United States Environmental Protection Agency
Office of Water 4607
EPA 815-R-01-004
August 2001

Statistical Design and Sample Selection for the Unregulated Contaminant Monitoring Regulation (1999)

Printed on Recycled Paper

Foreword

Under §1445(a)(2)(A) of the Safe Drinking Water Act (SDWA), as amended in 1996, the Environmental Protection Agency (EPA) is required to establish criteria for a program to monitor for unregulated contaminants and to publish a list of contaminants to be monitored. In response to this requirement, EPA published the Revisions to the Unregulated Contaminant Monitoring Regulation (UCMR) for public water systems (PWSs) on September 17, 1999 (64 FR 50556), and in supplemental rules, including, the Perchlorate and Acetochlor Rule (March 2, 2000 - 65 FR 11372), and the List 2 Rule (January 11, 2001 - 66 FR 2273). EPA expects to publish other rules detailing updates and modifications to the UCMR program, monitoring requirements, and analytical methods, as needed.

This document provides technical background information on the statistical process used to select the nationally representative sample of small PWSs (systems serving 10,000 or fewer people) for the UCMR. This document also explains the statistical selection process for large PWSs (systems serving greater than 10,000 people) selected to monitor for the Screening Survey component of the UCMR. Note that this document does not explain all UCMR program requirements in detail. Where more detailed and comprehensive information is available through other EPA guidance documents, the reader will be referred to these documents.

Acknowledgments

This document was prepared in support of the Unregulated Contaminant Monitoring Regulation (UCMR) for EPA's Office of Ground Water and Drinking Water. Charles Job served as EPA's team leader for development of the UCMR with James Taft as Targeting and Analysis Branch Chief. Rachel Sakata served as Work Assignment Manager. The UCMR Work Group provided technical guidance throughout. Andrew Schulman provided technical lead for finalizing the selection process. Also, Dennis Helsel of the US Geological Survey, and Christopher Frebis provided valuable assistance. External expert reviewers and many stakeholders provided valuable advice to improve the UCMR and this document. The Cadmus Group, Inc., served as the prime contractor providing support for various components of this and other UCMR support work. The major contributions of Kim Clemente, Maureen Devitt, Jonathan Koplos, and Piyali Talukdar are gratefully acknowledged. George Hallberg served as Cadmus' Project Manager.

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1. Introduction

1.1 Purpose and Background

The requirement to monitor unregulated contaminants was established by the 1986 Amendments to the Safe Drinking Water Act (SDWA). Public water systems (PWSs) were required to report the monitoring results for up to 48 unregulated contaminants to the States or primacy agency under several regulations (40 CFR 141.40(e), (j), and (n)(11) - (12)). Systems with less than 150 service connections were exempt, provided those systems made their facilities available for the States to monitor.

Under §1445(a)(2)(A) of the SDWA, as amended in 1996, the Environmental Protection Agency (EPA) was required to establish criteria for a program to monitor for unregulated contaminants and to publish a list of contaminants to be monitored. To fulfill the requirements of the SDWA, EPA published the Revisions to the Unregulated Contaminant Monitoring Regulation (UCMR) for PWSs on September 17, 1999 (64 FR 50556). This regulation included programmatic changes to the UCMR and provided a list of contaminants for which monitoring was required, or would be required in the future. The UCMR set up a three-tiered monitoring approach for contaminants based on the availability of analytical methods and insights on contaminant properties and fate and transport. In response to public comments, and as relevant analytical methods were refined and developed. EPA published the Perchlorate and Acetochlor Rule on March 2, 2000 (65 FR 11372), and the List 2 Rule on January 11, 2001 (66 FR 2273). As EPA continues to refine and develop additional methods and/or identify minor clarifications or modifications needed for the successful implementation of the UCMR, the Agency will provide additional guidance documents or fact sheets and will promulgate additional rules, as necessary.

The UCMR program was developed in coordination with the Contaminant Candidate List (CCL) and the National Drinking Water Contaminant Occurrence Database (NCOD). The UCMR and the CCL operate on a 5-year cycle to assess the impact of new and emerging contaminants on drinking water. The new UCMR program is a cornerstone of the sound science approach to future drinking water regulation. The data collected through the UCMR program will be stored in the NCOD to facilitate analysis or review of contaminant occurrence, and will be used to support the development of subsequent CCLs, and to support the Administrator's determination of whether or not to regulate a contaminant in the interest of protecting public health.

The SDWA provisions and EPA regulations described in this document contain legally binding requirements. This document does not substitute for those provisions or regulations, nor is it a regulation itself. It does not impose legally-binding requirements on EPA, States, or the regulated community, and may not apply to a particular situation based upon the circumstances. EPA and State decisionmakers retain the discretion to adopt approaches on a case-by-case basis that differ from this guidance where appropriate. Any decisions regarding a particular facility will be made based on the applicable statutes and regulations. Therefore, interested parties are free to raise questions and objections about the appropriateness of the application of this guidance to a particular situation, and EPA will consider whether or not the recommendations or interpretations in the guidance are appropriate in that situation based on the law and regulations. EPA may change this guidance in the future without notice or an opportunity for comment. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

The purpose of this document is to describe the statistical design and methods used to select the representative sample of small PWSs (systems serving fewer than 10,000 people) that are required to conduct Assessment Monitoring and Screening Surveys. This document also describes the process used to select large PWSs (systems serving more than 10,000 people) for the Screening Survey component of the UCMR. Portions of this document also describe how this process relates to individual State Monitoring Plans (SMPs). Under the UCMR, the listed unregulated contaminants will be monitored between 2001-2005. All large PWSs are required to monitor for UCMR contaminants. Section 1445(a)(2) of SDWA mandates that only a representative sample of small PWSs may be required to monitor under the UCMR. The representative sample must be of adequate size and quality to obtain the necessary and valid contaminant occurrence information upon which to base regulatory determinations while minimizing burden to the water system.

The objective of the statistical approach for the UCMR is to estimate contaminant exposure and occurrence in a nationally representative sample of small systems which will enable extrapolations of exposure and occurrence nationwide. For contaminant exposure assessments (the fraction of population that is exposed to a contaminant), the representative sample design was first weighted by population served by PWSs. However, information on contaminant occurrence is also necessary. The context of occurrence (for example, the size of a water system or its water source) is a factor when evaluating potential future regulatory implementation. Therefore, the representative sampling design incorporates a stratified sampling approach and allocates some samples among strata to enable evaluations of occurrence relative to system size (based on population served), water source type (surface water or groundwater) and, to some degree, geographic distribution. Although this statistical design is not strictly optimal for estimating either exposure or occurrence, the design meets the data quality objective for overall exposure estimates (99% confidence level with ±1% error tolerance, at 1% exposure), while providing more precise occurrence estimates for categories of small systems.

1.2 Overview of the UCMR Program

The first component of the UCMR is Assessment Monitoring which will be conducted by all of the approximately 2,800 large community water systems (CWSs) and non-transient non-community water systems (NTNCWSs) serving more than 10,000 persons (except those large systems that purchase *all* of their water from another PWS), and by a statistically representative sample of 800 small CWSs and NTNCWSs serving 10,000 or fewer persons (except those small systems that purchase *all* of their water from another PWS). Assessment Monitoring will be conducted for the UCMR (1999) List 1 contaminants, for which analytical methods have already been developed and refined.

The second component of the UCMR includes the Screening Surveys. Each of the two Screening Surveys will be conducted at 120 large systems, and at 180 small systems randomly selected from the pool of systems required to conduct Assessment Monitoring. Screening Survey monitoring will be conducted for the List 2 contaminants for which analytical methods have been developed, but may need further refinement before larger-scale monitoring is conducted.

The third component of the UCMR is Pre-Screen Testing which may be conducted at a combined total of up to 200 large and small systems. States will be asked to nominate systems that are particularly vulnerable to the Pre-Screen Testing contaminants. Pre-Screen Testing may be conducted for some of the UCMR (1999) List 3 contaminants for which analytical methods are in the initial stages of development. EPA will provide further guidance on Pre-Screen Testing contaminants and analytical methods as necessary.

EPA also selected 30 small systems to serve as Index Systems. These systems will conduct Assessment Monitoring each year of the 5-year UCMR cycle to provide additional programmatic information and data quality control. EPA contractors will collect data on temporal variations in contaminant occurrence, and on the environmental and operating conditions of these 30 small systems. Detailed information from the Index Systems, together with the monitoring data generated through general UCMR monitoring, will enable EPA to develop future regulations that better reflect the environmental characteristics and operating conditions of small PWSs.

General monitoring schedules are related to the type of monitoring (Assessment Monitoring, Screening Survey, or Pre-Screen Testing) being conducted. Each participating system must conduct Assessment Monitoring for the List 1 contaminants for a 12-month period in the first three years (2001 through 2003) of the 5-year UCMR contaminant monitoring cycle (2001-2005), as per §141.40(a)(5). Randomly selected large systems will sample for the UCMR List 2 contaminants in 2002 (for chemical contaminants) and 2003 (for the microbiological contaminant, *Aeromonas*), while small systems will sample in 2001and 2003, respectively. No time-frame has been established yet for Pre-Screen Testing for the UCMR (1999) List 3 contaminants.

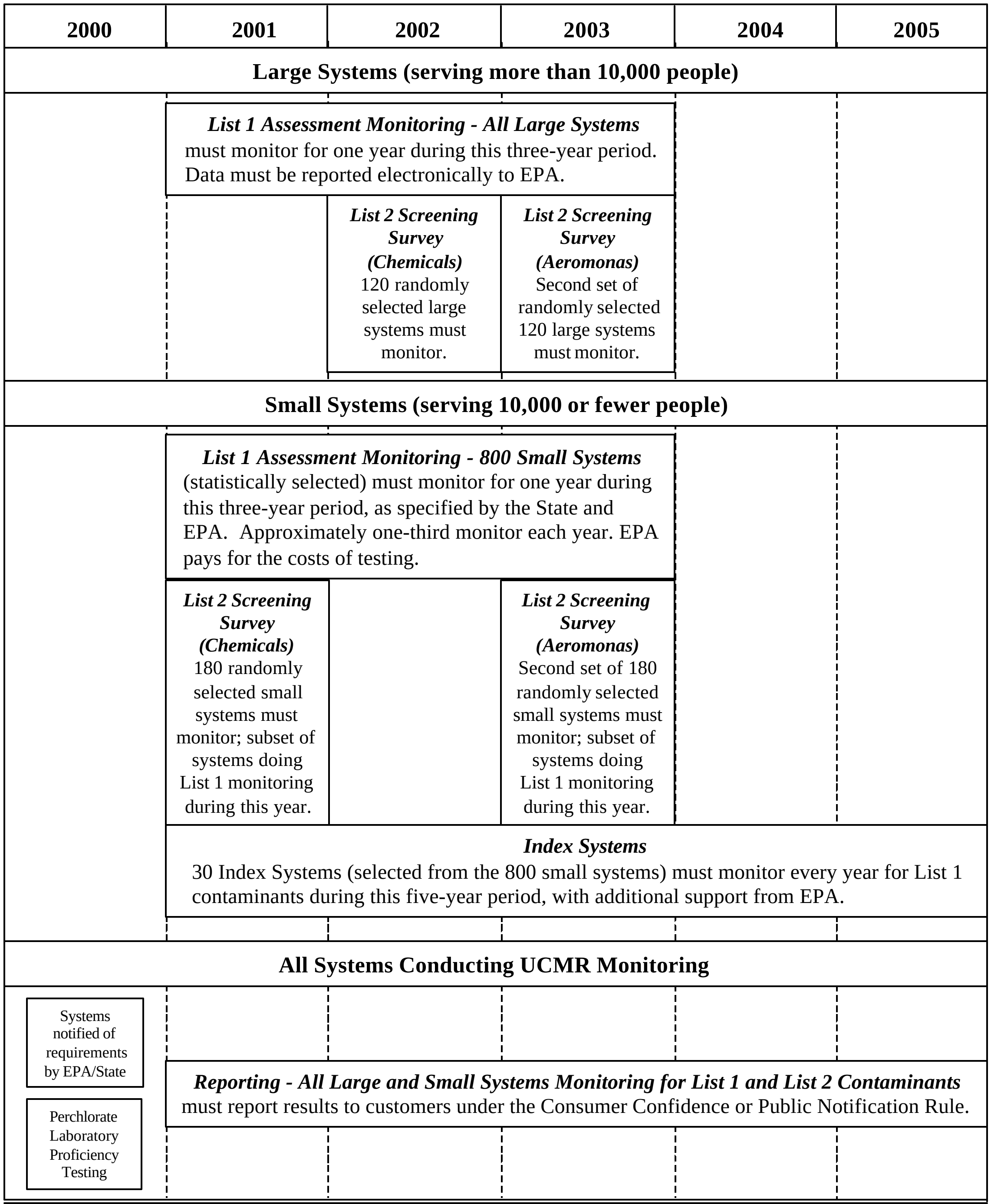
Required monitoring locations are also related to the type of monitoring (see §141.40(a)(5)). Assessment Monitoring samples must be collected at the entry point(s) to the distribution system unless otherwise specified by the State or EPA. Samples for the first Screening Survey (for the List 2 chemicals) must always be collected at the entry point(s) to the distribution system (source water samples are not permitted). Samples for *Aeromonas* must be collected in the distribution system. Sampling locations must include one midpoint in the distribution system where the disinfectant residual will be expected to be typical for the system (midpoint, or MD, as defined in the Rule), and two other points: one of maximum retention time and one where the disinfectant residual will have typically declined (point of maximum residence, or MR, and location of lowest disinfectant residual or LD, respectively, as defined in the Rule).

