how samples which have contaminant concentrations below the level of detection (i.e. “non-detects”) are utilized in calculating an exposure metric. Whether a study aims to assign categorical or continuous levels of exposure, non-detect samples should be treated in a way that utilizes all of the information available, possibly improving the "non-detect" designation. Much more information can be integrated into a single non-detect sample by, for example, taking into account properties of the contaminant, the analytical method detection limit for the contaminant, the sampling history at the station in question, and the sampling history at upstream stations along the same flow path. An investigation might establish a “zero” concentration for samples on a specific contaminant, in which the entire sampling histories at the station and at all upstream stations have resulted in non-detects. A separate category (e.g. possibly exposed) or non-zero value (e.g. some constant proportion of the method detection limit) might be attached to the non-detect sample, if the station itself or upstream samples have witnessed detections over time. In risk assessment studies the USEPA often uses half the detection limit. Whatever proportion is used, care must be taken to ensure that the resulting value does not conflict with reality. At the very least, the approximating value should never be higher than the maximum concentration observed at that station or any upstream station along the flow path.

3.i. Summary/Recommendations

The vast majority of the population of the US is served by CWS. Even though there are relatively few exceedances of the primary MCLs, tracking population exposures to contaminants in drinking water remains important to address new contaminants of concern, contaminants for which regulatory levels have changed (e.g., arsenic), or to address concerns about potential health effects in sub-populations that result from exposures associated with drinking water levels below MCL.

Due to the sampling requirements for CWS under the SDWA, there is a relatively uniform set of water quality data available from each state, as well as from the federal SDWIS database. State water quality databases generally contain more information than the federal database. While most required sampling occurs at the EPTDS and can be used directly to estimate water quality entering a distribution system, there may be significant data about source or raw water quality that might be a valuable resource when EPTDS water quality data are scarce or lacking specificity.

As with all estimation methods, assumptions must be made and the accuracy of the resulting estimates depend on how closely the assumptions are to reality. In estimating the water quality delivered to any specific user, assumptions about mixing and chemical reactions during distribution must be made. In most cases, smaller systems are less complex and less information about the system is needed to accurately estimate water quality at the service connection; for very simple systems and conservative constituents the quality observed at the EPTDS can be used directly. For complex systems with multiple inputs, such simplifying assumptions will lead to inaccurate estimates of quality for each service connection; improving these estimates, however, requires detailed information about the configuration and operation of the system. In all situations, the accuracy and precision of estimates of water quality delivered to the customer is ultimately limited by the amount and quality of the water quality data being used.

An important starting point is to gather basic information about each water system to assess the number of systems that are complex enough that detailed information and complex modeling would be needed to generate adequate estimates of water quality for different parts of the distribution system. The DWEG has proposed a water utility survey mechanism for gathering this preliminary information. However, details about how to administer this survey still require assessment and coordination.

The most critical information for generating population-level exposure estimates is to know who (i.e., which population groups) is being served by each water system, or even, by which part of a distribution system. At a minimum this requires the ability to spatially link data about populations with data about distribution systems, and this hinges on knowing the extent of distribution systems. While some states have GIS databases describing the extents of these distribution systems, this is more the exception rather than the rule. Based on these experiences, it is clear that developing such data can be a time- and resource- intensive effort. However, without such linkage methods the ability to track potential exposures from contaminants in drinking water and identify target populations will be severely hampered. The DWEG proposed the information systems requirements and architecture for collecting this type of spatial information.

4. ESTIMATING POPULATION EXPOSURES TO CONTAMINANTS IN PRIVATE WATER SYSTEMS

While approximately 85% of the population of the US uses CWS, an estimated 30 million individuals rely on their own wells or other sources for their domestic water needs. For this paper we are defining private domestic water systems (PDWS) as those serving a small number of households (fewer than 5) and not operated by a formal association or commercial purveyor. This is in contrast to small community water systems (SCWS), as defined above, as water systems serving generally more than four households year-round and run by an association or commercial purveyor. Many of the issues and techniques described below will also apply to SCWS. We use the term ‘domestic well’ to describe wells which serve SCWS or private domestic water systems.

There are few good estimates of the number of people served by PDWS or by SCWS. This number can be estimated by subtracting the estimated population served by CWS from the total population, however, estimates of the number served by CWS appear to be unreliable; for many states the reported population served by CWS (as reported in SDWIS) exceeds the total population reported by the US Census. Few states have generated their own estimates; Washington State used the Behavioral Risk Factor Surveillance System (BRFSS) telephone survey to ask about the type of water service the respondent had.

The USGS used SDWIS and other data to estimate the proportion of the population served by CWS and by PDWS and SCWS (see Table 2 below). Overall about 15% of the US population relies on PDWS or SCWS. This proportion varies considerably between states. In 12 states over a quarter of the population is served by PDWS or SCWS, and in six of those states (i.e., ME, VT, NH, NC, WI, AK) the proportion is greater than one in three.

Table 2: Population served by CWS, Self-supplied (PDWS + SCWS), and the percentage of the population on self-supplied water for all 50 states and District of Columbia.

State	Population (1000s)	# served by CWS	# self-supplied	% self-supplied
Alabama	4,450	3,580	868	20%
Alaska	627	421	206	33%
Arizona	5,130	4,870	265	5%
Arkansas	2,670	2,320	351	13%
California	33,900	30,100	3,810	11%
Colorado	4,300	3,750	555	13%
Connecticut	3,410	2,660	749	22%
Delaware	784	617	166	21%
District of Columbia	572	572	0	0%
Florida	16,000	14,000	1,950	12%
Georgia	8,190	6,730	1,450	18%
Hawaii	1,210	1,140	72.9	6%
Idaho	1,290	928	366	28%
Illinois	12,400	10,900	1,500	12%
Indiana	6,080	4,480	1,600	26%
Iowa	2,930	2,410	511	17%
Kansas	2,690	2,500	193	7%
Kentucky	4,040	3,490	552	14%
Louisiana	4,470	3,950	523	12%
Maine	1,270	726	549	43%
Maryland	5,300	4,360	932	18%
Massachusetts	6,350	5,880	473	7%
Michigan	9,940	7,170	2,770	28%
Minnesota	4,920	3,770	1,150	23%
Mississippi	2,840	2,190	654	23%

Missouri	5,600	4,770	824	15%
Montana	902	664	238	26%
Nebraska	1,710	1,390	324	19%
Nevada	2,000	1,870	124	6%
New Hampshire	1,240	756	479	39%
New Jersey	8,410	7,460	952	11%
New Mexico	1,820	1,460	360	20%
New York	19,000	17,100	1,890	10%
North Carolina	8,050	5,350	2,700	34%
North Dakota	642	493	149	23%
Ohio	11,400	9,570	1,790	16%
Oklahoma	3,450	3,150	299	9%
Oregon	3,420	2,730	692	20%
Pennsylvania	12,300	10,100	2,190	18%
Rhode Island	1,050	922	127	12%
South Carolina	4,010	3,160	847	21%
South Dakota	755	625	129	17%
Tennessee	5,690	5,240	453	8%
Texas	20,900	19,700	1,190	6%
Utah	2,230	2,180	56.2	3%
Vermont	609	362	247	41%
Virginia	7,080	5,310	1,770	25%
Washington	5,890	4,900	993	17%
West Virginia	1,810	1,300	505	28%
Wisconsin	5,360	3,620	1,750	33%
Wyoming	494	406	87.5	18%

United States	***285,000***	***242,000***	***43,500***	***15%***

Source: USGS (http://water.usgs.gov/watuse/ Accessed: Oct. 2006)

Even though a minority of the overall US population uses PDWS or SCWS, it is important to track exposures among those using these systems as they are more likely to be exposed to specific contaminants in drinking water. Most of these systems rely on relatively shallow wells (< 100 feet in depth) which are more vulnerable to contamination, and situated in agricultural areas where there is a higher risk of groundwater contamination by agricultural chemicals (Nolan et al. 2002). Further, there are no systematic monitoring requirements for tracking drinking water quality in domestic wells within the United States. As a result, there is no indication when contaminants are present, which can lead to prolonged exposure over a long period of time. Tracking this population is important to make informed decisions about the need for interventions to reduce such exposures, to evaluate the impacts of such efforts, and to generate data to better understand the relationship between such exposures and adverse health outcomes.

Common classes of contaminants most often found in domestic wells include microorganisms, radionuclides, nitrates and nitrites, VOCs, pesticides, heavy metals, and arsenic. Microbiological contaminants, such as bacteria, viruses and parasites, originate from wildlife, agricultural animals and on-site waste disposal. Nitrates and nitrites come from fertilizers and on-site waste disposal system. Radionuclides are radioactive elements in groundwater that are found in underlying rock and groundwater. Heavy metals arsenic, cadmium, chromium, lead, and selenium are found in underground rocks and soils leading to groundwater and seepage into domestic wells (USEPA, 2002). In certain states in which historical orchards have become areas of suburban expansion, the former use of mercury- and arsenic-based fungicides has contributed to well contamination.