Discussions with States and other stakeholders indicated the need to select a representative sample of systems across all States to ensure both confidence in the UCMR results and a comprehensive spatial distribution. To ensure that the sample is representative of the nation and to reduce the burden on small systems, EPA statistically selected a nationally representative sample of systems serving 10,000 or fewer people for the UCMR. States are participating in the UCMR through State Monitoring Plans (SMPs) as established by Partnership Agreements (PAs) with EPA. Note, however, that a State was not required to enter into a PA with EPA to participate in SMP development. Through the PAs and the SMPs, States were given an opportunity to participate in the UCMR program, while sharing some of the responsibilities with EPA. All steps involved with sample selection described throughout this document assume that a State has entered into a PA with the appropriate EPA Regional Office, or has decided to review the SMP.

As described later in this document, a list of the statistically-selected systems was provided by EPA to the States. The list was comprised of a “primary list,” an “alternate list,” and a “supplemental alternate list” of systems. These lists were provided to the States for their review and inclusion in their SMPs. States could either: (1) respond by accepting the primary list as their representative plans, or (2) propose an alternative plan by selecting other system(s) from the replacement list(s), in cases where EPA’s initial plan identified system(s) that no longer existed, because of merger or closure, or that switched to purchased water.

Figure 1 provides a summary of the UCMR three-tiered monitoring approach, and shows the implementation timeline of UCMR activities.

Figure 1. UCMR (1999) Implementation Timeline



2. Determining the UCMR Sampling Frame

2.1 Background

A critical first step in selecting a nationally representative sample of small PWSs for the UCMR is the selection of a sample frame, i.e., an appropriate inventory list of PWSs from which to select the sample. This is particularly true in a stratified sample such as designed for the UCMR. Stratified sampling studies are often subject to strata migration problems, which are caused by the inaccurate strata classification of systems in the design and sample selection phase and which can complicate and jeopardize the results of the strata-based sampling. Although the Safe Drinking Water Information System (SDWIS) provides the raw inventory list, or "total population," of PWSs from which the statistical sample is drawn, SDWIS is not designed to be a sample frame. Many properties of SDWIS, and, more importantly, some lingering problems of system classification in SDWIS, can result in many inaccuracies for sample frame applications such as the sample selection procedures necessary for the UCMR statistical sampling.

EPA utilized the inventory list provided by the 1999 Drinking Water Infrastructure Needs Survey (Needs Survey) to select small systems for Assessment Monitoring and Screening Survey monitoring, and to select large systems for Screening Survey monitoring. EPA then improved upon the SDWIS inventory and created a more suitable inventory list for a sample frame. The sample frame improvements and sample selection considerations used to improve the 1999 Needs Survey inventory information for use as the UCMR sampling frame are described in the following sections of this document.

2.2 Needs Survey Inventory Background

The Needs Survey is conducted every four years to assess infrastructure needs of the Nation's drinking water systems. The Needs Survey data, along with other relevant information, is also used to allocate State Drinking Water Revolving Fund (DWSRF) monies. The Needs Survey requires that inventory information is as accurate as possible so that PWS needs are accurately estimated. A process was established to develop a reliable and accurate database from which to draw the Needs Survey samples. The Needs Survey inventory is based on inventory information on all PWSs included in SDWIS as of March 1998. The steps used to ensure that inventory data (system status, population served, number of service connections, source of water, contact name and address, etc.) are correct are described in detail below.

2.3 Needs Survey Sample Frame Improvements

2.3.1 Community Water Systems

Inventory data are confirmed before being used by the Needs Survey. The Needs Survey uses the confirmed data in specific size categories (large and medium CWSs serving greater than 50,000 people, and 3,301 to 50,000 people, respectively) to select systems that will complete questionnaires describing current and future system infrastructure needs. Inventory data are also confirmed before small CWSs serving less than 3,300 people and non-profit non-community water systems are selected for site visits.

Problematic data were first identified and addressed based on the experience of the 1995 Needs Survey. This step included reviewing and cleaning up odd, repeated values (such as repeated "99s" for the population-served value). EPA then provided the confirmed inventory data to the States (including the Virgin Islands and Puerto Rico) for review and asked the States to provide any necessary changes.

EPA also worked with the States to identify the total "consecutive" population served (including the population of retail buyers) by many prominent large systems, and to group systems into size and type categories that more accurately reflect actual populations served by a particular water system. For instance, the reported population served by the Metropolitan Water District of Southern California (MWD) was adjusted to account for the fact that the system actually serves a much larger population than the SDWIS inventory suggests. Based on the SDWIS inventory, the MWD is categorized as a small system serving less than 3,300 people. Adjusting the population to account for the approximately 16 million consumers actually served by the system, the system is then reclassified as a large system, which accurately reflects how this system is regulated under the SDWA. This example highlights the types of changes incorporated into the adjusted sample frame through identification of the consecutive population served.

On site inventory verifications were conducted for States where: (1) the 1995 inventory verification discrepancy rate was greater than 1 percent; or (2) the number of CWSs in a State in SDWIS as of March 1998 was at least 3 percent greater than in the sampling frame used for the 1995 Needs Survey. On site inventory verifications were also conducted for States that contributed to at least 0.8 percent of total national need in the 1995 Needs Survey, and if EPA determined that SDWIS inventory may not accurately reflect a State's inventory. Inventory verifications were conducted in Arizona, Arkansas, California, Colorado, New York, North Carolina, Ohio, Oklahoma, and Tennessee. SDWIS-Fed inventory information for Virginia was replaced with SDWIS-State inventory information, since SDWIS-Fed was known to be an inaccurate source of current inventory.

The process of State corrections includes a variety of inventory review procedures and data verifications as described below:

- A stratified random sample of systems was used to select systems within each State that would then be subject to inventory verification. The systems were stratified by service size category and water source (surface or ground water), and a representative sample was selected for each State to represent a 95 percent confidence level with a relative error of 10 percent. The sample was selected based on the expected proportion of systems with discrepancies, from experience with data verifications conducted by EPA between 1991 and 1997. CWSs serving 25 to 1,000 people were expected to have a discrepancy rate of 7.5 percent, while CWSs serving 1,001 to 40,000 people were expected to have a discrepancy rate of 5 percent.
- A two-staged cluster sampling approach was used to select systems in New York, since data in this State are managed by numerous district offices. The first stage selected enough offices to include systems of all strata in the sample. The second stage was a random sample of systems within the district offices.
- Sanitary survey information, bacteriological results, or other chemical records in State files and/or databases were reviewed on site to ensure that inventory data were accurate. If inventory information was different between SDWIS and the State files and/or database, a discrepancy was issued. Each State so identified was then given an opportunity to provide monitoring results or other documentation of a system's characteristics, and, in some cases, documentation of a system's actual existence. Systems that were inactive were removed from the Needs Survey sampling frame, while other systems were re-categorized if necessary. For instance, SDWIS may have a system categorized as a surface water system, while State records indicate that the system purchases surface water. It is this type of mis-categorization that is routinely corrected in the Needs Survey sample frame.

- Based on results of the inventory verification, the total inventory for each State was further refined. The inventory verification results were extrapolated to all systems in each State to estimate the number of active systems in each size and type category (stratum). The determined proportion of inactive systems in the inventory verification sample was applied to the number of total systems in the sample frame. Then systems were assigned to each stratum based on the proportion of active systems that moved from one stratum to another. For instance, if 5 percent of systems in the inventory verification sample were inactive, then it was assumed that 5 percent of the total number of systems in the State were inactive. This was then applied to the revised active frame, reflecting the final inventory of active systems in a State.

The Needs Survey sample frame was further refined during the course of the data collection period. System status as of January 1, 1999 was used to determine inclusion and placement within the sample frame. Additional systems were added to the sampling frame based on information provided by the State of Virginia in the last quarter of 1999.

2.3.2 Non-transient Non-community Water Systems

Limited verification was conducted on the non-profit non-community water systems (NCWSs). A random sample of 100 systems was selected from the total number of non-profit NCWSs across the US to determine how many systems would be selected in each State for a site visit. This random sample was used only to estimate the number of systems in each State where EPA would conduct a site visit. The actual sample of non-profit NCWSs were then randomly selected from the counties in each State where EPA already had plans to conduct site visits at small CWSs. The sample of non-profit NCWSs was *not selected* based on strata, and *only non-profit* NCWSs were selected for review for the Needs Survey (since they are the only NCWSs that are eligible to receive DWSRF monies). The sample of non-profit NCWSs does not include transient non-community water systems. The sample size of 100 systems provides a confidence level of 95 percent and a margin of error of 30 percent.

Thus, for UCMR use, inventory data for NTNCWSs has undergone the least confirmation and correction. Each State participating in the UCMR through PAs with EPA reviewed the systems selected by the UCMR process for the SMP

2.3.3 Tribal Water Systems

The sample frame for Tribal systems and Alaska Native water systems was based on input from the Indian Health Service (IHS) Sanitary Deficiency System (SDS), Tribes, and EPA regions. There are approximately 940 systems nationwide that are owned and operated by Tribes and Alaska Natives. Some of the Tribal systems are regulated by the States, and many State-owned and operated systems serve a large population of American Indians. Since the Needs Survey considers all State-owned and operated systems, EPA worked with the Tribes, Alaska Natives, the IHS, and the States to determine how to classify each Tribal system. Each Tribe notified the appropriate EPA region if they believed that the State-owned or operated system should be considered in the Tribal system sample frame, rather than in the State sample frame. Inventory information for Tribal systems and Alaska Native systems were taken from SDWIS, then corrected, and updated by both the appropriate EPA Region and the IHS. The corrected data were then compiled and comprises the sample frame for the Needs Survey.

For the UCMR, the Alaska Native systems were grouped with the remainder of the Alaska CWSs and NTNCWSs. These systems were *not* grouped with the Tribal water systems. All State-owned and operated water systems that serve a large proportion of American Indians were *not* treated as Tribal water systems. The State-owned and operated water systems were treated as State systems in the UCMR sampling frame.

2.3.4 System Classifications

Another potentially problematic issue is the source water classification of systems used in SDWIS. Compliance and monitoring requirements under the SDWA are more stringent for surface water systems than for ground water systems based on historic occurrence data and vulnerability considerations. Generally, surface water systems are more vulnerable to releases, spills, and other potential sources of contamination than ground water systems. Also, water systems can depend on a single water source type, but can have a mix of sources. Therefore, to ensure that the level and type of compliance and monitoring requirements are appropriate to the type(s) of source water used by a water system, EPA created a hierarchy of system source water classifications. The hierarchy (or sequence from lowest to highest regulatory regime) is: purchased ground water, ground water, purchased ground water under the direct influence of surface water, ground water under the direct influence of surface water, purchased surface water, and surface water. This hierarchy helps establish the appropriate regulatory oversight relative to source water type to provide the highest degree of human health protection possible. A water system with mixed sources is regulated according to the water source type used that ranks highest in the regulatory hierarchy.

This hierarchy of compliance and monitoring classification scheme is designed to implement the most protective regulatory approach, but it may also pose a problem for the national representative sample. If a system uses ground water and also purchases surface water, the system will be listed in SDWIS as a purchased surface water system since purchased surface water ranks higher on the hierarchy. However, the UCMR sample selection criteria excludes purchased water systems; therefore, this system would not be selected for inclusion in the national representative sample. The number of purchased water systems is small compared to the total number of PWSs, and this exclusion of purchased water systems will not significantly affect the UCMR sample. States and PWSs adjusted their monitoring schedules to accommodate the above problems relative to the source of the actual entry points to the distribution system (EPTDS). Using the single SDWIS classification for each system resulted in some inaccuracies which could not be avoided. These inaccuracies were corrected where needed by the States or EPA when the SMPS were reviewed.

2.3.5 Additional Sampling Frame Improvements

The resulting Needs Survey inventory list may not exactly reflect the information in SDWIS in the fall of 1999 or 2000 since it is likely that a few systems will have changed status in the intervening time. To minimize the effect of system status changes, EPA verified the status, water source, population served, and system type for small CWSs in 19 States and three territories where there were three or fewer PWSs within each stratum (system size category by water source type). Eleven systems in five States were determined to be inactive. Four systems in four different States purchase their water, and were removed from the system list. One system changed from a CWS to a NTNCWS, and seven systems in four States changed their source water type from surface water to ground water. The population of 12 systems changed, and three systems were moved into a different service size category. The status of these systems was verified before sample selection to ensure that the sample of systems selected from these categories was truly representative of the number of systems in existence.

Each State, as noted earlier, has already received an additional opportunity to correct the inventory system data and the strata assignments when they reviewed and approved the systems selected for their SMPs. Each State (and EPA itself, in the cases where a State did not wish to participate) had an opportunity to improve the sample by removing systems from the sampling pool that were inactive, and replace them with active systems from the alternate/replacement list(s) provided to them. States or EPA were also permitted to remove systems from their SMPs for reasons other than those listed above, as long as the reasons were clearly explained in consultation with EPA. All changes were included in the final SMPs sent back to States or EPA so that systems could be notified of their requirements under the UCMR. States and EPA Regions will continue to update UCMR inventory information as changes occur.

3. Selecting the Statistical Population for Systems Serving 10,000 or Fewer People

3.1 Determining the Population of Small PWS for Inclusion in the UCMR Sample

The total population of small PWSs is comprised of CWSs, NTNCWSs and transient non-community water systems (TNCWSs). Two categories of PWSs were excluded from the population for selecting the sample. PWSs that purchase their entire water supply from another PWS are generally exempt from the regulation, since monitoring at these systems could result in double counting of systems using the same source. Additionally, TNCWSs were excluded from the UCMR, since projecting contaminant exposure from monitoring results is difficult and inconclusive due to the transient nature of the population that use these sources of drinking water.

EPA estimates that there are approximately 66,808 non-purchased CWSs and NTNCWSs, based on the 1999 Needs Survey inventory.[1] Table 1 illustrates the total number of non-purchased CWSs and NTNCWSs in each service size category (serving 25 to 500, 501 to 3,300, 3,301 to 10,000, 10,001 to 50,000, and greater than 50,000 people) by source water type (ground or surface water), from the UCMR sampling frame.

3.2 Stratifying the Population

In developing the representative sample, EPA considered factors such as (1) geographic location, (2) population served, and (3) water source. The sample was stratified by population served, allocating samples proportionately to each State by system size, and then by water source type. NTNCWSs were selected as a separate category since these systems may be a significant source of water consumed by residents of a community.

Sources of water may not be evenly distributed across any given State. Cities transfer water across watershed boundaries, or move water from one State to another. To account for the proportion of the population served by a specific water source, EPA defined "geographic location" as the location of the water source and stratified the sample further by source of water supply. For example, if 10 percent of the population in a State obtains their water from surface water supplied PWSs that serve less than 500 individuals, then approximately 10 percent of the sampled systems in that State should come from the PWSs in this size and source category. The distribution of systems across the State, then, is accommodated by the population-weighted statistical sample selection. As explained further in Section 4, the sample is not strictly population-weighted. The sample size for each State and each stratum were optimized to ensure that UCMR sampling results have a high level of confidence and a low margin of error. Therefore, the sample was stratified by system type (CWSs and NTNCWSs)

[1] As noted earlier, the inventory sampling frame is based on the 1999 Needs Survey. The original data were taken from SDWIS in March 1998.

Table 1. Systems Serving 10,000 or Fewer People

Population Served	**Total Population Served Nationally**					**Number of Non-purchased PWSs**				
Size Category	CWSs		NTNCWSs		**Total**	CWSs		NTNCWSs		**Total**
	Ground Water	Surface Water	Ground Water	Surface Water		Ground Water	Surface Water	Ground Water	Surface Water	
25 - 500	4,321,261	248,417	2,292,697	68,088	6,930,463	28,149	1,403	16,566	416	46,534
501 - 3,300	12,894,496	2,542,195	2,493,942	179,371	18,110,004	9,551	1,586	2,606	148	13,891
3,301 - 10,000	13,415,514	6,269,284	282,405	57,643	20,024,846	2,349	1,027	55	13	3,444
Subtotal	**30,631,271**	**9,059,896**	**5,069,044**	**305,102**	**45,065,313**	**40,049**	**4,016**	**19,227**	**577**	**63,869**
10,0001- 50,000	25,909,335	23,033,999	108,027	0	49,051,361	1,217	993	7	0	2,217
Over 50,000	30,478,607	139,106,597	0	0	169,585,204	240	482	0	0	722
Total	**87,019,213**	**171,200,492**	**5,177,071**	**305,102**	**263,701,878**	**41,506**	**5,491**	**19,234**	**577**	**66,808**

The population and water system information used in this table is from the 1999 Needs Survey inventory database. The information in this table was used to derive the sample distribution and statistical calculations found in other tables in this document.

and by source water type within each small system size category (categories 1 through 3) in each State.

3.3 Tribal Water Systems as an Individual Stratum

Small PWSs that are located on Tribal lands in each of the 10 EPA Regions were grouped into a single category for the representative sample; this Tribal category is equivalent to a State for the statistical selection process. Tribal systems had the same probability of being selected as other water systems in the stratified random selection process that weighs systems by water source and size class by population served. Using this discrete stratum ensures that some Tribal systems were selected as part of the national representative sample. The systems selected comprise the "SMP" for Tribal water systems.

3.4 Consistency of State Plans

EPA selected the representative sample from the population of CWSs and NTNCWSs nationally, then allocated the sample to individual States, weighted approximately for the proportion of the population served by each service size category and water source type. Based on a stratified random selection process applied to CWSs and NTNCWSs, the sample size was weighted by population served (to enable exposure assessments from Assessment Monitoring results) and water source type (to enable comparisons between surface or ground water) while allocated proportionately amongst States (to ensure geographic coverage) within service size category (categories 1 through 3). EPA also randomly selected two alternate/replacement systems for each PWS selected for the national representative sample. EPA selected a supplemental alternate/replacement list, in cases where the primary system, and both alternates were determined to be inactive. All of these systems appear in the initial SMPs sent to States.

States could have include the EPA-selected systems on the initial plan list in their SMP. If, however, the State review determined that a system on the initial plan list had closed or merged, the system could be removed from the SMP List. To remove a system from the SMP List and replace it with another system, the State should have notified EPA of the reasons for removal. Valid reasons for removal included system closure, system merger, or a determination that a system operates exclusively with purchased water. To identify a replacement system for the system removed, States selected the first water system (from the appropriate category) from the existing replacement list for the PWS removed. (See Section 5 for a more detailed discussion of initial plan and replacement list selection procedures.) More detailed directions on modifying the initial SMP and using the lists of alternate/replacement systems are included in the instructions of each SMP.

Once the list of systems was finalized, States informed the EPA Regional Office of the States' choice of plans (including the details of any modified plans). The EPA Regional Office worked with the State to develop an acceptable modified plan. This approach ensures a nationally consistent system selection process and enables acceptable SMP development with minimal State burden.

If the EPA Regional Office did not receive the notice of a final SMP within 60 days, EPA assumed that systems on the initial plan represented the final SMP. The plan also specifies the timing of the monitoring.

4. Selecting the Representative Sample for Systems Serving 10,000 or Fewer People

4.1 Objectives of the Sample

The representative sample of small PWSs must allow EPA to collect high quality data about contaminant occurrence. Such data must allow precise estimates of national occurrence (the fraction of *systems* in which a contaminant occurs) and exposure (the fraction of *people* exposed to a contaminant). The data must also provide enough information within smaller categories of systems (e.g., small, medium, or large systems) to inform the development of possible regulatory alternatives. The sample must also be representative of the population of small PWSs. Each of these data quality objectives are described in more detail in the following section.

4.1.1 Accuracy and Precision

The representative sample of small PWSs must be selected so that the data collected yield accurate and precise estimates of national contaminant occurrence and exposure.

Accurate or unbiased estimates are correct on average over the long term, or over many samples. For instance, if the sampling plan were to be carried out many times, the average of the occurrence or exposure estimates derived from all of the samples would be close to the true occurrence or exposure fraction of the population. The first data quality objective is that the sample estimates be unbiased.

Precise estimates have small variability. All estimators are variable: even if an estimator is unbiased over many samples, the estimate computed from any particular sample will be different from the true population value. The second data quality objective is to limit the amount of this variability.

Precision may be measured in terms of a margin of error and its associated confidence level. For estimates of exposure fractions, EPA will allow a margin of error of ± 1% with 99% confidence, when the estimated exposure fraction is 1%. That is, if the estimated exposure fraction is 1%, EPA must be able to state with 99% confidence that the true exposure fraction is between 0% and 2%. The meaning of “99% confidence” is that if the sampling plan were to be repeated many times, the true exposure fraction would fall within the margin of error around the estimate in 99% of all cases.

EPA specified these stringent statistical parameters to ensure high quality data and dependable monitoring results. In general, many similar random surveys with continuous variables use a lower level of confidence (95%) and/or a larger allowable error (plus or minus 5%). However, use of a larger error is unacceptable for the UCMR. Examination and analysis of current occurrence data show that many contaminants which are currently regulated, or being considered for regulation, occur in 1% or less of systems on a *national* basis. However, for many contaminants, a 1% occurrence nationally reflects a substantially larger occurrence regionally. Even a small percentage of systems with detections of a contaminant can translate into exposure of a significant population. By accepting a greater margin of error, and the resultant smaller sample size, such small national occurrence might be missed entirely.

There are also other uncertainties and sources of variation in such a sample program. For example, all contaminants have censored distributions (i.e., “less than the detection level” analytical results) and there are many factors that affect variability and vulnerability of ground water systems. The statistical sampling theory used to derive levels of accuracy and precision may not account for all of these sources of variation. Hence, the high confidence level, low allowable error, and consequent larger sample size should help ensure adequate data to meet the objectives of the UCMR program.

The data quality objective of a 1% margin of error with 99% confidence level holds for CWSs. EPA is allowing a 2.5% margin of error with a 95% confidence level for NTNCWS since these systems serve fewer people than CWSs. Therefore, less information is required about NTNCWSs to compute national exposure estimates. Although more information about contaminant exposure in NTNCWSs would be desirable, with only 800 systems available for Assessment Monitoring, trade-offs are required in placing sampling effort where it will yield the most information about exposure. Note that previous EPA contaminant occurrence research has not identified any significant difference in the quality of drinking water between CWSs and NTNCWSs (see EPA document A Review of Contaminant Occurrence in Public Water Systems, EPA 816-R-99-006, November 1999).

The precision of an estimate is determined in part by the size of the sample used to derive it. Other things being equal, a larger sample allows a more precise estimate. A rough idea of the sample size needed to achieve the stated goals for margin of error and confidence may be obtained from the formula:

$$n = \frac{z^2 * p(1-p)}{d^2} \qquad (1)$$

in which n is the sample size; p is the true or estimated exposure fraction, or 0.01 in our case; d is the desired margin of error, or 0.01; and z is the critical value of the normal distribution at the desired confidence level. For a 99% confidence level, a table of the normal distribution gives $z = 2.58$. Inserting the given values of p, d, and z into equation (1) gives $n = (2.58)^2(.01)(.99)/(.01)^2 \approx 659$. Therefore, approximately 659 CWSs are needed to achieve the UCMR's stated data quality objectives. Similarly for NTNCWSs, a 2.5% margin of error with 95% confidence gives $p = 0.01$, $d = 0.025$, $z = 1.96$, and therefore $n = 61$ NTNCWSs are required to meet UCMR data quality objectives.

The underlying assumptions of the approximation used to derive equation (1) are: (1) that the sample is a simple random sample from the population of systems; (2) that the sample is large enough for a normal approximation to hold; and (3) that in each system the presence of a contaminant can be determined with certainty. However, these assumptions are more or less untrue for the UCMR sample, so the estimate of 659 systems is only a rough guideline. Under the more complicated stratified sampling plan described in Section 4.2, the 800 systems allocated to Assessment Monitoring are more than enough to meet the objectives of accuracy and precision.

4.1.2 Stratification

EPA must be able to evaluate contaminant occurrence not only nationally, but within categories (or "strata") of systems, including source water type (ground or surface), size (3 categories), and system type (CWS or NTNCWS). Many statutes and regulations are implemented differently for systems of different size, or for different source water categories. Combining the representative (small system) sample with the results from all large systems provides increased power in the total sample, but EPA must also be able to evaluate occurrence, and possible regulatory options, related to the small systems themselves. The SDWA and many current rules focus on burden reduction for small systems when feasible.

EPA has not placed a specific limit on the precision that can be achieved within each category of water systems. In general, the level of precision that can be achieved within any category is less than for all systems taken together, because fewer samples are taken within a single category. Therefore, instead of requiring a set level of precision for each category, EPA has taken the approach of minimizing the highest amount of variability of the estimates within any of the categories, while maintaining the objectives of accuracy and precision of the overall estimates, as described above. This approach is described further in Section 4.2.

4.1.3 Representativeness

A representative sample should be *representative*. This implies some sort of fairness in selecting systems and thereby a fairness in imposing the burden of required sampling. Some properties of a fair and representative sample are: systems are selected at random; all systems have a chance of being selected; the characteristics of the sample will be close on average to that of the population, such as system sizes and types; and systems from all subgroups of interest (e.g., Minnesota, or Size 1 surface water NTNCWS) are present in the sample.

In a representative sample, every system should have a chance of being selected, but not all systems will necessarily have the same chance. Whether that is true depends on what the sample is intended to represent. To accurately estimate contaminant occurrence (percent of systems) in PWSs, the sample should be selected based on systems, so it makes sense to assign an equal probability of selection to each system. To represent exposure, the sample should be selected based on people exposed to a contaminant. In this case it makes sense to assign sampling probabilities in proportion to the population served, so that the systems that serve the most people are most likely to be selected. Clearly these two types of representativeness conflict and cannot both be optimized in the UCMR sample. Since EPA needs to represent both contaminant occurrence and exposure for the UCMR, EPA devised a sampling plan to reflect both the number of systems and the population served by those systems while maintaining balance between the two objectives.

Although occurrence is important, EPA is interested first in estimating contaminant exposure. If this were the only criterion, then EPA would allocate systems to States in proportion to the population served. Then systems that serve the most people would be sampled most often. This population-weighted allocation can be shown to lead to the most accurate and precise estimates of *overall* or national exposure. But a problem with this approach is that it assigns small numbers of systems, or even zero systems, to the smallest States and territories. For example, Guam serves 0.015% of the population served by PWSs in the U.S., so a population-weighted allocation would assign 0.015% of 800 systems to Guam. That is 0.1 systems, or rounded off, zero systems assigned to Guam. Similarly, American Samoa and the Mariana Islands would each receive zero systems, and Rhode Island would receive one system. Such a sample would not be fully representative of the population of CWSs in the U.S.

EPA believes that to be fully representative of the nation, a sample of water systems must include at least 2 systems from each State and Territory in the U.S. Therefore, EPA has imposed the additional constraint that its representative sample must contain at least 2 systems from each State and Territory in the U.S. (The exception is Guam, which has only one PWS in the Needs Survey inventory; so exactly one system was selected to sample in Guam.)

4.1.4 Summary

To summarize, a sample of small PWS must provide data that meet the following data quality objectives:

- provide national exposure estimates that are unbiased, and have a margin of error of ± 1% with 99% confidence for CWSs, or a margin of error of ± 2.5% with 95% confidence for NTNCWSs, when the estimated exposure fraction is 1%;

- minimize the maximum variability of exposure estimates within categories of system size and source water type; and

- sample at least 2 systems from each State and Territory.

The next section describes the sampling plan that EPA designed to satisfy these objectives.