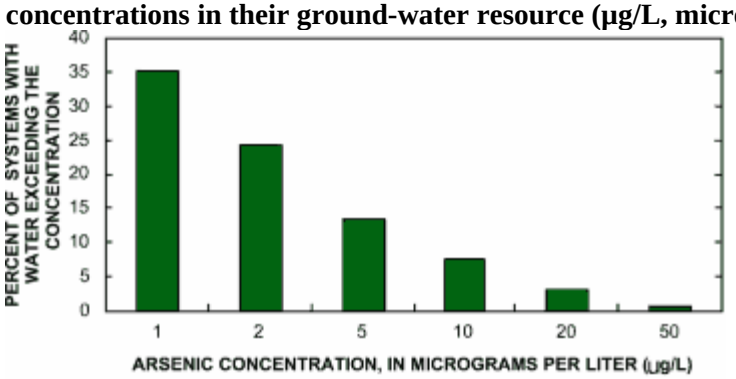
Nine percent of domestic wells sampled by the U.S. Geological Survey's National Water-Quality Assessment (NAWQA) Program during 1993-2000 had nitrate concentration exceeding the USEPA's maximum contaminant level (MCL) of 10 milligrams per liter (mg/L), compared with two percent of public-supply wells. These exceedances are based on 1,710 domestic wells and 264 public-supply wells, irrespective of depth to ground water (Nolan et al. 2002).

Data from the U.S. Geological Survey (USGS) National Water Information System (NWIS) were used in a retrospective analysis of arsenic in the ground-water resources of the United States. The 1,528 counties with sufficient data included 76 percent of all large public water-supply systems (serving more than 10,000 people) and 61 percent of all small public water-supply systems (serving more than 1,000 and less than 10,000 people) in the United States. Targeted arsenic concentrations of 1, 2, 5, 10, 20, and 50 µg/L were exceeded in the ground-water resource associated with 36, 25, 14, 8, 3, and 1 percent respectively of all public water-supply systems accounted for in the analysis, as seen in Figure 2 (Focazio et al. 1999). EPA set the arsenic MCL at 10 µg/L with CWS having to comply as of January 23, 2006.

Arsenic and nitrates are perhaps the most often studied contaminants in epidemiologic investigations of exposure to domestic wells and have been associated with health effects ranging from cancer to adverse reproductive and developmental outcomes (Colt et al. 2002; Manassaram et al. 2006; Ward et al. 1996). A review of maternal exposures to nitrates in drinking water and adverse reproductive and developmental outcomes found that while evidence is still not conclusive between a direct relationship between nitrates and reproductive outcomes, several studies suggest that an association between drinking water exposure

to nitrates and spontaneous abortions, intrauterine growth restriction, and birth defects (Manassaram et al. 2006). At the same time, a working group report from the International Society for Environmental Epidemiology reviewing the public health protectiveness of the current nitrate standard of 10 mg/L nitrate-nitrogen (nitrate-N) found that the current standard may be protective for preventing methemoglobinemia in infants but does not take into consider other chronic health risks such as cancer and additional research is needed to truly understand the magnitude of public health risks posed by nitrate and nitrite concentrations found in domestic drinking water supplies (Ward et al., 2006).

Figure 2: Percentage of small public water-supply systems estimated to exceed targeted arsenic concentrations in their ground-water resource (µg/L, micrograms per liter).



Source: USGS (http://water.usgs.gov/watuse/ Accessed: Oct. 2006)

Arsenic exposure in private wells has been the focus of many recent studies of private and domestic wells within the United States as the USEPA revised its current drinking water standard from an MCL of 50 µg/L to 10 µg/L and many communities who had not exceeded EPA health standards in the past are now finding themselves out of compliance. Arsenic exposure has been associated with several different types of cancer including bladder, skin and lung cancer (NAS, 1999). A recent ecological study in New England found significant correlations between the total proportion of populations served by domestic wells and bladder cancer in New England for both men and women (Ayotte et al. 2006). Similar correlations between bladder cancers were not se`en in other regions throughout the United States and it is suspected that elevated rates of arsenic in New England's private wells are contributing to the excess bladder cancer rates (Ayotte et al. 2006; Colt et al. 2002).

4.a. Estimating water quality in domestic wells

Similar to the framework presented above for CWS, there are four general steps for estimating population exposures to contaminants in domestic wells:

1) Estimate the quality of water produced by the well.

   This is estimated by using water quality observations from that well, or by an using predictive models.

2) Estimate the quality of water delivered to the household.

   This will usually be the same as the quality produced by the well, except for situations where the household has installed filtration, chlorination or other treatment processes.

3) Determine the demographic characteristics of the individuals served by domestic wells.

   Similar to the techniques described above, this is accomplished by using data about groups living in a defined area, or by using information about individual households.

4) Estimate the exposure levels for these individuals and populations.

   This would be based on the estimated water quality delivered to the household and observations and/or assumptions about water use behaviors. This is discussed in detail in Section 5.

4.a.1. Well-specific water quality data

Ground water is used as a source of drinking water for approximately one-half of the United States and accounts for the majority of source water for domestic water supplies (Focazio 2002). If domestic wells are sampled frequently enough relative to seasonal variation, these data can be used to directly generate estimates of water quality delivered by a specific well. As regulations under the SDWA do not apply to systems with fewer than 15 connections and which serve less than 60 residents year round, the amount, type, consistency and quality of private domestic well data vary dramatically by state. Understanding the strengths and limitations of data available for monitoring drinking water quality in domestic wells within each state is an important factor to consider in estimating individual and population exposures to drinking water.

Because little regulatory structure exists, and the majority of domestic wells are privately owned, they are usually not routinely monitored. Drinking water quality samples are most often taken at the time of construction or at the time of a property transfer. Each state has its own monitoring structure and mechanism for maintaining drinking water quality data for domestic wells. Some states have extensive private well testing programs, others do not. The form and ease of use also vary across states as some states maintain detailed electronic records and others have historical records in paper format.

In a pilot effort to assess the availability and quality of domestic wells water quality data, the members of the DWEG developed a list of the types of data that might be needed to generate population exposures, and compiled information from their respective states (see Table 3 below).

Table 3: Data gap assessment for the five pilot states

State	The number of water sources (wells and surface water); Size of population served	Location: (lat/long; street address; spatial extent of water body)	Monitoring data: (date of sampling; detection limit; actual values; frequency of sampling)	Characteristics: (Age; status; casing type; depth; screening depth)	Uses (potable, irrigation, etc.)
CA	*Who:* Local/County planning/ building/permitting office/Dept. of Env. Health. CA Department of Water Resources (DWR) *Format*: Mostly handwritten hard copy. Many well log/permits have been scanned into electronic graphic files; Many counties maintain electronic databases of well log/permit information. *Quality*: Databases have varying structure, quality, and completeness	*Who:* Local/County/DWR *Format*: Handwritten/hardcopy /scanned. Some county databases. *Quality*: There are often fields for street address, well siting diagrams, towship/range/section/ tract, and lon/lat coordinates on well log/permit forms. Fields not always filled out.	*Who:* Local/County . USGS NAWQA. State Water Resources Control Board GAMA program *Format*: Electronic *Quality:* Quality is good, but completeness is varies	*Who:* Local/County/D WR *Format*: Handwritten/har dcopy/scanned. Some county databases. *Quality*: Varying	*Who:* Local/County/ DWR *Format*: Handwritten/h ardcopy/scann ed. Some county databases. *Quality*: Varying

NM	*Who:* Office of the State Engineer, Information Technology, Program Support. "WATERS" database, (Water Administration Technical Engineering Resource System). *Format*: Electronic *Quality*: Fairly good quality, current efforts underway to bring in over 100 years of water rights paper files into electronic. These efforts are estimated to take 10-15 years.	*Who:* Office of the State Engineer, Information Technology, Program Support. "WATERS" database, (Water Administration Technical Engineering Resource System). "EGIS" database (extrapolation of WATERS spatial data with additional information added later). *Format*: Electronic *Quality*: Fairly good quality, current efforts underway to bring in over 100 years of water rights paper files into electronic. These efforts are estimated to take 10-15 years.	*Who:* Possibly from New Mexico Environment Department and NM Energy and Minerals Department (OCD) for injection and monitoring wells but these wells are rarely used for drinking purposes. *Format*: Electronic	*Who:* Office of the State Engineer, Information Technology, Program Support. "WATERS" database, (Water Administration Technical Engineering Resource System). *Format*: Electronic *Quality*: Fairly good quality, current efforts underway to bring in over 100 years of water rights paper files into electronic. These efforts are estimated to take 10-15 years.	*Who:* Office of the State Engineer, Information Technology, Program Support. "WATERS" database, (Water Administratio n Technical Engineering Resource System). *Format*: Electronic *Quality*: Fairly good quality, current efforts underway to bring in over 100 years of water rights paper files into electronic. These efforts are estimated to take 10-15 years.