4.2 How the Samples Were Allocated

EPA is using a representative sample of 800 small systems for Assessment Monitoring. The sample size was selected for various statistical and budgetary considerations. A sample of 800 systems is more than the approximately 720 systems (659 CWSs and 61 NTNCWSs; see section 4.1.1, above) needed to meet the first data quality objective, and allows at least two PWSs to be selected in each State.

To meet the data quality objectives described above, the crucial step is to allocate the sampling effort in the right amounts among strata (categories) of system size, source water type, and State or Territory. With 3 size categories, 2 source water types, 2 system types, and 56 States and Territories, there are $3 \times 2 \times 2 \times 56 = 672$ strata in which to allocate the 800 systems for Assessment Monitoring.

EPA used the following three-step procedure to allocate the 800 systems:

1. The systems were allocated among the 56 States and Territories. The allocation was roughly in proportion to population, but with at least 2 systems allocated to each State or Territory.

2. Within each State or Territory, a probability was selected for each of the 12 categories of system size, source water type, and system type.

3. Within each State or Territory, a category was selected at random for each allocated system, using the probabilities computed in step 2. Within the selected category, a PWS was selected at random, with probability proportional to its population served among all PWSs in the category.

In this way, each of the 800 systems was assigned first to a State, then to a category within that State, then to a particular PWS within the category.

The rest of this section describes how the State allocations and category probabilities were selected in Steps 1 and 2 above, in order to achieve the UCMR's stated data quality objectives. The random assignment of PWSs to categories in Step 3 is described in Section 5. The description in this section is meant to convey the idea of the procedure and the assumptions used to derive it, but it is not a complete technical description. A complete description and justification of the procedure is provided in Appendix A.

4.2.1 Allocation of Systems to States and Territories

To obtain the most precise national exposure estimates, the optimal allocation of systems to each State should be in proportion to the State's population served. For example, Table 2 below shows that Texas has about 8.9% of the population served by small systems, so Texas should receive 8.9% of the 800 systems, or 71.4 systems. This population-weighted allocation has two drawbacks. First, the allocation is only theoretical, since each State receives a fractional number of systems. Second, under this scheme some small States receive fewer than two systems. For example, Rhode Island would receive 1.1 systems, and American Samoa would receive 0.1 systems. To get around this problem, the population-weighted allocation was modified as follows:

Table 2. Distribution of Small Systems Required to Conduct Assessment Monitoring and Screening Survey in Each State/Tribe/Territory

State/Tribes/ Territories	Population Served by Small Systems (10,000 or less people)[1] (P_n)	Number of Small Systems Conducting Assessment Monitoring,[2] (A_n)	Number of Small Systems Conducting Screening Surveys,[3] (S_n)
Tribes[4]	394,267	7	2
Alabama	826,868	15	4
Alaska	207,650	4	3
American Samoa	6,278	2	2
Arizona	654,139	12	3
Arkansas	736,435	13	8
California	2,706,432	48	24
Colorado	545,759	10	6
Connecticut	348,727	6	2
Delaware	128,494	2	1
Florida	1,810,083	32	11
Georgia	1,254,642	22	12
Guam	5,504	1	0
Hawaii	159,339	3	2
Idaho	436,697	8	2
Illinois	1,599,786	28	8
Indiana	1,108,704	20	8
Iowa	940,771	16	10
Kansas	675,059	12	6
Kentucky	505,977	9	4
Louisiana	1,552,807	27	14
Maine	323,762	6	3
Mariana Islands	12,769	2	1

Table 2. Distribution of Small Systems Required to Conduct Assessment Monitoring and Screening Survey in Each State/Tribe/Territory

State/Tribes/ Territories	Population Served by Small Systems (10,000 or less people)[1] (P_n)	Number of Small Systems Conducting Assessment Monitoring,[2] (A_n)	Number of Small Systems Conducting Screening Surveys,[3] (S_n)
Maryland	463,283	8	2
Massachusetts	713,312	12	3
Michigan	1,372,119	24	13
Minnesota	912,075	16	8
Mississippi	1,687,841	30	9
Missouri	1,129,714	20	8
Montana	343,389	6	3
Nebraska	471,233	8	4
Nevada	216,851	4	1
New Hampshire	343,257	6	2
New Jersey	934,202	16	6
New Mexico	449,245	8	6
New York	1,700,436	29	14
North Carolina	1,257,791	22	11
North Dakota	199,303	4	2
Ohio	1,595,309	28	7
Oklahoma	853,024	15	5
Oregon	585,945	11	6
Pennsylvania	2,131,859	37	19
Puerto Rico	493,374	9	4
Rhode Island	56,834	2	0
South Carolina	644,915	11	7
South Dakota	219,176	4	2
Tennessee	823,726	14	9
Texas	3,989,818	71	28
Utah	385,852	7	4
Vermont	238,493	4	3
Virgin Islands	92,555	2	1
Virginia	917,521	16	7
Washington	1,013,103	17	10
Washington DC[6]	0	0	0
West Virginia	547,661	10	6

Table 2. Distribution of Small Systems Required to Conduct Assessment Monitoring and Screening Survey in Each State/Tribe/Territory

State/Tribes/ Territories	Population Served by Small Systems (10,000 or less people)[1] (P_n)	Number of Small Systems Conducting Assessment Monitoring,[2] (A_n)	Number of Small Systems Conducting Screening Surveys,[3] (S_n)
Wisconsin	1,193,154	21	12
Wyoming	153,712	3	2
Total	**45,071,031**	**800**	**360**

1 The distribution of samples above is based on the population and water system information in the 1999 Needs Survey database inventory.
2 This column represents the total number of small systems allocated in individual States/Tribes from the national representative sample of 800 systems.
3 There are 360 small systems shown for two Screening Surveys (180 for Screening Survey 1 and 180 for Screening Survey 2) . Note that each Screening Survey Group of 120 large systems will also be required to monitor. Therefore, there is a total of 300 small and large systems (a total of 600 Screening Survey systems) in each Survey.
4 The number of Tribal water systems includes Tribal systems in each of the 10 EPA Regions. Tribal systems were aggregated as a State to ensure that Tribal systems were represented in the national representative sample of small systems in the UCMR.
5 U.S. Territories include American Samoa, Guam, Northern Mariana Islands, Puerto Rico, and the Virgin Islands. Territories were aggregated as a State to ensure that Territories were represented in the national representative sample of small systems in the UCMR.
6 The Washington DC water supply is provided exclusively by large PWSs.

1. An initial allocation was computed for each State, in proportion to that State's population served by small systems.

2. All allocations were rounded *up* to the next largest integer, and any allocations less than two were increased to two. Each State was allocated at least two systems, but the total number of allocated systems increased to more than 800 systems.

3. Systems were removed one at a time from various States, in such a way as to minimize the increase in variance of an overall exposure estimate and keep all State allocations at or greater than two, until the total allocation was reduced again to 800.

The resulting State allocations are shown in Table 2. The results are very close to what one would get by simply rounding the population-weighted allocations to the nearest integers.

Given the small individual State sample size, no statistically valid conclusions may be drawn at the State level. However, EPA still considers it important that all States are represented and have the opportunity to participate in the UCMR. Some contaminants, such as some pesticides, may only be used intensively in specific regions of the country. It is possible that with the relatively small number of systems in the representative sample, monitoring may miss contaminants with such targeted regional use patterns. However, including systems in every State in approximate proportion to the population served should ensure that contaminants with regional use patterns, to the extent that they potentially contaminate water supplies, are proportionately represented by the national sampling design.

4.2.2 Calculation of Category Sampling Probabilities

Once systems are allocated to States, they must be allocated to categories of system size, system type, and source water type, within each State. This allocation is computed not in terms of fixed sample sizes, but by choosing the probability of drawing each system from each category. In this way, systems from even the smallest categories have some chance of being sampled.

To see how the sampling probabilities were chosen, consider first a simple allocation in which the probability of drawing from each category is proportional to the population served in that category. As described above, this allocation gives the most precise overall national exposure estimates. Table 3 shows the results of such an allocation, in terms of the expected number of systems sampled from each category, and the resulting margins of error. For CWSs, an overall exposure estimate of 1% would have a margin of error of ± 0.97%, or a confidence interval of 0.03% to 1.97%, with 99% confidence. This is slightly better than the first data quality objective described in Section 4.1. On the other hand, the margins of error in the size-by-source-water-type categories are as high as ± 12%, so that not much information is gathered about some categories. Similarly for NTNCWS, the margin of error for an overall exposure estimate is ± 2% at 95% confidence, well within the first data quality objective; but within smaller categories the margin of error is as high as ± 19%.

Table 3. Sample Allocation Proportional to Population Served: Expected Number of Systems Drawn From Each Category, and Resulting Margins of Error for Exposure Estimates

System Type	Size Category	Ground Water-Supplied Systems		Surface Water-Supplied Systems		Total	
		n [1]	error [2]	n [1]	error [2]	n [1]	error [2]
CWSs	500 and Under	78	±3.0	5	±12.1	83	±2.9
	501 to 3,300	228	±1.7	46	±3.8	274	±1.6
	3,301 to 10,000	237	±1.7	111	±2.5	348	±1.4
	Total	**543**	**±1.1**	**162**	**±2.0**	**705**	**±0.97**
NTNCWSs	500 and Under	40	±3.1	1	±17.4	42	±3.0
	501 to 3,300	44	±3.0	3	±10.8	47	±2.9
	3,301 to 10,000	5	±8.8	1	±19.0	6	±8.0
	Total	**89**	**±2.1**	**6**	**±8.3**	**95**	**±2.0**

Rows and columns do not add up to totals due to rounding.
[1] n = expected number of samples drawn.
[2] error = expected normal-theory margin of error, in percent, when the estimated exposure fraction is 1%, at 99% confidence for CWSs and 95% confidence for NTNCWSs.
Note: The population-weighted distribution of samples is based on population and water system information from the 1999 Needs Survey database inventory.

Table 3 shows that there is room for improvement in the proportional allocation. By shifting some sampling effort into the categories with smaller allocations, more information can be collected about those categories. This would reduce the widest margins of error. For example for CWSs, systems could be shifted into the smallest surface water stratum. The cost would be to gather less information about the other categories, and also increase the error in the overall estimate. But if the systems are reallocated, the widest margin of error can be minimized (the UCMR's second data quality objective), while keeping the overall margin of error at or below 1% (the first data quality objective).

Appendix A describes the procedure for reallocating PWSs as described above, in order to meet the first two data quality objectives. Starting from the proportional allocation shown in Table 3, sampling probabilities are reduced in the categories with the narrowest margins of error, and increased in the categories with the widest margins of error. As the sampling plan moves farther away from the proportional allocation in Table 3, the overall margin of error increases. The procedure stops when further reallocation would cause the overall margin of error to exceed 1% for CWS, or 2.5% for NTNCWS.

Using this procedure, sampling probabilities for Assessment Monitoring were derived for the categories of system size, system type, and source water type, to satisfy the first two data quality objectives described in Section 4.1. The third data quality objective, sampling at least 2 systems per State or Territory, was already satisfied by allocating systems to States in Section 4.2.1. The resulting sampling probabilities are provided in Appendix B. Table 4 shows a summary of the results. Compared to Table 3, systems were shifted to the smallest surface water stratum for CWSs,

Table 4. Sample Allocation for Assessment Monitoring: Expected Number of Systems Drawn from Each Category, and Resulting Margins of Error for Exposure Estimates

System Type	Size Category	Ground Water-Supplied Systems		Surface Water-Supplied Systems		Total	
		n [1]	error [2]	n [1]	error [2]	n [1]	error [2]
CWSs	500 and Under	72	±3.1	47	±4.1	119	±2.9
	501 to 3,300	218	±1.8	41	±4.1	259	±1.6
	3,301 to 10,000	225	±1.7	102	±2.6	327	±1.4
	Total	**515**	**±1.1**	**190**	**±2.1**	**705**	**±1.00**
NTNCWSs	500 and Under	31	±3.9	10	±9.2	41	±3.8
	501 to 3,300	31	±3.8	9	±9.2	41	±3.6
	3,301 to 10,000	5	±9.2	8	±9.2	13	±7.8
	Total	**68**	**±2.6**	**28**	**±6.0**	**95**	**±2.50**

Rows and columns do not add up to totals due to rounding.
[1] n = expected number of samples drawn.
[2] error = expected normal-theory margin of error, in percent, when the estimated exposure fraction is 1%, at 99% confidence for CWSs and 95% confidence for NTNCWSs.

and to the various surface water strata for NTNCWSs. As a result, the maximum margin of error in any of the categories decreased from 12.1% to 4.1% for CWSs, and from 19.0% to 9.2% for NTNCWSs. Although still somewhat high, these errors represent the best that can be achieved with a sample of 800 small systems, while maintaining a good overall exposure estimate. The resulting sample allocation reflects the difficulty of obtaining precise information in all categories of systems from a limited sample. At the same time, the margins of error for overall exposure estimates increased to exactly 1% for CWSs and 2.5% for NTNCWSs, meeting the first data quality objective. Margins of error in some categories also increased slightly, by up to 0.8%.

The methodology used to derive the sampling probabilities requires some simplifying assumptions. As a result, the margins of error in Table 4 are only approximately correct. The methodology and its limitations are described in detail in Appendix A. An important simplifying assumption is that once a system is selected for sampling, the presence or absence of a contaminant can be determined with certainty. Of course this assumption is not true; if a contaminant is not detected in a system in a finite number of samples, it may never be present there, or it may only have been absent or undetectable when the samples were taken. Because the derivation or the sampling probabilities ignore this source of uncertainty, the margins of error tend to be underestimated. Occurrence estimates may also turn out to be negatively biased, since contaminants that are present will not always be detected in a finite number of samples. To account for this additional uncertainty would require data or assumptions about the frequency and spatial and temporal variability of occurrence, as well as the spatial distribution of samples. Such information was not available for the design of the sampling plan. Once sampling takes place and some occurrence data are available, corrected confidence intervals and occurrence estimates may be computed.