NJ	*Who:* New Jersey Department of Environmental Protection (NJDEP) Private wells tested for most SDWA parameters at property transfer Est. 500,000 private wells ~10-15,000 tested/year first two years of testing *Format*: Electronic *Quality*: Good, but well locations and results treated as confidential; availability restricted to DEP staff and local health follow-up. Summary data could be made available at appropriate scale (2002 to present).	*Who:* New Jersey Department of Environmental Protection (NJDEP) *Format*: Electronic	*Who:* New Jersey Department of Environmental Protection (NJDEP) PWTA program *Format*: Electronic *Quality*: Measures of total coliform, VOCs with MCLs, arsenic, lead, mercury, nitrate, 48-hr gross alpha activity are available. Measurements occur at time of property transfer	Unknown	*Who:* New Jersey Department of Environmental Protection(NJDEP) PWTA program *Format*: Electronic
WA	*Who:* Washington Department of Health (WA-DOH) *Format*: Electronic *Quality*: Summary data	variable	Variable	some data is available at the Department of Ecology	some data is available at the Department of Ecology

WI	*Who:* Department of Agricultural, Trade and Consumer Protection (DATCAP) *Format*: Electronic *Quality*: Varies, there is a randomly sampled well survey every 3-5 years that goes out in addition to a collection of all private well samples taken housed by DATCAP. The quality of the data depends in part on who did the sampling and which lab the sampling was done in.	*Who:* Department of Agricultural, Trade and Consumer Protection (DATCAP) *Format*: Electronic *Quality*: Varies, there is a randomly sampled well survey every 3-5 years that goes out in addition to a collection of all private well samples taken housed by DATCAP. The quality of the data depends in part on who did the sampling and which lab the sampling was done in.	*Who:* Department of Agricultural, Trade and Consumer Protection (DATCAP) *Format*: Electronic *Quality*: Varies, there is a randomly sampled well survey every 3-5 years that goes out in addition to a collection of all private well samples taken housed by DATCAP. The quality of the data depends in part on who did the sampling and which lab the sampling was done in.	*Who:* Department of Agricultural, Trade and Consumer Protection (DATCAP) *Format*: Electronic *Quality*: Not available in all cases	*Who:* Department of Agricultural, Trade and Consumer Protection (DATCAP) *Format*: Electronic *Quality*: Not available in all cases

In California, information on private well construction is typically housed at municipal and county governments, most often within the environmental health agency. Copies of the drilling permits are then forwarded to the California State Department of Water Resources (DWR). The majority of files are maintained in paper format, although scanning of the drill logs began in 1999 in an effort to create an electronic well log database. Currently, well log permit forms are collected at the time wells are drilled. Municipalities and counties may require water quality testing at the time of drilling or property transfer, but no statewide database of these results has been compiled. The USGS National Water Quality Assessment (NAWQA) and the CA State Water Resources Control Board (SWRCB) Groundwater Ambient Monitoring Assessment (GAMA) program are the only statewide scale databases that include water quality monitoring of private wells. The California Environmental Health Tracking Program initiated a project in 2006 that aims to establish a historical electronic well log database that places heavy emphasis on collecting the most accurate well drilling spatial information. The data enhancement tool allows scanned well logs to be harvested for address information, which are then geocoded, and it allows for the heads-up digitization of well coordinates using a well siting diagram on the scanned image. This

project is designed to spearhead with a proposed future project that will establish a statewide centralized reporting system for new drilling permits.

In contrast to California, both New Jersey and Wisconsin have electronic data files containing both current and historical private well information. Wisconsin's private well data is housed both within their environmental agency, the Department of Natural Resources (DNR) and the Department of Agriculture Trade and Consumer Protection (DATCP). The electronic database is maintained by the State Lab of Hygiene and contains all private well tests conducted by state agencies. The database also contains some samples that are received from private wells throughout the state. Domestic well water quality data within the database are from a variety of sources including initial drilling of wells and any repeat samples that were requested by either state agencies in investigation of a potential problem or individuals who think a problem may exist or are interested in maintaining a safe well. While the database is extensive, these data are not systematically collected and are often focused on problem areas. However, DATCP also conducts a systematic, random sample of private wells in an effort to characterize groundwater quality in agricultural areas, including information on nitrates and 17 different pesticides and/or their metabolites.

In New Jersey, an electronic data file containing all information on newly drilled wells is maintained by The New Jersey Department of Environmental Protection (NJDEP). In addition, NJDEP has recently begun a private well data inventory that requires testing and documentation of all private wells at the time of property transfer. Private wells are tested for the majority of SDWA parameters. Currently, there are an estimated 500,000 private wells within the state and approximately 10,000-15,000 wells have been tested during the first two years of the program. The data are, however, confidential and any transfer or use outside of the state agencies is restricted.

The New Mexico Office of the State Engineer maintains New Mexico's private well data set. The Water Administration Technical Engineering Resource System (WATERS) database is an electronic database that contains location information on private wells, the estimated number of private wells and the size of population served by private wells. The database also contains important information on the well characteristics including age, status, casing type, depth and screening depth as well as potential uses. These data are considered to be of fairly good quality. Current efforts are underway to develop an historical record of over 100 years of water rights papers in New Mexico into electronic format and these efforts are estimated to take up to ten to fifteen years to complete. Water quality monitoring data is not maintained within the WATERS database. Some data is collected some private well monitoring data may be available through the Oils Conservation Division (OCD) of the New Mexico Energy, Minerals, and Natural Resources Department (EMNRD) for injection and monitoring wells but these wells are rarely used for drinking water purposes.

Washington State's well monitoring data are maintained by the Washington Department of Health and the State Department of Ecology. The Department of Health maintains estimates on the number of wells and population served by domestic water supplies. The Department of Ecology maintains some information on domestic well characteristics and their uses. The location of private wells and their distribution are available for some but not all wells. All available data is maintained in an electronic format but the quality and availability of the data varies greatly.

The National Water Quality Assessment (NAWQA) Warehouse and the National Water Information System (NWIS) are two potential sources of national domestic water supply data maintained by the

United States Geological Survey (USGS). The attached map shows the 42 study basins within the NAWQA where the USGS has been collecting data from domestic wells in the United States since 1991. The data warehouse currently contains and links the following data up through 9/30/2005.

- Chemical concentrations in water, bed sediment, and aquatic organism tissues for about 2000 chemical constituents
- Site, basin, well and network characteristics with many descriptive variables
- Daily stream flow information for fixed sampling sites
- Ground water levels for sampled wells
- 7,600 surface water sites and 8,100 wells
- 49,000 nutrient samples and 31,000 pesticide samples as well as 9,000 VOC samples
- 2,500 samples of bed sediment and aquatic organism tissues

(Source: The USGS National Water Quality Assessment. http://infotrek.er.usgs.gov/traverse/f?p=NAWQA:HOME:11711979771608694112 Accessed: 8/31/2006 at 2:28 CST)

The majority of the data found within the NAWQA database can also be found within the NWIS. The NWIS is a much larger data repository that includes many additional study sites and data in addition to the systematic data collected as part of the NAWQA program.

Depending on the scope and scale of the investigation which generated the data, or the frequency and extent of state level well monitoring programs, there are potentially large spatial gaps in the distribution of the data points. Similarly, domestic well samples are generally collected at one point in time and repeat sampling results are not available. Depending upon the contaminant of concern, contaminant levels may change dramatically over time resulting in potentially significant under- or over-estimation of exposure. Some domestic well data are derived from convenience samples or special studies that are exploring for specific issues, or are taken because a suspected problem exists. These samples may also lead to potentially biased estimates that may over or under estimate total population exposures within a particular region.

4.a.2. Predictive models

The paucity of data available for estimating drinking water quality in domestic wells makes the use of other techniques virtually requisite for a comprehensive assessment of population exposures. These techniques range from the simple to the complex, however, each of them is essentially a model, that is, some set of assumptions are used to predict the quality of water for a well (or a region) based on other information.

Nearest neighbor

The simplest 'models' are based on the observation that water quality in an aquifer is spatially correlated, that is, that the concentration of a contaminant at one location is more likely to be similar to the quality at another location the closer the two locations are together. The simplest method is to use existing water quality information to represent water quality in a well lacking data. Typically a well lacking data is assigned the data from the nearest well that has data.

Spatial models

In cases when there is no well close enough to the well of interest, data from several wells in the region can be combined to generate a prediction. The simplest method is to simply generate a mean concentration. Weighted mean can be generated with the weight being proportional to the distance from the target well, or some other function (e.g., the square) of the distance. With these techniques predicted values can be generated for all points in a region, providing a smooth surface of expected contaminant concentrations. If predictions are needed for several target wells over a region, then different forms of these models can be developed using some of the available data, and the predictions for other locations where data were available but not used can be compared to the predicted values to assess how well each model predicts ('fits') the observed levels. These techniques can be implemented using an off-the-shelf GIS package.

Kriging is a more sophisticated technique which uses existing data to generate a surface of expected contaminant levels based on assumptions about the underlying spatial correlation of contaminant levels. Different assumptions about the correlation will lead to different predictions. Such models can also be checked (validated) by comparing predicted values to observed values.

Each of these techniques provides only an estimate, and the accuracy and precision of these estimates will vary substantially. The ability of a model to generate good predictions will vary with well construction characteristics, hydraulic characteristics of the aquifer and the soil, the contamination pathways, rainfall and other factors. As such no one model will be the best for any specific location. Kriging and other similar techniques are also available in off-the-shelf software packages; however, making reasonable assumptions to select appropriate forms of these models requires specialized expertise.

Modeling the fate and transport of contaminants

Groundwater has intrinsic vulnerability to contamination. The vulnerability is dependent on aquifer hydrogeology, climate, and contaminant-specific parameters. The physical and chemical properties of a particular contaminant combined with ground water flow within a particular groundwater system can increase or decrease the vulnerability of drinking water sources from both natural and anthropogenic groundwater contamination (Focazio 2002). Many kinds of mathematical models have been developed to predict the movement and chemical reactions of contaminants in groundwater. These models predict contaminant concentrations across an aquifer resulting from some source of that contaminant based on assumptions about the rate of release, the chemical properties of the contaminant, rain or irrigation flows, soil types, and aquifer hydraulics. As the resulting predicted values are often highly dependent on the assumptions made, the models are difficult to apply for wide regions and require highly skilled personnel to implement.

In New Jersey, assessments of hazardous waste sites provide important information regarding the types of past contamination and industrial sources of pollutants that may pose a threat to groundwater. These predictions often use groundwater modeling to understand distribution of underground plumes and any potential threats to drinking water supplies. Therefore, on the community level, state level hazardous waste and remediation site programs offer a potentially important source of information regarding risks of exposure to domestic wells.

Models based on determinants of groundwater contamination

The level of a given contaminant in an aquifer at a particular location, depth and time is the result of several processes, for example, the application of a nitrate-based fertilizer or pesticide, the interaction of that chemical with the soil, downward migration as a result of irrigation and rainfall, the transmissivity of each strata between the surface and the aquifer, etc. In lieu of developing mathematical models of actual contaminant transport, general categories of groundwater quality, or categories of the potential for groundwater contamination, can be developed using simple combinations of existing data that represent these determinants of groundwater quality.

The simplest models are those that use one or more factors to identify areas where the probability of contamination is higher than other areas. Many of the factors are represented by simple categorical variables, such as whether the land is used for agriculture, whether the aquifer is shallow or the type of underlying bedrock. Many models, such as the DRASTIC model, have used several such factors together to generate indices to assess the vulnerability of an aquifer to contamination. These are used to identify areas where sampling and/or mitigation efforts should be focused. The same classifications can be used to generate a very general indicator of the potential for water contamination, and thus, or exposure to contaminants in drinking water.

In Wisconsin, agriculture accounts for approximately 40% of the state's economy. It is estimated that agricultural practices account for approximately 70-80% of pesticide contamination in groundwater. Wisconsin's EPHT program built a state-wide model to estimate the potential for exposure to agricultural pesticides in groundwater. The model combines several types of information about factors associated with the presence of pesticides, including state level pesticide use, land cover, and county level crop acreage, and integrates these with groundwater susceptibility factors (soil type and geology), chemical properties of the contaminant which affect its persistence and propensity to move towards groundwater, along with a relative ranking of the toxicological properties of the chemical. The model serves as an important tool for identifying geographic regions where domestic wells would be at greater risk of having elevated concentrations of pesticides. The model allows for prioritization of pesticides based on a specific health endpoint of concern, and provides a very simple yet comprehensive metric of the potential population exposure to pesticides in groundwater.

In New Mexico, well depth and casing are important determinants of potential contamination. Once the general geology and hydrology of a system are understood and potential sources of contamination at different levels in the aquifer are identified, and determined to be relatively stable, the location, depth and casing of a well can be used to assess the vulnerability of that domestic well to source and non-point source contaminants, both from anthropogenic and natural sources.

Statistical models of the probability of contamination

Researchers have begun to recognize the importance and utility of understanding predictors of groundwater contamination (Squillace et al. 2002). Over the past few years the USGS has developed statistical models to assess the relationship between commonly used vulnerability factors and actual measurements of contaminant levels. In this approach a statistical model is developed where the probability that the concentration of a specific contaminant is above a set level is modeled as a function of land cover, underlying geologic formations, depth to the aquifer and other vulnerability factors. As a result the factors which best describe the observed variability in the probability of contamination above the target value are identified. Once models are developed and validated, predicted values can be generated and used as estimates of specific contaminant concentrations, or probability of having a concentration above a specific value, for any well in the study area which is tapping into that aquifer. Further, the method identifies the most important determinant, which then can be used to generate more reliable classifications of groundwater contamination potential, as described above.

The primary source of information on groundwater quality and its determinants is the NAWQA data set. Using data from the NAWQA program, the USGS has focused on a number of different projects to explore the relationship between land cover (urban, rural, suburban and undeveloped), geology and aquifer type, and VOC, pesticide and MTBE contamination (Squillace et al. 2002). Epidemiologic investigations have begun to use land use, geologic and other data in combination with existing private well sampling data to build to predict where elevated levels of contaminants may exist and use these predictions to estimate groundwater quality when actual water quality data are missing (Ayotte et al. 2006). Similar models have been developed covering the entire US for nitrate contamination (Nolan et al. 2002). A collaborative project between the Washington State Department of Health and the USGS Water Science Center in Tacoma, WA, is using this technique to generate predicted probabilities of exceeding set nitrate levels for specific basins.

The aquifer modeling approach for estimating potential exposures within domestic wells is preferred to proxy data alone because it provides comprehensive and scientifically defensible results using actual data on ground water quality for its predictions. These methods may be cost prohibitive to state and local partners without joint efforts with the USGS. At the same time, once predictive factors within a geographic region are identified, these factors can be used as indicators by which to assess the potential for individual and population level exposures without developing an exhaustive and costly domestic well monitoring program.

4.a.3. Summary

Contaminant levels in domestic wells are influenced by a number of significant factors that influence the potential for estimating spatially and temporally accurate exposures. The sources of groundwater, the physical and chemical properties of the contaminants of concern, well characteristics such as well depth and well casing, changes in land use, and geological and hydrological processes which influence ground water flow and how persistent contaminants are in the water tables, and how far contaminants move and change over time are all important factors to consider when examining point level well monitoring data and how the spatial and temporal limitations may impact exposure estimates. For example, within certain

groundwater aquifers in Wisconsin arsenic levels wells are not stable over time. Arsenic is often undetected when wells are initially drilled, but through a reductive geochemical process, arsenic levels increase over time as the wells begin to pull out groundwater. In this case, using arsenic levels at one point in time to generate historical exposure assessments may drastically overestimate or underestimate individual and total population exposures. In contrast, arsenic levels in New Mexico's ground and surface waters have remained relatively constant over several generations. An arsenic level detected at one point in time is stable and can be suitably used for constructing historical estimates of drinking water exposure.

By using existing data, perhaps in combination with one or more of the predictive models discussed above, estimates of water quality can be derived for all wells in a target area, or for the underlying aquifer of an area, regardless of whether the locations of all wells in that area are known. In many instances the choice of which method(s) to use will be driven by the availability of data and/or the available time and expertise. Using multiple methods and comparing the results of the validation analysis will assist in selecting the most appropriate method. Clearly some of these water quality estimates may be quite inaccurate, to the point that the analyst would choose to characterize the level of contamination as ‘unknown’ rather than to use an inaccurate estimate. Clearly, a “one size fits all” approach for the entire US is not appropriate or applicable without considering the potential sources of spatial and temporal variations over time as well as the variation in primary contaminants of concern across various states.

4.b. Estimate the quality of water delivered to the household

The quality of water actually delivered to the home may be different than the quality at the well if the household or SCWS has installed treatment systems. While chlorination is the most commonly used treatment used, the potential for creating DBPs is small as organic loading are generally low in aquifers. The impact on the concentration of specific contaminants depends on the type and efficacy of the specific treatment hardware. As with CWS, assumptions about treatment efficiency can be used to adjust the estimated concentrations of specific contaminants if the type of treatment is known for a PDWS or SCWS.

The availability of information about treatment processes used by SCWS varies by state. Generally there is little information available, either on the individual or group level, regarding the proportion of households which have treatment systems for their domestic wells, the type of treatment, and how well the system is maintained. Some information is available from special studies in select areas. However such information can be gathered through population-based surveys such as the BRFSS. Based on the experience in Washington State, residents often know they have some sort of treatment, however, they may not be sure what type of treatment it is.

4.c. Estimate exposures for populations

Once some estimate of water quality has been derived for the wells in the target region, or as a spatial surface of contaminant concentrations, this information needs to be linked with population data to

generate exposure estimates for these populations, as well as for sub-populations based on demographic or geographic characteristics. This linkage can be between made between geographically-defined groups and some summary estimates of water quality across that area, or between individuals/households and the quality of water estimated or observed for their domestic well. The approach used will depend on whether information about the location(s) of specific households is known, or if the only source of information about individuals/households is aggregate data, such as census data. Methods for these two approaches are described below.

4.c.1. Linking water quality estimates to groups of individuals

When linking populations to CWS, water quality was assumed to be generally the same for all service connections within a defined water quality zone or other part of the distribution system. As such, groups of individuals, identified from census data, could be linked to these water quality areas. Estimating exposures for groups served by PDWS and SCWS poses greater challenges.

"Self-supplied" population estimates

The simplest assessment is to estimate the proportion of the population that is "self-supplied," that is, not supplied by a CWS. This provides an estimate of the population potentially exposed to contaminants as they are served by PDWS or SCWS not regulated or regularly monitored (in most states). The proportion of the population that is "self-supplied" has been estimated for each county by the USGS (Hutson 2004). As presented above, the proportion of households that are "self-served" ranges widely between states, from virtually no one, to 43% of the households in Vermont (Table 2). Overall 15% of the US population relies on PDWS or SCWS and in six states more than one in three households rely on such systems as their source of tap water.