Due to the small sample size of the NTNCWSs in the ground water and surface water categories within each size category (Categories 1 through 3), statistical conclusions about NTNCWSs must be analyzed with caution. Conclusions about NTNCWSs cannot be based on source water type since the margin of error would be too great. Note that since the actual allocation of systems to each

Table 5. National Representative Sample Distributed by System Size Category and Water Source Type as Selected for the Initial SMPs

Size Category (by population served)		**Number of CWSs**		**Number of NTNCWSs**		**Subtotal of All Systems by Water Source Type**		**Total**
		Ground Water	Surface Water	Ground Water	Surface Water	Ground Water	Surface Water	
Category 1	500 and Under	76	51	36	8	112	59	171
Category 2	501 to 3,000	208	38	30	7	238	45	283
Category 3	3,001 to 10,000	230	106	4	6	234	112	346
	Total	**514**	**195**	**70**	**21**	**584**	**216**	**800**

service size category was randomized, the number of systems selected to monitor for each service size category were different from the expected sample allocation once the random number generator was used, as described in more detail in Section 5. Table 5 shows the composition of the actual national representative sample of 800 systems as selected for the initial SMPs. Once each State reviewed their initial SMP, the sampling distribution was expected to change. For instance, if a State had only one ground water system serving 25-500 people which was selected to monitor for the UCMR and this system was inactive (and had no replacement systems), this system was likely replaced by a system in the State within another service size and/or water source category (replacement systems are discussed further in Section 5). The number of systems that monitor for the UCMR within each stratum will be included in future EPA documents that describe sampling results.

4.3 Statistical Implications of the Sampling Plan

Once system selection, sampling, chemical analysis, and reporting are complete, EPA will estimate occurrence and exposure of the 12 List 1 contaminants (see Section 8, Assessment Monitoring), and their associated margins of error. These estimates will take into account the nature of the sampling plan, in particular the different probabilities of sampling from systems in different strata. In this section the occurrence and exposure estimates and two different kinds of confidence intervals are described, which take the sampling plan into account. This section provides only a summary; a complete description is provided in Appendix A.

4.3.1 Occurrence and Exposure Estimates

When some systems are more likely to be sampled than others, an unbiased estimate of occurrence or exposure has to take the sampling probabilities into account, by giving less weight to those systems that are more likely to be sampled. An estimator that does this is:

$$\hat{\mu} = \sum_{i=1}^{800} \frac{W_i c_i y_i}{p_i} \qquad (2)$$

where

- Σ stands for "summation";
- i are the sampled systems, 1,...,800;
- y_i = 1 if the contaminant occurs in system i, 0 otherwise;
- W_i is the weight given to system i
  = population served by system i, for exposure estimates; or 1, for occurrence estimates;
- p_i is the probability of choosing system i;
- c_i is a constant, computed in Appendix A.

For example, for an exposure estimate, a sampled system receives more weight in equation (2) if it serves more people (greater W_i), and less weight if it is more likely to be chosen under the sampling plan (larger p_i in the denominator). Because of the weighting in equation (2), some systems were made more likely to be sampled in order to meet the UCMR's data quality criteria, as described in Section 4.2, without incurring any bias in the exposure or occurrence estimates. (The constant c_i in equation (2) performs a similar function to n^{-1} in an ordinary arithmetic mean, correcting for the total number of observations in the sample. Details and a more precise definition of $\hat{\mu}$ are provided in Appendix A.)

There is an overlap between the populations served by CWSs and NTNCWSs. In the absence of information about the number of people obtaining their drinking water from CWSs or NTNCWSs and their degree of exposure, there is no way to combine exposure estimates from these two classes of systems in the right proportions to reflect people's total exposure. For this reason, exposure estimates will be computed separately for CWSs and NTNCWSs, and will not be combined into a single overall exposure estimate.

4.3.2 Margins of Error

The error ranges in Table 5 were computed using the statistical formulas shown in Appendix A, using the sampling probabilities and a normal approximation to the estimation error. The normal approximation is valid when the expected number of detections is large enough. The expected number of detections is $n*p$, where n is the number of systems selected and p is the fraction of systems in which the contaminant occurs. In order for the normal approximation to hold, Casella and Berger (1990) recommend $n*p \geq 5$, while Parzen (1960) recommends $n*p \geq 10$. For CWSs in Table 5, where $n = 705$ and $p = 0.01$, $n*p = 7.05$. By this measure, the normal approximation may not be valid. Moreover, Table 5 shows a clear problem with the normal approximation: the error bounds are so wide that they include negative occurrence fractions within the margin of error. For example, among very small ground water CWSs in Table 5, when the observed fraction of systems with a contaminant is 1 percent, a 99% confidence interval for the true fraction is 1% ± 3.1%, or [−2.1%, 4.1%]. This interval allows the possibility of a negative fraction of occurrence, which cannot logically occur. The interval may be truncated to [0, 4.1%], but the need to truncate suggests that the normal approximation does not lead to an accurate confidence interval.

The normal-based confidence interval is only one of several possible confidence intervals for an estimated proportion. Newcombe (1998) compares seven such intervals, including two varieties of the normal interval. Of these, the Wilson score interval without continuity correction (Wilson, 1927) has good statistical properties (e.g., the stated confidence level is approximately correct for a wide range of n and p), is simple to compute, and unlike the normal interval, always gives confidence limits between 0 and 1. Given an estimated occurrence fraction p from a sample of size n, the Wilson score interval for p is computed as shown in equation (A-13) of Appendix A.

Table 6 compares the normal and Wilson confidence intervals for CWS, still assuming an estimated occurrence fraction of $p = 0.01$, and using the expected sample sizes summarized in Table 3. A simple interpretation of these intervals is that the normal interval equals p, the estimated fraction, plus or minus some amount, while the Wilson interval is approximately p times or divided by some amount. For example, for very small ground water CWSs, the Wilson interval is [0.1%, 11.2%], or about 1% x / ÷ 11. So according to the Wilson interval, the true occurrence fraction lies somewhere between 0.1% and 11.2%, with 99% confidence. By comparison, the normal interval for this example is -2.1% to 4.1%. Although the Wilson interval in this example is wider than the normal interval, it is more believable in part because it does not include negative occurrence values.

The normal-based error ranges in Tables 3 and 4 are useful as a rough guide to the expected precision of an estimated occurrence fraction. Moreover, the normal approximation yields the simple formula in equation (1) for estimating the sample size needed to achieve a given precision with given confidence. However, when computing confidence intervals for the estimated proportion, the Wilson score interval is preferred, both because of its good statistical properties and because it avoids the possibility of including negative occurrence values.

Table 6. Comparison of 99% Normal and Wilson Score Confidence Intervals for Exposure Estimates in CWSs under Assessment Monitoring

Size Category	Ground Water-Supplied Systems	Surface Water-Supplied Systems	All
Normal Confidence Intervals			
500 and under	[-2.1, 4.1]	[-3.1, 5.1]	[-19, 3.9]
501 to 3,300	[-0.8, 2.8]	[-3.1, 5.1]	[-0.6, 2.6]
3,301 to 10,000	[-0.7, 2.7]	[-1.6, 3.6]	[-0.4, 2.4]
All	[-0.1, 2.1]	[-1.1, 3.1]	[0.0, 2.0]
Wilson Score Confidence Intervals			
500 and under	[0.1, 11.2]	[0.1, 17.9]	[0.1, 10.3]
501 to 3,300	[0.2, 4.8]	[0.1, 18.2]	[0.2, 4.3]
3,301 to 10,000	[0.2, 4.7]	[0.1, 8.4]	[0.3, 3.7]
All	[0.3, 2.9]	[0.2, 6.2]	[0.4, 2.6]

Confidence intervals are in percent, when the estimate exposure fraction is 1%.

5. Selecting Systems for the Initial Plan List and the Replacement List in Each State

EPA selected the PWSs for the national representative sample through a two-staged random selection process. Once the number of Assessment Monitoring systems were selected for each State, EPA selected the individual stratum from which the systems would be selected. The individual systems within each stratum were then selected. The sampling process is described in detail below.

EPA first calculated the probability of selecting each stratum for both CWSs and NTNCWSs together (i.e., so that the cumulative probability of selecting *any* stratum from an individual State equals one). The method of computing the sampling probabilities was described in Section 4.2. A random number generator was then used to allocate the systems to strata of system type, system size, and source water type. For instance, for a State that is allotted 10 PWSs for the UCMR sample, the random number generator was run 10 times and was then compared to the cumulative probability of selection to designate the strata from which the individual PWSs were selected.

In the example shown in Table 7 for the State of Colorado, the random number generator was run ten times, returning the following set of numbers: 0.793739, 0.474497, 0.245539, 0.647118, 0.558134, 0.647613, 0.416625, 0.889291, 0.94107, and 0.457243. Based on comparing these randomly generated numbers to the cumulative probability column in Table 7, one PWS was a surface water based CWS serving 25-500 people, one was a ground water based CWS serving 501-3,300 people, three were surface water based CWSs serving 501-3,300 people, two were ground

Table 7. Cumulative Probability of Selection by Stratum for Colorado

System Type	System Size	Water Source	Probability	Cumulative Probability	Expected Number of Systems	Actual Number of Systems
CWS	25-500	GW	0.089138	0.089138	1	1
CWS	25-500	SW	0.188764	0.277903	2	1
CWS	501-3300	GW	0.166154	0.444056	2	0
CWS	501-3300	SW	0.138157	0.582213	1	3
CWS	3301-10000	GW	0.129963	0.712176	1	2
CWS	3301-10000	SW	0.21383	0.926007	2	2
NTNCWS	25-500	GW	0.002338	0.928344	0	0
NTNCWS	25-500	SW	0.008918	0.937263	0	0
NTNCWS	501-3300	GW	0.001276	0.938538	0	0
NTNCWS	501-3300	SW	0.001898	0.940436	0	1
NTNCWS	3301-10000	GW	0	0.940436	0	0
NTNCWS	3301-10000	SW	0.059564	1.000000	1	0

water based CWSs serving 3,301-10,000 people, two were surface water based CWSs serving 3,301-10,000 people and one was a surface water based NTNCWS serving 501-3,300 people. When the random number does not exactly match the cumulative probability, the random number was "rounded" up to the next category. The number of systems to be selected from each stratum was calculated with replacement. This means that each stratum in the State could be selected more than one time.

Table 7 also shows the expected number of systems to be allocated to each stratum within the State. The "Expected Number of Systems" column shows the sample distribution if the sample were selected solely based on the proportion of the population served by each stratum. The actual sampling distribution based on using the random number generator is shown in the next column. Appendix B shows the cumulative probabilities of selection, as well as the expected and actual number of systems that were allocated to each State for the Assessment Monitoring portion of the UCMR.

Once systems were allocated to each stratum, systems were then chosen at random from the strata. To ensure that the systems selected from each stratum were representative of population served, the probability of selection for each system was taken to be proportional to its population served within that stratum. For example, a system that served 5% of all people in the stratum of Category 1 ground water systems in Nebraska would have a 5% chance of being drawn when a system was selected from that stratum. For systems not to be selected twice, each time a system is selected it is removed from consideration in its stratum, and the system selection probabilities are re-computed. This is called sampling without replacement. (Although the systems are sampled *without* replacement, the stratum sampling probabilities in Section 4.2 were derived under the assumption of sampling *with* replacement. This assumption makes the calculation tractable, at the cost of introducing some error. The error is small enough to be ignored; see the discussion in Section A.5. in Appendix A.

The Initial SMP included detailed tables with the total number of systems allocated to a State through this two-staged random selection process. The alternate/replacement list is a list of additional systems that were randomly selected to replace primary systems in the SMP if necessary.

Primary systems were replaced when the primary system was found to be inactive (i.e., the system closed, merged, or now purchases all of its water from another system). Primary systems could have also been replaced for other reasons, but the State should have already submitted a request and the reasons the systems were removed to EPA with their modified SMP.

EPA randomly selected two alternate/replacement systems for each primary system for every State. A supplemental replacement list was also generated for each State. The replacement lists were generated individually to select one replacement for each system selected to monitor for the UCMR. Once the first replacement list was generated, the second set of replacement systems was selected. This ensured that each system selected to monitor for the UCMR had two replacement systems selected from the appropriate stratum. These systems were selected in the same manner as the initial system list. The third, or general replacement list consisted of a randomly selected number of PWSs from the remaining PWSs in the State, regardless of system size category, source water type, and system type. For example, if a ground water based CWS serving 501-3,300 people was inactive, and if both replacement systems selected for that system were inactive, any system remaining in the sample frame list may be randomly selected to monitor for the UCMR regardless of system type, size, and source water type.

6. Selecting Systems for the State Plan

Each State, Tribe, and territory had 60 days to review the initial plan list. The State/Tribe either: (1) accepted the selections as its SMP and notified the Regional Administrator of its acceptance or (2) proposed changes to the initial plan list and selected alternates from the replacement list, including the reasons for the changes, informing the Regional Administrator of the proposed changes; or (3) took no action within 60 days, which allowed the Regional Administrator to specify the portion of the representative sample applicable to the State as its SMP. In the second case, the Regional Administrator had 60 days to work with the State to develop a suitable plan, if problems were encountered. The Reference Guide for the Unregulated Contaminant Monitoring Regulation (EPA 815-R-01-023) provides a more detailed discussion of the SMP process.

Any system(s) removed from the Initial SMP list must be replaced by the system(s) assigned as replacement systems. If the State determines that both replacement systems are no longer active, the first active system on the supplemental replacement list becomes the replacement system.

Each State/Tribe/EPA Region reviewed their SMP to determine that the systems selected have the appropriate operational status. The State/Tribe/EPA Region then submitted its representative sample listing to the EPA Regional Office, with all changes from the initial list marked and the reasons for any changes noted.

States/Tribes may also sample additional systems. However, any additional PWSs sampled will not be combined with those of the representative sample for the purpose of computing national estimates of exposure and occurrence. EPA cannot pay for the testing of these additional systems. These additional systems, though providing useful information, will bias the national set of systems if included with those selected using the stated national criteria. However, if the States provide the results of such monitoring, EPA will receive the data through SDWIS for input to the NCOD.

7. Index System Monitoring

EPA identified 30 CWSs in the lower 48 States from the representative sample of small systems to be “Index” systems. Five systems were selected from each size and source water stratum. The data collected from the Index Systems will be used partly for added quality control and to better characterize monitoring results and operating characteristics of small systems. These systems will be monitored every year during the five year UCMR-listing cycle. This will provide detailed information regarding temporal variation during the course of UCMR monitoring, as well as possible effects related to operational changes. EPA will pay for this monitoring, and will provide for sampling equipment, labor for sample collection, shipment of samples, testing and analysis. Additional water quality and operational data from these systems may be collected at the same time, with minimal burden to the systems. The Index Systems were selected so that they are located within watersheds that have been studied extensively under the United States Geological Survey’s (USGS) National Water Quality Assessment Program. This allows both the EPA and the USGS to share information on source water and finished water quality in watersheds across the US. Table 8 shows the number of systems chosen in each size category as Index Systems from the representative sample.

Table 8. Distribution of Index Systems in the Representative Sample

Size Category	Number of Non-Index Systems	Number of Index Systems
Ground Water		
500 and Under	71	5
501 to 3,000	203	5
3,001 to 10,000	225	5
Surface Water		
500 and Under	46	5
501 to 3,000	33	5
3,001 to 10,000	101	5
Number of Systems in the Representative Sample	**679**	**30**

Note: The distribution of samples indicated above is based on the 1999 Needs Survey database inventory.

8. Assessment Monitoring

The first component of the UCMR is Assessment Monitoring which will be conducted by all of the large CWSs and NTNCWSs (except those large systems that purchase *all* of their water from another PWS), and by a statistically representative sample of 800 small CWSs and NTNCWSs (except those small systems that purchase *all* of their water from another PWS). Assessment Monitoring will be conducted for the 12 UCMR (1999) List 1 contaminants (listed in §141.40(a)(3) Table 1, UCMR (1999) List 1). One-third of the representative sample (267 systems) will monitor in each of the three Assessment Monitoring years (2001 to 2003). This sampling distribution is designed to facilitate laboratory scheduling and other logistical considerations. The small systems were delegated to a sampling year by random selection with a 33 percent probability that each system would be selected in each of the three years. The year for the first system was randomly selected, then the year for the rest of the systems were chronologically ordered. For instance, the random number generator selected the year 2002 as the sampling year for the first system. The second system was then assigned the year 2003, and the third system was assigned 2001, until each system in the sample had an assigned monitoring year.

After the sampling year was selected, the sampling months were randomly selected for the systems, with four samples per year for surface water (and GUDI) systems and two samples per year for ground water systems. The first month was selected randomly as described above for the sampling year, then subsequent months were assigned consecutively. One sampling period must be during the most vulnerable period (May 1 through July 31), as designated in the regulation. Specification of the monitoring year and month not only facilitates scheduling of laboratory resources, but also ensures that sampling covers vulnerable periods and all seasons to assess some aspect of temporal occurrence patterns. To provide States with flexibility in determining vulnerable periods, EPA allowed the State to modify the vulnerable period for some or all systems in their SMP. The State should have notified EPA of the reasons for the change. EPA specified the sampling date as the 15^{th} of each month, plus or minus two weeks. Systems may sample at any time during the month, as long as all subsequent samples are taken on the same day. The second ground water sample may be taken within 5 to 7 months of the initial vulnerable period sample. While Index Systems sample during all five years of the UCMR cycle, each Index System was also assigned an “official” sample year. Only the data from the official sample year will be used in the national summary of results from Assessment Monitoring, for consistency with the sample design.

The UCMR does not specify any particular year for Assessment Monitoring for the large PWSs, but does specify that they must conduct their monitoring within the first three years (2001-2003) of the UCMR cycle. EPA expects that large system UCMR monitoring for unregulated contaminants will coincide, whenever possible, with required monitoring for regulated contaminants. Since monitoring schedules for regulated chemicals depend on system size and detection history, compliance schedules vary significantly. EPA recognizes that although it will be desirable to collect UCMR samples concurrently with compliance samples for regulated chemical contaminants, sometimes it may be difficult to coordinate the two sampling events. Large systems are required to bear the costs of sampling, testing and reporting the results, and coincident monitoring may help reduce the burden.

9. Screening Surveys

The second component of the UCMR includes the Screening Surveys. Each Screening Survey will be conducted at a combined total of approximately 300 PWSs randomly selected from the pool of systems required to conduct Assessment Monitoring. Screening Survey monitoring will be conducted for the UCMR (1999) List 2 contaminants for which analytical methods have been developed, but may need to be further refined before large-scale Assessment Monitoring is conducted. There are 15 unregulated contaminants on the UCMR (1999) List 2. Fourteen of these contaminants are chemical contaminants, and one is a microbiological contaminant. These contaminants are listed in §141.40(a)(3) Table 1, UCMR (1999) List 2.

The Screening Surveys are being conducted to assess contaminant occurrence in PWSs, and not to determine exposure assessment by population (as is the purpose of Assessment Monitoring). EPA estimates that there will be two different groups of systems involved in the Screening Surveys. Each group will be comprised of 300 large and small CWSs and NTNCWSs. Small systems will conduct the first Screening Survey in the year 2001, while large systems will conduct the Screening Survey in 2002 for the contaminants identified in the List 2 rule. EPA expects that *Aeromonas* will be monitored in 2003, since the analytical method will not be completed before the first Screening Survey. Sampling schedules have been established, in part, to enable Screening Survey samples to be collected coincident with the Assessment Monitoring samples whenever possible to minimize the burden to small systems. Large systems are responsible for coordinating their Screening Survey sample selection with Assessment Monitoring.

EPA is examining general thresholds to evaluate Screening Survey results, relative to the margin of error in the sample. For example, if a contaminant occurs over a certain threshold (i.e., in a percentage of systems/population served), the contaminant may then be placed on the Assessment Monitoring list and monitored in the next round of the UCMR by all large systems and a representative sample of small systems. If the contaminant occurrence is below this threshold, it is possible that no further testing will be required. Factors such as health effects levels will also need to be considered; hence, thresholds may vary by contaminant.

Systems were selected from all the size and water source categories. However, selection was not proportionately weighted by population served, or by the proportion of systems in each size category. If the sample was weighted by population served, a disproportionate number of large systems would be included in the Screening Surveys. If the sample were weighted by the number of systems in each size category, a disproportionate number of small systems would be represented. Therefore, each size category was given equal importance with 60 systems selected from each size category, with the selected systems distributed evenly between surface water and ground water systems, wherever possible (i.e., 30 ground water, and 30 surface water systems were targeted to be selected to monitor for each Screening Survey. Note, however, that there were not enough very small (serving less than 500 people) systems in the sample to select a full 30 systems in this category for each Screening Survey year. Only 20 very small surface water systems were selected to monitor for UCMR (1999) List 2 contaminants in 2001. However, the extra 10 systems were selected from the very small ground water category, so that a total of 40 systems will monitor for the Screening Survey in 2001. This results in 180 small systems and 120 large systems in each of the Screening Surveys (i.e., a total of 360 small systems and 240 large systems in the two Screening Surveys). To make national occurrence or exposure estimates, the resultant data will need to be weighted in relation to these sample distributions.

Table 9 illustrates the allocation of systems in each size category in each group for each Screening Survey and the associated margin of errors of estimation at the 99 and 95 percent confidence levels to evaluate the measurement precision for the sample of 300 systems. Even though there are a total of 600 systems involved, there will be, as noted, two Screening Surveys performed, by two mutually exclusive groups of systems, analyzing water samples for two different sets of contaminants.

Table 9. Allocation of Systems for Screening Surveys by Size Category with the Associated Confidence Levels and Margins of Error

Size Category	Ground Water-Supplied Systems			Surface Water-Supplied Systems			All		
	n [1]	99% [2]	95% [2]	n [1]	99% [2]	95% [2]	n [1]	99% [2]	95% [2]
500 and Under	40	±4.1	±3.1	20	±5.7	±4.4	60	±3.3	±2.5
501 to 3,300	45	±3.8	±2.9	15	±6.6	±5.0	60	±3.3	±2.5
3,301 to 10,000	30	±4.7	±3.6	30	±4.7	±3.6	60	±3.3	±2.5
Subtotal Small Systems	**115**	**±2.4**	**±1.8**	**65**	**±3.2**	**±2.4**	**180**	**±1.9**	**±1.5**
10,001 to 50,000	30	±4.7	±3.6	30	±4.7	±3.6	60	±3.3	±2.5
50,001 and over	30	±4.7	±3.6	30	±4.7	±3.6	60	±3.3	±2.5
Subtotal Large Systems	**60**	**±3.3**	**±2.5**	**60**	**±3.3**	**±2.5**	**120**	**±2.3**	**±1.8**
All	**175**	**±1.9**	**±1.5**	**125**	**±2.3**	**±1.7**	**300**	**±1.5**	**±1.1**

[1] Values in the columns with the heading of "n" indicate the number of PWSs allocated to a specific system size category.

[2] These column headings indicate the confidence level used for evaluation. The values preceded by "±" listed in these columns are the normal-theory margins of error, in percent, associated with the given confidence level (either 99% or 95%). Error calculations in the table assume an estimated occurrence fraction of $p = 0.01$.

Results from the Screening Surveys are likely only suitable for aggregate national estimates given the 99 percent confidence level and ± 1.5% margin of error. Only aggregated national estimates are appropriate because the error margin may be too large in small subcategories (e.g., surface or ground water systems in a given size category) to be conclusive, particularly in cases where no detections occur. For example, in very small surface water systems, if a contaminant does not occur in the screening survey, there is a 95% chance that the national occurrence fraction of that contaminant is less than 4.4%. Note also that since the total number of systems allocated to each size category is equal (60 systems per category), the monitoring results will have to be weighted by the proportion of the population served within each service size category. Monitoring results will have to be carefully analyzed to correctly assess the possible implications of such results.

To implement the Screening Surveys, EPA selected 180 small PWSs from the set of 267 systems (i.e., one-third of the 800 systems in the national representative sample), scheduled to conduct Assessment Monitoring in 2001 (for the first group) and again in 2003 (for the second group). Although a Screening Survey is not currently scheduled for 2002, systems were still selected for this year (in case it was necessary to conduct a Screening Survey in 2002). The probability of a system being selected for Assessment Monitoring (A) in any given year is 267/800, or $P_n(A)$=33%.

Given that a system was first selected for Assessment Monitoring (*A*) in any given year *n*, the probability of that system also being selected for Screening Survey (*S*), is:

$$P_n(S|A) = (\frac{180}{267}) = 0.67 \qquad (3).$$

Overall, there was a 22% probability that a system would be selected for the Screening Survey and Assessment Monitoring in the same year (67% chance of being selected for Screening Surveys, multiplied by a 33% chance of being selected for Assessment Monitoring). However, if the first Screening Survey is conducted in the year 2002, the systems selected to conduct Assessment Monitoring in the year 2001 have no chance of being selected for a Screening Survey. Overall, there is a 45% chance for a small system to be selected for both Assessment Monitoring and a Screening Survey simultaneously. Therefore, the probability of a system being selected only for Assessment Monitoring is estimated as 55%. Figure 2 depicts the number of systems and the probability of a system being selected for Assessment Monitoring and a Screening Survey.

Similarly, for the large CWSs and NTNCWSs, the probability of a system being required to participate in a Screening Survey (*S*) is:

$$P_{large}(S) \equiv (\frac{240}{2774}) = 0.0865 \qquad (4).$$

Therefore, there is approximately a 9% probability that a large system will be chosen for a Screening Survey.

Again, based on the proportion of population served by small CWSs and NTNCWSs in each State, the number of systems selected for the two groups of Screening Surveys (S_n) in each State/Tribe *n*, is calculated as:

$$S_{ni} = \frac{P_{ni}}{NP_i} * Z_i \qquad (5).$$

where P_{ni} is the population served by small systems in State/Tribe *n* in category *i*, and NP_i is the total national population served in system category *i*, and Z_i is the total number of systems required to conduct the survey in that category *i*.