The accuracy and quality of these estimates varies by state. In some states estimates of the population served by CWS are updated annually, for others they are updated every five years. The data are self reported estimates derived by each community water supply. These estimates may be appropriate for general state wide indicator development, but may be lacking in accuracy for more refined individual and sub-population estimates.

The demographic characteristics of those on PDWS or SCWS can be estimated if the areas served by the CWS are known. Areas not served by CWS can then be delineated and the demographic characteristics of those living in those areas can be estimated using census data and census geographical boundaries (e.g. block groups). As the boundary of the area not served by CWS will likely not line up with the census boundaries, the population in that area will need to be split between the area served by CWS and the area that is "self-served." GIS packages can be used to carry out these types of spatial linkages (i.e., overlays) between population data for defined areas and areas not served by CWS.

The US Census gathered information on each household's source of tap water in 1990. With these data the proportion served by water systems could be estimated for various demographic groups. Unfortunately these questions were dropped from the 2000 Census.

While these methods are straight-forward, they only differentiate between those that are served by regulated systems, and those who are not; it does not capture any of the differences in water quality between individual wells. As there is great variability in water quality between domestic wells, this method provides limited information on any actual exposures.

Using regions of similar/uniform water quality

Similar to defining areas of a water distribution system that would be expected to have relatively uniform water quality, the assessments of groundwater quality described above may indicate that there are regions where groundwater quality is expected to be relatively uniform. The population and demographic characteristics of those residing in such an area can be estimated using US Census data for that region. Census areas (e.g. tracts) can be quite large in rural areas, and may be much larger than an area thought to have relatively uniform well water quality. In such situations it is difficult to accurately estimate the number and characteristics of the people residing in that area as the population is clearly not uniformly distributed throughout a rural census tract. Further, applying census data about demographic characteristics for a region is based on the assumption that the demographic profile for that census region (such as census tract) is the same in all areas of that region. Such assumptions are often not true, however, the degree that this biases sub-population exposure estimates needs to be assessed using local knowledge of the area's population.

4.c.2. Linking water quality estimates to individuals

The second method for generating population level estimates of exposure to contaminants in water is to link individuals or households to specific estimates of water quality, and then aggregate them, in total or by the demographic characteristics of each household.

The ability to link specific households to specific domestic wells depends on the available data. Based on the assessment of the data available regarding domestic wells (see section 4.a.1 above), the actual location (latitude/longitude) of many domestic wells is readily available. If a listing of households by address is available, then the two can be linked based on location, that is, each household is linked to the nearest well, ideally to a well at the same address or within a short distance from that address. Spatial linkage may not be needed if local data about domestic wells includes the address of the person who owns that well, and/or the address of the parcel or tract where the well is located.

Demographic information about individual households is usually not readily available. However, data about privately owned wells may include information about the household that uses that well, such as the number of people who resided at that address when the well was installed or last tested. Individual demographic data may only be available in special circumstances such as when there is an epidemiological study.

Once estimates of water quality have been generated for each well in an area of interest, either from actual water quality data or using one of the estimation methods described above, the population distribution of exposure can be generated by linking the number of people being served by each domestic well with the expected level(s) of contamination. Exposure estimates for demographic sub-populations

can be computed directly, if demographic information is available for each household, or indirectly using census data and assuming that as a group, the distribution of a demographic characteristic (e.g., ethnicity) of the individuals in a census region (such as a census tract) is the same in all parts of that region.

If the location, or even the existence, of a domestic well serving a specific household is unknown, and if there is no domestic well close enough to that household to reasonably be served by that well, then one of two situations may exist: 1) the household is being served by a SCWS, whose well or source is located some distance from the address, or 2) the well has not been captured by the data system being used.

The locations of SCWS are usually known by state agencies. Alternatively, the existence of a SCWS may be deduced if there are several households in a small area with no corresponding wells. This is often the case for newer developments which were planned and developed with a SCWS in mind. Trailer courts and multi-family units are other situations where all residents are likely served by the same well via a SCWS. In such cases the water quality observed or predicted for that well would be assigned to all households assumed to be served by that system.

If it doesn't appear that the household is served by a nearby SCWS, then the assumption is that they have a private domestic well, and that the well is just not part of the database being used. In these cases the water quality predicted for that location in the most commonly used aquifer would be assigned to the individuals in that household.

4.d. Summary/Recommendations

Estimating individual and population-level estimates of exposures to water contaminants among those with private domestic wells and those served by small unregulated water systems is an important aspect of tracking and is a focus of epidemiologic studies as these individuals are at higher risk of exposure to several classes of contaminants than those served by CWS. Furthermore, this group constitutes a significant proportion of the population in many states, and represents an important well-defined demographic group, rural residents.

Conducting such assessments is primarily hampered by the lack of available water quality and well characteristic data for domestic wells. In a few states such information is collected in a centralized database, however in many states the existing data are kept only at the local level and often not in electronic format. Developing data systems to capture these data in a systematic fashion is a central need.

Where such data are lacking, estimating population exposures will rely on modeling techniques. Applying simple techniques should be feasible for most areas; however, the resulting metrics would provide only measures for the potential for exposure. More sophisticated methods would be needed to estimate actual contaminant concentrations and variability. A comprehensive assessment of the cost and validity of these methods would be very useful.

There is also a need to capture both water quality data and distribution spatial extent information for SCWS. While collecting distribution system extent data would be more difficult for SCWS as compared to CWS due to the number of systems and limited capacity to share such information electronically, a vast

majority of these small systems will by simple systems. As such, system extent information and water quality data could be directly used to estimate the quality of water delivered to the users of the system with major adjustments for multiple inputs or complex hydraulic conditions.

5. HOUSEHOLD WATER EXPOSURE ASSESSMENT

The methods described in Sections 3 and 4 can provide estimates of the number and percentages of a population that are served tap water at given levels of water quality. However, these do not necessarily represent levels of exposure, as they do not take into account behavioral and household factors, such as drinking bottled water, frequency of showering and swimming, or household water treatment, that are key determinants of the level of exposure.

There are three potential routes of exposure to contaminants in tap water. Contaminants may be ingested when water is consumed directly, as part of a prepared drink, or in foods that were prepared using tap water. Contaminants which are volatilized or aerosolized can be inhaled, such as during a shower. Contaminants may also be absorbed directly through the skin, such as during bathing or swimming. The behavioral and household factors affecting levels of exposure via these routes of exposure are discussed below.

Modeling ingestion exposure is the most straightforward, as the exposure depends primarily on how much water a person consumes in their drinks or food. Modeling dermal exposure is more complex as it depends on how long people are in contact with the water, what parts and how much of their bodies are in contact with the water, the contaminant concentration in the water, and the temperature of the water. Modeling the inhalation route is potentially the most complex as it deals with a multitude of factors. If the contaminant is non-volatile, the inhalation route is of small consequence, since only minimal exposure occurs due to aerosolization (Wilkes, 1999). However, if the contaminant is volatile, the model must represent all the water-use activities in the home; simulate the chemicals' release from the water sources; represent the chemicals' transport throughout the home; and represent the locations of the individuals throughout the day.

5.a. Exposure via ingestion

Ingestion is the primary exposure route for non-volatile contaminants in drinking water. The amount and type of water consumed (tap vs. bottled), quality of bottled water, and treatment of water in the home are important determinants of the level of exposure to contaminants in drinking water.

5.a.1. Water intake

Historically, the USEPA and other organizations have used the quantity 2.0 L/day for adults and 1.0 L/day for infants (defined as weighing 10 kg or less) in their exposure assessment. After reviewing various studies, surveys, and other papers, this value was modified downwards to 1.4 L/day for adults (USEPA 1997). This value is the mean of observed water consumption rates from two national studies (Ershow and Cantor 1989; Canadian Ministry of Health and Welfare 1981). The average of the 90th percentile (2.35 L/day) is the recommended upper limit, and the previously used 2.0 L/day corresponds to the 84th percentile. An analysis of one day diet recall as part of the National Health and Examination Survey (NHES) found that 87% of adults drank water, with an average daily consumption of 1.53 liters (Popkin, Barclay and Nielsen, 2005). Other factors, such as hot climate, high activity, as well as age can significantly increase or reduce water consumption rates.

EPA's current default drinking water intake rate for infants (individuals of 10 kg body mass or less) and children is 1 L/day (USEPA 1980; USEPA 1991). This rate includes drinking water consumed in the form of juices and other beverages containing tap water (USEPA 2002).

For population-based exposure estimates, using standard consumption rates or established distributions of consumption would likely be sufficient, particularly given the amount of effort needed to collect population-specific data. However, there may be substantial differences in consumption patterns between demographic groups. Variations in water intake between individuals can be a very significant determinant of exposure via ingestion. In a simulation study to assess the effect of using standard assumptions in generating DBP exposure levels, Wright et al. (Wright et al. 2005) found that water intake was the most important factor in modifying estimated exposure levels.

5.a.2. Use and quality of bottled water

Water quality at the tap has little relevance for estimating ingestion exposures if a person chooses to consume bottled water. Tap water consumption patterns vary between individuals and groups, mainly influenced by perception of source water quality and various socio-demographic factors. A North Carolina study reported 15% of their subjects (pregnant women) used filtered water, and 24% as bottled water as their primary source of drinking water, compared to a Colorado study where 11 % of the pregnant women used filtered water and 14% used bottled water (Shimokura et al. 1998; Zender et al. 2001). In a population-based telephone survey (BRFSS) in Washington State, 16% of the respondents reported drinking bottled water (VanDerslice, personal communication). Consumption of both tap and bottled water also appears to be common; a study in Ontario found that while 48% reported that their entire water intake was tap water, and 32% drank no tap water, the remaining 20% used a combination of sources (Jones et al. 2006).

While the Environmental Protection Agency (EPA) regulates tap water as a utility, the Food and Drug Administration regulates bottled water products under the Federal Food, Drug, and Cosmetic Act (FD&C Act) as a packaged food product. Under the FD&C Act, manufacturers are responsible for producing safe, wholesome and truthfully labeled food products, including bottled water products (USFDA 2004).

FDA bottled water regulations include Standard of Identity, Good Manufacturing Practices (GMPs) and Standard of Quality (SOQ). To assure the safety of bottled water, the FDA has developed standards that set a minimal acceptable level of quality. The quality standards address substances in the water that may be harmful to health, as well as substances that affect the smell, color, and taste of water. The quality standards also require public notification whenever the microbiological, physical, chemical, or radiological quality of bottled water falls below the standard.

States also regulate bottled water. They are responsible for inspecting, sampling, analyzing, and approving water sources. States certify testing laboratories and perform unannounced and annual inspections. Some states have unique bottled water regulations, and many base their regulations on FDA, and in some cases, industry-based standards. Domestic bottled water producers that sell their products in other states (interstate commerce) are subject to periodic, unannounced inspections by FDA. Upon inspection, the producers must be in compliance with all aspects of the SOQs and GMPs for bottled water, the Fair Packaging and Labeling Act, and all other applicable regulations that are incorporated in the FDA quality standards. Domestic bottled water producers are subject to inspection by state health officials and must comply with all applicable state laws and regulations. Some states (e.g. California, Pennsylvania, and New York) have adopted regulations that are stricter than federal requirements (NRDC 1999).

The National Resources Defense Council (NRDC) undertook a four-year investigation, sampling more than 1000 bottles of 103 brands of water using three independent labs. They found that one third of the samples contained significant contamination, that is, levels of chemical or bacterial contaminants exceeding those allowed under a state or industry standard or guideline. Arsenic and some SOCs were the most commonly identified chemical contaminants. The NRDC concluded that “one cannot assume on faith, simply because one is buying water in a bottle, that the water is of any higher chemical quality than tap water” (NRDC 1999).

Given that a significant proportion of the population consumes bottled water, ignoring this factor may significantly bias population exposures to contaminants in drinking water. The choice to drink bottled water rather than tap water is likely to be correlated with demographic and cultural factors. As such, general estimates of the use of bottled water may not be adequate, and state-specific data may be needed. The lack of good data on the actual quality of bottled water affects the accuracy of an overall estimate of population exposure to contaminants in drinking water. However, if the focus is on exposure to contaminants from water delivered to the home (CWS, SCWS or domestic wells), then accounting of the proportion of the population that uses bottled water would likely be sufficient for tracking such exposures.

TABLE 3. Key Differences Between EPA Tap Water and FDA Bottled Water Rules

Water Type	**Disinfection Required?**	**Confirmed *E. Coli* & Fecal Coliform Banned?**	**Must Filter to Remove Pathogens, or Have Strictly Protected Source?**	**Must Test for *Cryptosporidium, Giardia,* Viruses?**	**Testing Frequency for Most Synthetic Organic Chemicals?**	**Must Test for and Meet Standards for Asbestos & Phthalate?**	**Must Report Violations to State, Feds?**	**Consumer Right to Know About Contamination?**
Bottled Water	No	No	No[a]	No	1/year	No	No	No

Carbonated or Seltzer Water	No	No	No	No	None	No	No	No
Big City[b] Tap Water (using surface water)	Yes	Yes	Yes	Yes	1/quarter (limited waivers available if clean source)	Yes (though limited waivers available if clean source)	Yes	Yes
Small Town[c] Tap Water (using a well)	Yes[d] (as possible corrective action)	Yes	Yes[d] (as possible corrective action)	Yes[d] (under some conditions)	1/quarter (waivers available if clean source)	Yes (though waivers available if clean source)	Yes	Yes

a. FDA requires state or local approval of bottled water sources, but there is no federal definition or control of what may be a bottled water source; the FDA "approved source" requirement thus has been called a "regulatory mirage."
b. Big city refers to city system serving 100,000 people or more. A big city using only wells would have to comply with all requirements noted for a surface water-supplied city, except that if its wells were not under the influence of surface water, it currently would not have to disinfect, filter, or test for *Cryptosporidium*, *Giardia*, or viruses. A new rule for such groundwater-supplied systems must be issued in 2002, which may require some cities using wells to disinfect or filter and do additional microbial monitoring.
c. Small town refers to a town of 20,000 people. Such a small town using surface water would have to comply with all the same requirements noted for a large city using surface water, except the monitoring frequency for coliform would be 20/month, and there currently are no *Cryptosporidium*, *Giardia*, or virus monitoring requirements for small towns.
d. The Environmental Protection Agency (EPA) issued the Ground Water Rule on October 11, 2006 designed to protect drinking water sources from pathogen contamination. The rule requires sanitary surveys, source water monitoring when a samples tests positive for total Coliform, corrective action, and compliance monitoring. See http://www.epa.gov/safewater/disinfection/gwr/.

Source: adapted from NRDC (1999)

5.a.3. Effect of home water treatment

There is little information on the extent of water treatment in the home. In Washington State an estimated 40% of the public use some type of water filter. Of those, 37% reported using the filter for aesthetic reason, 19% because of health concerns, and 33% for both reasons (VanDerslice, personal communication). Point-of-use filtration devices in the home can effectively remove a wide range of contaminants; however the efficiency of removal can be affected by how well the unit is maintained. In a Russian study of exposures to drinking water DBPs, the researchers found 92% average removal efficiency for chloroform using a Brita pitcher following 100L of use, and a removal efficiency ranging from 39-95% in 1 to 100 L of Brita pitcher use (Egorov et al. 2003).

The impact of home water treatment on exposure estimates may be substantial; disregarding home water treatment would lead to an overestimate of exposure levels. There are no comprehensive data sets regarding the use, type and maintenance of point-of-use units. The issue of such systems will likely vary systematically across demographic groups. Furthermore, people in areas with water that has tastes and/or odors may be more likely to install filters. Population-based survey data may be needed to generate accurate exposure estimates.

5.a.4. Exposures from consuming water at other locations

Most school-age children and adults spend significant amount of their waking hours at locations other than their residences. As such a significant amount of their water consumption may occur at a school or workplace. For example, among a sample of pregnant women working full-time, total water consumption outside the home was virtually the same as the amount consumed in the home (Shimokura et al. 1998). In contrast, women who worked part-time or less consumed only about a fifth of their total water intake outside the home. Kaur et al. (2004) reported that only 63% of fluid intake of pregnant women in London occurred in the home, and that the consumption of bottled water was higher outside the home (Kaur et al. 2004). If the quality of water at these other locations is different than that at their homes, estimates of exposure may be significantly biased.

Differences in tap water quality would be more likely if the type of water system serving the home is different than the type serving the school or workplace (e.g. domestic at home and a CWS at the workplace). Most workplaces and schools are in areas served by CWS, and schools with their own wells are regulated as NTNC systems under the SDWA. As such, it is more likely that any significant differences in water quality between a residence and a school or workplace would be due to a situation where the quality of water from a domestic well serving a residence was poorer than the quality delivered to a school or workplace via a CWS or a NTNC water system. While such differences might be significant, taking these factors into account would require individual level data about the place of work and school, and location-specific estimates of water consumption.

5.a.5. Cooking and boiling

High temperatures can significantly reduce the concentration of volatile compounds in water. Krasner et al. (2005) observed large reductions in most DBP concentrations in boiling experiments of chloraminated and chlorinated finished water samples (Krasner and Wright 2005). Boiling removed up to 98% of DBPs in another study (Weinberg et al. 2006). Hot beverages account for the majority of consumption of water via prepared beverages and foods. For twenty-five percent of pregnant women in one study, the intake of hot beverages accounted for 25% or more of total water intake (Kaur et al. 2004). Adjustments for reductions in DBPs using general assumptions about hot beverage consumption may be indicated when generating population exposure distributions. Accounting for individual hot beverage consumption patterns may be necessary for epidemiological studies.

5.b. Exposure via inhalation and dermal absorption

Inhalation or dermal absorption of contaminants can be a significant source of exposure. In many cases exposure via these routes occurs at the same time, such as during bathing or showering. These exposure pathways are important for contaminants that can volatilize or aerosolize, such as radon, THMs, TCE, and chloroform. Various models of indoor exposure to contaminants in drinking water have estimated that inhalation intake of VOCs can be up to six times more than the intake due to ingestion, and dermal intake

up to the same rate as the ingestion rate (McKone 1993). Other models indicate that the importance of ingestion and dermal intake vis-à-vis ingestion varies by compound (Kim et al. 1999), and that variability in personal and household conditions is responsible for a ten-fold variation in exposure levels. Recent studies of dermal uptake of contaminants in drinking water have primarily focused on DBPs. Several studies have found that activities associated with inhaled or dermal exposure routes resulting in a greater increase in blood THM concentrations than that attributable to daily water ingestion (Jo et al. 1990; Jo et al. 1990; Weisel and Jo 1996; Weisel et al. 1999; Xu and Weisel 2005).