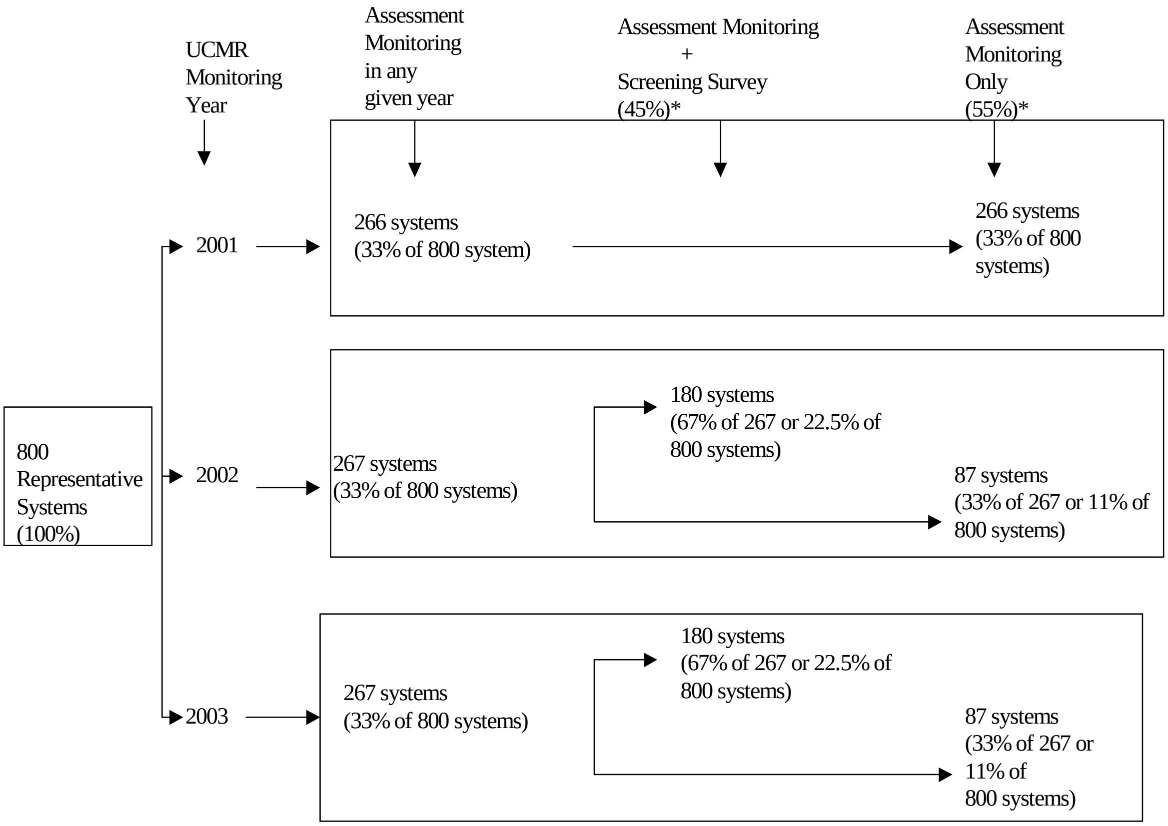
Figure 2 illustrates the allocation of systems conducting Assessment Monitoring and two Screening Surveys in each State/Tribe based on the population served by the systems.

10. Pre-Screen Testing

The third monitoring component of the UCMR is Pre-Screen Testing. EPA established this third tier of the UCMR monitoring with its stakeholders for contaminants of concern for which analytical methods are in the early stages of development and/or whose methods are currently too expensive for wide-scale monitoring. Pre-Screen Testing may also address contaminants that have recently emerged or been identified as a concern, such as through the Governors' petition process. The purpose of this monitoring component will be to determine whether the methods in early development will provide adequate analytical results in conditions under which the contaminants are most likely to occur. There are nine contaminants on the UCMR (1999) List 3, including seven microbiological contaminants and two radiological contaminants. The complete list may be found in §141.40(a)(3) Table 1, UCMR (1999) List 3.

EPA will ask each State to identify a list of between 5 and 25 systems that might be most vulnerable to the UCMR (1999) List 3 Pre-Screen Testing contaminants. EPA will define a process to select up to 200 large and small PWSs from the list of systems nominated by States. The Pre-Screen Testing will use analytical results from a small sample to evaluate and improve methods, and to conduct an initial assessment of occurrence. Given the small number of Pre-Screen Testing systems, the monitoring results cannot be used to estimate national occurrence of UCMR (1999) List 3 contaminants in a statistically rigorous manner. EPA will provide further guidance on Pre-Screen Testing contaminants after the List 3 Rule is promulgated.

Figure 2. Number and Probability of Small Systems Chosen for Assessment Monitoring and Screening Surveys for the UCMR Years 2001-2003



* Overall Probability (over three years)

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Appendix A

Statistical Theory and Optimal Choice of Probabilities for Probability-Weighted Estimation

This appendix presents some statistical theory for the methods of estimation, confidence intervals, and selection of sampling probabilities that were used to derive the sampling plan for Assessment Monitoring, as described in Section 4. The theory is presented here in order to show that, subject to the approximations described in Section A.5, the sampling plan will provide occurrence and exposure estimates that meet the UCMR's data quality objectives of accuracy and precision, as described in Section 4.

The discussion below requires that the reader be familiar with basic statistical theory, for example as in Casella and Berger (1991). It extends some of the sampling theory of Cochran (1977), but does not require that the reader be familiar with that book.

A.1 Probability-Weighted Estimation

Suppose we have a population of N systems of interest. For example, we could consider the population of $N = 63{,}869$ small PWSs in the United States and Territories. Fix a single contaminant of interest. For each system $i = 1, \ldots, N$, let $y_i = 1$ if the contaminant occurs at any time in system i, or 0 otherwise. We want to estimate the weighted mean

$$\mu = \sum_{i=1}^{N} W_i y_i \tag{A-1}$$

where the W_i are given weights. For example, if W_i is the number of people served by system i, then μ is the number of people exposed to the contaminant. If S is a subset of systems and $W_i = \mathbf{1}\{i \in S\}/\#\{S\}$, where $\mathbf{1}\{A\}$ equals 1 if the event A is true or 0 if A is false, and $\#\{S\}$ is the number of systems in S, then μ is the fraction of systems in S that have some occurrence of the contaminant.

In order to estimate μ, consider the following sampling scheme. We draw D independent samples. The d-th sample consists of n_d i.i.d. system numbers $I_{d1}, \ldots, I_{dn_d}$ drawn with replacement from the distribution $P(I_{d1} = i) = p_{di}$, where $p_{d1}, \ldots, p_{dN}$ are given probabilities, $\sum_{i=1}^{N} p_{di} = 1$. The systems numbered $I_{d1}, \ldots, I_{dn_d}$ are then sampled, and $y_{I_{d1}}, \ldots, y_{I_{dn_d}}$ are obtained. The total number of systems sampled is $n = \sum_{d=1}^{D} n_d$.

To compute an unbiased estimate of μ using this sampling scheme, let $q_{di} = \mathbf{1}\{p_{di} > 0\}$, $c_i = \left(\sum_{d=1}^{D} n_d q_{di}\right)^{-1}$, and

$$\hat{\mu} = \sum_{d=1}^{D} \sum_{j=1}^{n_d} \left(\frac{Wyc}{p_d}\right)_{I_{dj}}. \tag{A-2}$$

Here $\left(\frac{Wyc}{p_d}\right)_i$ is a simplified notation for $\frac{W_i y_i c_i}{p_{di}}$. This notation simplifies formulas and is used repeatedly below.

We call $\hat{\mu}$ the *probability-weighted estimator* of μ, given the sampling probabilities p_{di}. $\hat{\mu}$ includes two bias corrections: c_i acts like n^{-1} in a sample mean, correcting for the total number of possible observations on a system; and p_{di}^{-1} gives greater weight to observations that are expected to be drawn less often within a sample. In order for c_i to be defined, we require that $\sum_{d=1}^{D} n_d q_{di} > 0$ for each i. This is equivalent to assuming that each system has positive probability of being sampled at least once.

Cochran (1977, Section 9A.3) considers $\hat{\mu}$ in the case $D = 1$. He calls $\hat{\mu}$ the "probability proportional to p" estimator. A special case is probability proportional to size (pps), in which $p_{di} \propto W_i$. In this case systems are sampled in proportion to their weight in μ, and when $D = 1$ the estimator is just the sample mean, $\hat{\mu} = n^{-1} \sum_{j=1}^{n} y_{I_j}$. The pps estimator is easily shown to be the minimum variance unbiased estimator of μ when there are no constraints on the ps.

The following Theorem gives properties of $\hat{\mu}$. See also Cochran (1977, Section 9A.3) for the case $D = 1$.

Theorem 1. Let $\mu_d = \sum_{i=1}^{N} (Wycq_d)_i$ and $\hat{\mu}_d = n_d^{-1} \sum_{j=1}^{n_d} \left(\frac{Wyc}{p_d}\right)_{I_{dj}}$.

(a) $\hat{\mu}$ is an unbiased estimate of μ.

(b) $\mathrm{Var}(\hat{\mu}) = \sum_{d=1}^{D} n_d \sum_{i=1}^{N} p_{di} \left(\left(\frac{Wyc}{p_d}\right)_i - \mu_d\right)^2$.

(c) An unbiased estimate of $\mathrm{Var}(\hat{\mu})$ is $\hat{V}(\hat{\mu}) = \sum_{d=1}^{D} \frac{n_d}{n_d - 1} \sum_{j=1}^{n_d} \left(\left(\frac{Wyc}{p_d}\right)_{I_{dj}} - \hat{\mu}_d\right)^2$.

Note. When $p_{di} = 0$, we define $\hat{\mu}$ in (A-2) to replace p_{di}^{-1} by an arbitrary number. This leaves the estimator unchanged, since the affected systems are sampled with probability zero. But in Theorem 1(b) and below it allows us to write $p_{di}/p_{di} = 0$ when $p_{di} = 0$.

Proof of Theorem 1. First prove some facts about μ_d and $\hat{\mu}_d$:

$$\mu = \sum_i (Wyc)_i \sum_d n_d q_{di} = \sum_d n_d \sum_i (Wycq_d)_i = \sum_d n_d \mu_d, \tag{A-3}$$

$$\hat{\mu} = \sum_d n_d \hat{\mu}_d, \tag{A-4}$$

$$E(\hat{\mu}_d) = E\left(\frac{Wyc}{p_d}\right)_{I_{d1}} = \sum_i p_{di}\left(\frac{Wyc}{p_d}\right)_i = \sum_i (Wycq_d)_i = \mu_d, \tag{A-5}$$

$$\mathrm{Var}(\hat{\mu}_d) = n_d^{-1}\,\mathrm{Var}\left(\left(\frac{Wyc}{p_d}\right)_{I_{d1}}\right) = n_d^{-1}\sum_i p_{di}\left(\left(\frac{Wyc}{p_d}\right)_i - \mu_d\right)^2. \tag{A-6}$$

(a) $E\hat{\mu} = \sum_d n_d E\hat{\mu}_d = \sum_d n_d \mu_d = \mu$, by (A-4), (A-5), and (A-3).

(b) $\mathrm{Var}(\hat{\mu}) = \sum_d n_d^2\,\mathrm{Var}(\hat{\mu}_d)$ by (A-4); apply (A-6).

(c) Let $\hat{v}_d = \sum_{j=1}^{n_d}\left(\left(\frac{Wyc}{p_d}\right)_{I_{dj}} - \hat{\mu}_d\right)^2$. Standard results give $E\hat{v}_d = (n_d - 1)\,\mathrm{Var}\left(\left(\frac{Wyc}{p_d}\right)_{I_{dj}}\right) = n_d(n_d-1)\,\mathrm{Var}(\hat{\mu}_d)$, so $E\hat{V}(\hat{\mu}) = \sum_d \frac{n_d}{n_d-1} E\hat{v}_d = \sum_d n_d^2\,\mathrm{Var}(\hat{\mu}_d) = \mathrm{Var}(\hat{\mu})$ by (A-4). ■

A.2 Stratified Sampling

Suppose now that the N systems are divided into T strata. The s-th stratum contains N_s systems, so $N = \sum_{s=1}^{T} N_s$. For the purposes of the UCMR, a stratum is a combination of State or Territory (1 of 56), system size (1, 2, or 3), source water type (GW or SW), and system type (CWS or NTNCWS). Thus there are $T = 56 \times 3 \times 2 \times 2 = 672$ strata. We could also consider smaller sets of strata, for example just the 6 size-by-source-water-type strata.

Instead of a single system number i, each system is now identified by a stratum number s and a system number h within stratum s. This is just a relabeling of the systems, so the development of Section A.1 still holds, with i and I replaced everywhere by (s, h) and (S, H). The estimand is $\mu = \sum_{s=1}^{T}\sum_{h=1}^{N_s} W_{sh}y_{sh}$, and in the d-th sample we draw i.i.d. stratum and system number pairs $(S_{d1}, H_{d1}), \ldots, (S_{dn_d}, H_{dn_d})$ using $P(S_{d1} = s, H_{d1} = h) = p_{dsh}$.

An important special case is when the mean weights W_{sh} and sampling probabilities p_{dsh} are the same for all systems h within a stratum. That is, assume

Assumption 1. $W_{sh} = W_s$ and $p_{dsh} = p_{ds}$ for all d, s, and h.

In this case let r_{ds} be the probability of drawing the next system from stratum s: then $r_{ds} = P(S_{d1} = s) = \sum_h p_{dsh} = N_s p_{ds}$, so $\hat{\mu}$ becomes

$$\hat{\mu} = \sum_{d=1}^{D}\sum_{j=1}^{n_d}\left(\frac{Uc}{r_d}\right)_{S_{dj}} y_{(S,H)_{dj}} \tag{A-7}$$

where the new mean weights are $U_s = W_s N_s$. The U_s have a "per stratum" interpretation instead of "per system." For example, if before W_{sh} was the number of people served by system h in stratum s, now U_s is the number of people served by all of stratum s.

From here forward we consider only the special case of Assumption 1. This has the advantage that instead of simultaneously drawing S and H using p_{dsh}, we can now think of first drawing a stratum number S with probabilities r_{ds}, then drawing a system number within S from a uniform distribution on $\{1, \ldots, N_S\}$. Since the system numbers are uniformly distributed within each stratum, we do not have to compute their probabilities and will concentrate on the strata.

A.3 Optimal Choice of Probabilities

In this section we describe a procedure for choosing the sampling probabilities r_{ds} in order to minimize the variance of certain mean estimates, subject to upper bounds on the variance of other mean estimates. Some simplifying assumptions are required in order to solve the problem. We first formulate the optimization as a nonlinear programming problem, and then describe some details of the implementation.