5.b.1. Bathing and showering

DBP exposure due to inhalation or dermal exposure resulting from showering and bathing activities has been studied by comparing exhaled breath and blood biomarkers to the concentrations in water (Ashley and Prah 1997; Backer et al. 2000; Gordon et al. 2006; Gordon et al. 1998; Jo et al. 1990; Miles et al. 2002; Weisel and Jo 1996; Weisel et al. 1999). It has been found found that a ten minute shower and a twenty minute bath each consistently resulted in at least a two-fold increase in the median blood and exhaled breath of TTHM (Nuckols et al. 2005). Jo et al. (1990) and Weisel and Jo (1996) analyzed breath concentration of subjects after normal showers and inhalation-only showers (with subjects wearing water-proof clothing). They concluded that inhalation and dermal exposure routes were responsible for equivalent amounts of internal dose, as measured by DPB levels in exhalable breath (Jo et al. 1990; Weisel and Jo 1996). Heating water accelerates the formation of chlorination by-products when they are present in water. Dermal absorption of chloroform was calculated to be thirty times higher in water at forty degrees Centigrade compared to thirty degrees Centigrade (Gordon et al. 1998). Other studies (Gordon et al. 2006; Weisel and Jo 1996; Xu and Weisel 2005) have shown a significant or a greater increase in blood THM concentration compared to ingestion.

Clearly, bathing and showering may account for a large proportion of total exposure to DBPs, and the level of exposure to DBPs from these activities appears to be highly variable, depending not only on the frequency and duration of bathing and showering, but perhaps the temperature of the water used. These behaviors would likely be different across demographic groups. As collecting bathing and showering data for populations would entail significant effort, average values taken from the literature may be the only practical approach for accounting for these routes of exposure for population-based exposure estimates. Further research is needed in designing epidemiologic studies that minimize data collection burden yet maximize accuracy in classification of dermal and inhalation exposure to drinking water contaminants.

5.b.2. Household water use

Other household uses of water may lead to significant inhalation and/or dermal absorption of some water contaminants. Nuckols et al (2005) measured blood and exhaled air concentration of THM as biomarkers of exposure after conducting fourteen common household water use activities. All hot water use activities yielded a two-fold increase in blood or breath THM levels in at least one of the seven subjects. The results indicated that hand dishwashing, indirect shower exposure and other hot water activities could be important sources of exposure.

As with showering and bathing, substantial effort may be required to develop state or region-specific estimates of household water use patterns for population exposure estimates. In a recent review of personal water exposure data, Wilkes and colleagues (Wilkes et al. 2005) compiled data from various national surveys to characterize the US population as a function of demographic characteristics. This does not provide information on individual subjects, but perhaps provides a more accurate characterization of the US population's water-use behavior. In the report, frequencies and durations of use of showers, baths, clothes washers, dishwashers, toilets and faucets are presented and compared for various demographic groups. These analyses were conducted using the National Human Activities Pattern Survey (NHAPS) database, the Residential End Uses of Water Study (REUWS) database, the Residential Energy Consumption Survey (RECS), data from current literature, and manufacturer information. Volumes and flow rates are also analyzed from REUWS for the various water uses. Furthermore, tap water ingestion data are analyzed for various population groups derived from the Continuing Survey of Food Intake by Individuals (CSFII) as well as from NHAPS and current literature. Typical parameters of indoor water uses are presented and recommended for use in human exposure modeling. While such estimates would be very valuable to population exposure estimates, individual estimates for epidemiological studies would likely require individual level data due to the high level of variability expected between homes (Kim et al. 1999). \

5.b.3. Swimming

DBPs can not only be found in drinking water, but also in swimming pools. Weisel and Chen (Weisel and Chen 1994) measured mean chloroform level of 85 µg/l in the water and 87 µg/m3 in the air in swimming pools. Lindstrom et al. (Lindstrom et al. 1997) reported chloroform levels of 68 and 73 µg/l in pool water. Matthiessen and Jentsch (1999) measured average THM levels of 29.7 µg/l in water and 142 µg/m3 in air in swimming pools in Germany.

Researchers have found correlations between chloroform levels measured from exhaled breath or blood samples and chloroform levels in the water and air after swimming (Aggazzotti et al. 1995; Aggazzotti et al. 1998; Aggazzotti et al. 1993; Aggazzotti et al. 1990). Levesque et al (Levesque et al. 1994) looked at the body burden from chloroform after a 1-hr swim, and estimated a dose of 65 µg/kg/day, 141 times the dose from a 10 min shower (0.46 µg/kg/day) and 93 times greater than exposure by tap-water ingestions as calculated by Jo et al. (Jo et al. 1990). In a simulation study similar to the study conducted by (Whitaker et al. 2003; Wright and Bateson 2005), found mothers who swam regularly received far greater doses of chloroform than did non-swimmers.

Even population estimates of the proportion of residents who swim, the frequency and duration, are lacking. Collecting such data via simple means, such as telephone surveys, should produce reliable estimates as swimming is a clearly defined and time related activity. However large differences in swimming behaviors would be expected between ethnic and age groups.

5.c. Summary/Recommendations

Various studies have demonstrated how critical it is to take behavioral and household factors into account when estimating exposures to contaminants in water delivered to a home. The biases introduced if these factors are not considered are likely systematic. As such, behaviors and household conditions are clearly correlated with socio-demographic factors. For many of these factors, incorporating very simple information can greatly improve the accuracy of the resulting exposure estimates (e.g. % of consumption that is from tap water). There are few systematic efforts to capture such data for specific population and demographic groups, but feasible methods exist (e.g. BRFSS modules). Collecting such simple information in a consistent manner would greatly improve our ability to track these population exposures.

More detailed information is needed to meet the accuracy and precision requirements for most epidemiological studies. As a result detailed individual level data needs to be collected. The specific factor and behaviors of interest will depend on the types of contaminants being studied. Inhalation and/or dermal uptake are significant routes of exposure for contaminants which volatilize or aerosolize.

6. Overall Recommendations and Conclusions

The current ability of states to generate population exposure estimates to contaminants in drinking water for use in EPHT depends in large part on the existing data at their disposal. State and federal level priorities for the future development of methods and data systems needed to implement tracking of exposure to contaminants in drinking water will depend on several factors, including: the desired spatial and temporal specificity of population exposures; the number of people whose exposure estimates would be improved from a given improvement in data availability and/or quality; the current level of concern regarding a population's potential exposure to a specific contaminant; and/or specific considerations to underserved groups or susceptible populations.

Many of these factors are also related to the different types of drinking water delivery in a state and the proportion of the population represented. For example, CWS generally have much more complete water quality and water system data than small community water systems or private domestic water supplies. However, if a significant proportion of a state's population does not receive drinking water service from CWS, or, if the greatest concerns are in regards to those who are not served by CWS, a state might prioritize the tracking of small community water supplies and private domestic water supplies.

The primary data gaps and needed tools for deriving estimates of the quality of water delivered to a residence vary with the type of water system. For CWS the priority areas to be addressed are:

§ A survey or census of water systems to understand the general degree of complexity of the system, in order to determine the magnitude of the need for detailed distribution system configuration and operation information;

§ Spatial data describing the extent of area served by each water distribution system;

§ Methods for easily collecting water system information, specifically, distribution system inputs, flow data, treatment train information, and other configuration/operations information;

§ Tools and methods for consistently identifying water quality zones, and feasible methods for estimating water quality when such zones can not be delineated; and

§ Tools for estimating changes in water quality for constituents whose concentrations can change during distribution (e.g. DBPs).

The needs are somewhat different for private domestic water systems. The priority data needs are:

§ Centralized databases of well location, well characteristics (e.g. depth), and water quality data; and

§ Easily accessible databases of groundwater quality from various sources, and a toolbox for estimating groundwater quality over regions using a variety of predictive models, as a means of estimating water quality for wells for which data is inadequate or lacking altogether.

Data needs for estimating population-level exposures for those on SCWS share aspects of the other two types of water systems. The priorities are dependent on the situation in each state, however, the main gaps are:

§ Centralized databases of well location, well characteristics (e.g. depth), and water quality data;

§ Spatial data describing the extent of area served by each water distribution system;

§ A survey or census of water systems to understand the general degree of complexity of the system, in order to determine the magnitude of the need for detailed distribution system configuration and operation information;

§ Methods for easily collecting water system information, specifically, distribution system inputs, flow data, and configuration/operations information;

§ Methods for estimating groundwater quality in situations where direct water quality measurements are not available.

Finally, an accurate picture of exposures is not possible without a better understanding of the behavioral and household factors affecting exposure. In order to track potential or actual exposures among demographic groups, the following improvements are needed:

§ Systematic collection of data on key water use behaviors and household factors (e.g. water treatment, consumption of bottled water) from representative population samples, including socio-demographic information; and

§ Methods for capturing other key, but more complex water use data that are feasible for an ongoing EPHTN.

Future EPHT activities concerning drinking water quality indicators and drinking water exposure assessment, particularly those in the Content Workgroup, should build off of the lessons learned and products developed during this project.

7. GLOSSARY OF TERMS

BRFSS: Behavioral Risk Factor Surveillance System

CAD: Computer-aided Design

CAWQMD: California Water Quality Monitoring Database

CDC: Centers for Disease Control

COPD: Chronic Obstructive Pulmonary Disease

CSFII: Continuing Survey of Food Intake by Individuals

CWS: Community Water Systems

DATCP: Department of Agriculture Trade and Consumer Protection

DBPs: Disinfection By-Products

DNR: Department of Natural Resources

DWEG: Drinking Water Exposure Group

DWR: Department of Water Resources

DOM: Document Object Model

EMNRD: Energy, Minerals, and Natural Resources Department

EPANET: A desktop application that performs extended period simulation of hydraulic and water-quality behavior within pressurized pipe networks developed by the US EPA's National Risk Management Research Laboratory.

EPHT: Environmental Public Health Tracking

EPHTN: Environmental Public Health Tracking Network

EPTDS: Entry point to the distribution system

FD&C Act: Federal Food, Drug, and Cosmetic Act

FDA: Food and Drug Administration

GMPs: Good Manufacturing Practices

GIS: Geographic Information Systems

HAAs: Halo Acetic Acids

HTML: Hypertext Markup Language

IT/GIS: Information Technology/Geographic Information Systems

IOCs: Inorganic Contaminants

MCL: Maximum Contaminant Limit

NAWQA: National Water Quality Assessment

NHAPS: National Human Activities Pattern Survey

NHES: National Health and examination Survey

NJDEP: New Jersey Department of Environmental Protection

NRDC: Natural Resources Defense Council

NWIS: National Water Information System

OCD: Oils Conservation Division

PDWS: Private Domestic Water Systems

PHASE: Public Health Air Surveillance Evaluation

PM 2.5: Fine Particles, which are 2.5 micrometers in diameter and smaller

POE: Point-of-entry

PWS: Public Water Supplies

RECS: Residential Energy Consumption Survey

REUWS: Residential End Uses of Water Study

SCWS: "Small" Community Water System

SDWA: Safe Drinking Water Act

SDWIS: Safe Drinking Water Information System

SMF: Standard Monitoring Framework

SOCs: Synthetic Organic Contaminants

SOQ: Standard of Quality

TCE: Trichloroethylene

TEM: Total Exposure Model

THMs: Trihalomethanes

TTHMs: Total Trihalomethanes

USEPA: United States Environmental Protection Agency

USGS: United States Geological Survey

VOCs: Volatile Organic Compounds

WATERS: Water Administration Technical Engineering Resource System

WFS: Web Feature Service

WFS-T: WFS Transaction

XML: Extensible Markup Language

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10. APPENDIX B. CONTAMINANT CLASS-SPECIFIC MONITORING REQUIREMENTS BY USEPA STANDARD MONITORING FRAMEWORK

The USEPA SMF is set within nine-year cycles or "compliance periods", starting in 1993. The text below is mostly adapted from the Standardized Monitoring Framework Quick Reference Guide at http://www.epa.gov/safewater/pws/pdfs/qrg_smonitoringframework.pdf .

Nitrate/Nitrites. The nitrate/nitrite rules require annual nitrate sampling at each EPTDS for surface water systems having at least four quarters of results that are less than one-half the MCL. Annual EPTDS sampling is required for groundwater sources that are reliably and consistently below the MCL. The frequency of nitrite monitoring is specified by the primacy agency for systems with detections below one-half the MCL. If nitrites are reliably and consistently below the MCL, then one annual sample is required at each EPTDS. Systems with nitrate or nitrite samples greater than or equal to one half the MCL are required to take quarterly samples at the EPTDS.

Inorganic Contaminants (IOCs). Systems served by groundwater sources with previous detections below the MCL are required to monitor for IOCs once every three years, if the system does not have a waiver. A waiver can be granted if analytic results of 3 rounds of monitoring at each entry point to the distribution system (EPTDS) are below the MCL. Systems served by groundwater sources that have received waivers are only required to sample one time every nine years. Waivers are not permitted under the current arsenic requirements; however systems are eligible for arsenic waivers after January 23, 2006. Monitoring of IOCs is required once a year for surface water systems without a waiver and once every nine years for surface water systems with waivers. Groundwater systems that have had a detection above MCL, but have returned to having detections at or below the MCL, are required to monitor once every three years, surface water sources once per year and if there is an MCL violation, or the system is not reliably and consistently at or below the MCL they are required to take quarterly samples of IOCs. If a groundwater or surface water system has detections above MCL, they are required to collect quarterly samples, at the appropriate sampling point, until the system is determined by the primacy agency to be reliably and consistently below the MCL.

Synthetic Organic Compounds (SOCs). Monitoring requirements for SOCs with samples found at or below the detection limit are required to take two quarterly EPTDS samples, during one calendar year of a three year compliance period. Systems receiving a waiver are not required to sample at all. If SOCs are detected but are reliably and consistently below the MCL, one sample is required at each EPTDS. If SOC samples are detected above the MCL or are not reliably and consistently below the MCL, they are required to take four quarterly samples at each entry point to the distribution system within the time frame designated by the primacy agency.

Volatile Organic Compounds (VOCs). VOCs in groundwater systems that have VOC levels below detection limits and receive a waiver are required to sample at the EPTDS once every six years. If groundwater systems do not have a waiver, they are required to sample once every year at the EPTDS. Sampling requirements are the same for surface water sources without a waiver, however, if they are below the detection limit or have a waiver, surface water systems are not required to sample. For both

source types, if sampling results are above the detection limit but consistently below the MCL, one annual sample at the EPTDS is required. If a sample is greater than an MCL or not reliably and consistently less than or equal to the MCL, quarterly monitoring at the EPTDS is required.

Disinfection By-Products. Beyond the SMF, there are regulations governing monitoring of disinfection by-products (DBP). In contrast to contaminants regulated under the SMF, monitoring of DBPs is required at various points throughout the distribution system and the frequency and number of sampling points is driven by source water type and the estimated population served by each CWS. The Stage 2 Disinfectants and Disinfection By-products Rule (DBPR) establishes routine monitoring requirements that are based on system type and population served by the system. The Stage 2 DBPR rule was established to improve public health by reducing risks associated with DBPs, the rule supplements the Stage 1 DBPR rule and focuses on two classes of DBPs – TTHMs and HAA5 – in drinking water. The larger the system and the more people served by the system increases the frequency of monitoring as well as the number of required monitoring locations. Larger surface water systems that fall under the Surface Water Treatment Rule (or "Subpart H" systems) are required to monitor the most frequently. For example, a surface water system having a served population of more than 5 million people must have 20 total distribution system monitoring locations per monitoring period.

Radionuclides. Monitoring for radionuclides is comparatively more complex, but is does not distinguish between groundwater and surface water systems. When allowed by the primacy agency, data collected between June 2000 and December 2003 could be used ("grandfathered") instead of collecting fresh data in 2004 for gross alpha, radium-226/228 and uranium. If that data is greater than the MCL, 4 quarterly samples must be collected each year from 2004 through 2007 for each EPTDS. If that data is less than the detection limit, 4 quarterly samples need to be collected during that time frame. If those data average less than the MCL, reduced monitoring is possible. Otherwise, quarterly sampling must continue through successive 3 year segments until the total 3 year quarterly samples average less than the MCL. The reduced monitoring (during 2008-2019) plan following the first collection period (2004-2007) is: 1) one sample per EPTDS per three year period, if the data from the first period was greater than half the MCL but less than the MCL; 2) one sample for each EPTDS per six year period, if the data from the first period was greater than or equal to the detection limit and less than or equal to half the MCL; or 3) one sample for each EPTDS per nine year period (and one in the last 3 years), if the data from the first period was less than the detection limit.

Asbestos. Monitoring for asbestos is not required, if the primacy agency provides a waiver. Monitoring is required once per nine year period during 2002-2019, if the primacy agency does not provide a waiver. For systems above the MCL quarterly testing is mandatory.

Lead/Copper. Lead and copper testing is unusual, because it is based on an action level rather than an MCL and because the testing takes places at residential kitchen cold water taps in homes selected as a worst case based on age and type of indoor plumbing and service connections. Compliance is based on the 90th percentile of a set of samples being below the action level. The number of sample sites is based on system size, from as few as 5 to as many as 100 (or 50 with reduced sampling). Sampling is conducted twice annually if the samples are above the action levels, but may be reduced to once every year for systems serving less than 50,000 people, if results are below both action levels for two consecutive 6 month periods, or the water meets optimal water quality parameter specifications (for pH, alkalinity, calcium, and corrosion inhibitors) for two consecutive 6 month periods. Similarly, those systems may be

reduced to monitoring once every three year, if the levels are below both action levels for three consecutive years, or the water meets optimal water quality parameter specifications for three consecutive years, or the 90th percentiles are below 0.005 mg/L for lead and 0.65 mg/L for copper for two consecutive 6 month periods. Systems that are smaller than 3,300 people may have to test only once every 9 years depending on certain criteria.

Unregulated Contaminant Monitoring Rules. These rules have served to inform USEPA's rule-making process by providing occurrence information from the larger systems and a sample of the smaller systems. Currently the rules help decide which contaminants are placed on the Candidate Contaminant List for future regulation. The sampling typically runs only for a couple of years and can be conducted at the EPTDS or, in the case of DBPs, in the distribution system.