A.3.1 Problem Formulation

Let $\mu_1, \ldots, \mu_{E+F}$ be means of interest, each determined by a given set of weights: $\mu_i = \sum_{s,h} W_{ish} y_{sh}$. Suppose that a set of samples will be drawn as described in Section A.1, and each μ_i will then be estimated by $\hat{\mu}_i$ as in (A-7). The problem in this section is to find sampling probabilities r_{ds} that minimize the maximum variance of $\hat{\mu}_1, \ldots, \hat{\mu}_E$, subject to given upper bounds on the variances of $\hat{\mu}_{E+1}, \ldots, \hat{\mu}_{E+F}$. If $\boldsymbol{R} = [r_{ds}]_{d=1,s=1}^{D\ \ T}$ is the matrix of sampling probabilities, then we want $\boldsymbol{R}$ that solves

$$\begin{aligned} \min_{\boldsymbol{R}}\ & \max\,\{\mathrm{Var}(\hat{\mu}_1), \ldots, \mathrm{Var}(\hat{\mu}_E)\} \\ \text{s.t.}\ & \mathrm{Var}(\hat{\mu}_{E+i}) \leqslant u_i, \quad i = 1, \ldots, F \\ & \boldsymbol{R}\mathbf{1} = \mathbf{1} \\ & \boldsymbol{R} \geqslant \mathbf{0} \end{aligned} \tag{A-8}$$

The variance bounds u_i could be chosen, for example, to give normal-theory confidence intervals of no more than a specified width at a specified confidence.

The first simplifying assumption is that mean weights and sampling probabilities are constant within each stratum. This is Assumption 1 of the previous section. Assumption 1 poses no problem for estimating occurrence, since then we are just counting systems and every system in a stratum can receive the same weight. On the other hand for estimating exposure, Assumption 1 is restrictive since each system should be weighted by its number of customers, which varies within a stratum. Under Assumption 1 we are forced instead to use, say, the mean number of customers per system in each stratum. However, if the strata are based sufficiently on size so that most of the variation in system size is between and not within strata, then the restriction due to Assumption 1 will be mild. Moreover, if information were available about the size distribution within each stratum, a different assumption could be substituted to use that information. Similarly, other assumptions could be substituted about the proportions of the p_{dsh}.

Under Assumption 1, the argument of Section A.2 can be applied to Theorem 1(b) to give

$$\mathrm{Var}(\hat{\mu}_i) = \sum_{d,s} n_d \left(\frac{U_i^2 c^2 q_d \bar{y}}{r_d} \right)_s - \sum_d n_d \left(\sum_s (U_i c q_d \bar{y})_s \right)^2 \tag{A-9}$$

where $\bar{y}_s = N_s^{-1} \sum_{h=1}^{N_s} y_{sh}$. The only unknowns in (A-9) are $\bar{y}_s$ and r_{ds} (since for the purposes of optimization, $q_{ds} := \mathbf{1}\{r_{ds} > 0\}$ are assumed to be given as part of the problem). In order to leave only r_{ds} unknown, we make the next simplifying assumption:

Assumption 2. $\bar{y}_s = \rho$ for all s and some $\rho \in [0, 1]$.

The user has to specify a value of ρ. The results of the optimization will be valid only for this value. For example, the user could choose to optimize the sampling plan for contaminants which occur on average in $\rho = 1\%$ of systems, as in Section 4.

Assumption 2 says that the fraction of occurrence is identical in each stratum. This is obviously unrealistic, but is a reasonable default in the absence of other information. Again, any other assumption that simplifies or summarizes the effect of the y's could also be used. For example, the $\bar{y}$'s could be assumed to depend in a simple way on mean system size in each stratum.

Using (2), we can rewrite (A-9) as

$$\mathrm{Var}(\hat{\mu}_i) = \rho \sum_{d,s} \frac{a_{ids}}{r_{ds}} - \rho^2 b_i \tag{A-10}$$

where $a_{ids} = n_d (U_i^2 c q_d)_s$ and $b_i = \sum_d n_d \left(\sum_s (U_i c q_d)_s \right)^2$. We can now rewrite (A-8) in matrix form. For each i, let $\boldsymbol{a}_i$ be a $1 \times DT$ row vector of the a_{ids}: $\boldsymbol{a}_i = [a_{i11}, \ldots, a_{i1T}, \ldots, a_{iD1}, \ldots, a_{iDT}]$. In the same way, arrange the r_{ds} and r_{ds}^{-1} into $DT \times 1$ column vectors $\boldsymbol{r}$ and $\boldsymbol{r}^{-1}$, respectively. Let $\boldsymbol{A}_1 = [\boldsymbol{a}'_1 \ldots \boldsymbol{a}'_E]'$, $\boldsymbol{A}_2 = [\boldsymbol{a}'_{E+1} \ldots \boldsymbol{a}'_{E+F}]'$, $\boldsymbol{b}_1 = [b_1, \ldots, b_E]'$, $\boldsymbol{b}_2 = [b_{E+1}, \ldots, b_{E+F}]'$, and $\boldsymbol{u} = [u_1, \ldots, u_F]'$. Then (A-8) can be written as

$$\begin{aligned} &\min_{\boldsymbol{r}} \max \; (\rho \boldsymbol{A}_1 \boldsymbol{r}^{-1} - \rho^2 \boldsymbol{b}_1) \\ &\text{s.t.} \qquad \rho \boldsymbol{A}_2 \boldsymbol{r}^{-1} \leqslant \rho^2 \boldsymbol{b}_2 + \boldsymbol{u} \\ &\qquad\qquad \boldsymbol{S}\boldsymbol{r} = \mathbf{1} \\ &\qquad\qquad \boldsymbol{r} \geqslant \mathbf{0} \end{aligned} \tag{A-11}$$

where $\boldsymbol{S}$ is a matrix of 1's and 0's such that $\boldsymbol{S}\boldsymbol{r}$ is the same as $\boldsymbol{R}\mathbf{1}$ (in fact $\boldsymbol{S} = \boldsymbol{I}_D \otimes \mathbf{1}_{1\times T}$, where $\otimes$ is the Kronecker or tensor product).

Problem (A-11) is a nonlinear program, with both a nonlinear objective function and nonlinear constraints. It has to be solved numerically. Fortunately, the nonlinearity in (A-11) is not too bad: each minimax objective and constraint is a linear function of either $\boldsymbol{r}$ or $\boldsymbol{r}^{-1}$. Solution with nonlinear programming software is therefore more or less routine. The next subsection describes some details of the implementation.

A.3.2 Implementation

We programmed the optimization described above in Matlab (The MathWorks, Inc., 1996), a matrix computation language. For the optimization step we used the `fminimax` function in Matlab's Optimization Toolbox (The MathWorks, Inc., 1999).

The optimization requires that the user provide the following input:

- The number of systems and number of people served in each of the 672 sampling strata. For the UCMR this information came from the 1999 Drinking Water Infrastructure Needs Survey, as described in Section 2.
- A skeletal sampling plan:
  - D, the number of independent samples;
  - $n_1, \ldots, n_D$, the numbers of systems in each sample;
  - q_{ds}, the indicators of positive sampling probabilities. If $q_{ds} = 1$, then the optimization searches for the optimal positive probability r_{ds} of drawing from stratum s during each draw in the d-th sample. If $q_{ds} = 0$, then the optimization sets $r_{ds} = 0$, so no systems will be drawn from stratum s during the d-th sample.
- ρ, the assumed occurrence fraction in each stratum.
- W_{is}, the response weights for the means of interest. In our implementation each mean may have either occurrence or exposure weights in any combination of strata. Each mean is also identified as being either part of the minimax objective or subject to a variance constraint.
- u_i, the upper bounds for the variance constraints. We parameterized u_i by a desired confidence level and half-width of a normal-theory confidence interval.

There are $\sum_{d,s} q_{ds}$ probabilities to optimize over, or at most DT probabilities. With $T = 672$ strata and multiple samples, this number can easily become large enough to prevent the optimization from converging quickly or at all. Some experimentation is required in order to find a sampling plan for which the optimization succeeds. We tried several unsuccessful plans before arriving at the following successful two-step procedure:

1. Determine the number of systems to draw from each State, by adjusting the population-weighted allocation as described in Section 4.2.1.

2. Specify a sampling plan with $D = 56$ samples, one for each State and Territory. The number of systems in each sample (= State) is determined in Step 1. Each sample allows positive sampling probability in each of the 12 system-type-by-source-water-type-by-system-size strata within its State or Territory, and zero sampling probability in all other States and Territories.

This plan allows $56 \times 12 = 672$ positive sampling probabilities. The resulting optimal probabilities are tabulated in Appendix B.

In order to help the optimization converge, we simplified the problem further by partitioning it into two subproblems, one for CWSs and one for NTNCWSs. The minimax objectives and variance constraints already break down in this way, since each of the target means (e.g. Size 1 GW CWSs) puts positive weight either only on CWSs, or only on NTNCWSs. In order to partition the probability constraints, we imposed a further constraint, which is our last simplifying assumption for the optimization:

Assumption 3. The sums of the CWS and NTNCWS sampling probabilities in each sample (= State) are proportional to the respective populations served.

For example in Texas, CWSs serve 93.2% of the population, so by design each system allocated to Texas has a 93.2% chance of being drawn as a CWS, as Appendix B confirms.

Using Assumption 3, the optimization may be decomposed from a single problem in 672 unknowns, into separate CWS and NTNCWS optimizations each in 336 unknowns. The resulting subproblems are solved in about 3 hours each on a 400 MHz Pentium-II computer. Note however that even if Assumption 3 were not required, solving the two subproblems is not equivalent to solving the original problem, because we now perform two separate minimax optimizations, which give different optimal values. As a result the widest confidence interval for CWSs in Table 5 is narrower than for NTNCWSs. We consider this difference to be an advantage: it reflects a decision that CWSs, which serve more people, should comprise a larger proportion of the systems sampled for the UCMR.

A.4 Confidence Intervals

A normal-theory $100(1-\alpha)\%$ confidence interval for $\hat{\mu}$ may be computed in the usual way as $\hat{\mu} \pm z_{1-\alpha/2}\sqrt{\hat{V}(\hat{\mu})}$, where $\hat{V}(\hat{\mu})$ is the variance estimate defined in Theorem 1.

Under simple random sampling, the Wilson score confidence interval without continuity correction (Newcombe, 1998; Wilson, 1927) for a proportion ρ is derived by using the normal interval to find the range of parameter values for which the parameter estimate is plausible:

$$\begin{aligned} \hat{\rho} &\in \rho \pm z\sqrt{\rho(1-\rho)/n} \\ \Leftrightarrow \quad \rho &\in \left(2n\hat{\rho} + z^2 \pm z\sqrt{z^2 + 4n\hat{\rho}(1-\hat{\rho})}\right)\Big/ 2(n+z^2) \end{aligned} \tag{A-12}$$

so (A-12) defines the Wilson score confidence interval for ρ. Under Assumptions 1 and 2, the same derivation can be applied to a probability-weighted estimator with stratified sampling. Writing (A-10) as $\text{Var}(\hat{\rho}) = V_1\rho - V_2\rho^2$, we have

$$\begin{aligned} \hat{\rho} &\in \rho \pm z\sqrt{V_1\rho - V_2\rho^2} \\ \Leftrightarrow \quad \rho &\in \left(2\hat{\rho} + V_1 z^2 \pm z\sqrt{V_1^2 z^2 + 4(V_1\hat{\rho} - V_2\hat{\rho}^2)}\right)\Big/ 2(1+V_2 z^2) \end{aligned} \tag{A-13}$$

so (A-13) may be considered an approximate Wilson score confidence interval for ρ. The interval is only approximate because it requires Assumptions 1 and 2.

A.5 Problems

The method described in this Appendix has the following weaknesses.

1. The theory assumes that systems are sampled with replacement, while the sampling plan for Assessment Monitoring (Sections 4 and 8 above) uses sampling without replacement. When the sampling fraction n/N is small, the sampling probabilities under sampling without replacement do not change much from one sample to the next, so the difference between the two methods is small. In Section 4, the sampling fraction is 800/63,869, or about 1.25%, which is probably small enough to ignore. By comparison, in simple random sampling, a sampling fraction of this size reduces standard errors by about 0.6%, and is commonly ignored.

2. The optimization forces the probability of drawing a CWS or NTNCWS to be proportional to the population served by CWSs and NTNCWSs in each State (Assumption 3). So about 88% of the systems selected for Assessment Monitoring will be CWSs, since CWSs serve 88% of the total population served by small systems. Although this constraint was imposed for computational reasons as described in Section A.3.2, it agrees with the principle of sampling in proportion to the population served.

3. The optimization assumes that the mean weights and sampling probabilities are constant within each stratum (Assumption 1). As discussed in Section A.3, this assumption is mildly restrictive for exposure estimates, where weights and probabilities should increase with system size, which varies mostly between strata but also somewhat within strata.

4. The optimization also assumes that the occurrence fraction ρ is the same in each stratum (Assumption 2). As argued in Section A.3, this assumption is unrealistic but is a reasonable default in the absence of information about how occurrence depends on stratum properties. Even if

such information were available, it would probably be different for each contaminant and so again Assumption 2 is a reasonable default.

5. The optimization depends on a user-specified value of ρ. If a new value of ρ is hypothesized, the optimization must be rerun. Moreover a single sampling plan has to be used for many contaminants, which will occur with different frequencies; so the sampling plan will be suboptimal for most contaminants. The sensitivity of the optimal sampling plan to the assumed value of ρ has not been tested.

6. Theorem 1 ignores sampling error in the y_i's. It assumes that once the system number is chosen, we can go to the system and observe y without error. This is a classical assumption in sampling, but it does not hold in this case. The response y_i equals 1 if the contaminant of interest occurs at detectable levels at any time in system i, or 0 otherwise. But of course y_i cannot be observed without error: a finite number of samples is drawn from each system, and instead of y_i we observe $\hat{y}_i$, which equals 1 if the contaminant is observed in our few samples, or 0 otherwise. The approximation of y_i by $\hat{y}_i$ introduces bias and additional variance. In particular, $\hat{y}_i$ will be negatively biased for y_i, since we will often miss a contaminant which is only occasionally present.

   In order to study the effect of $\hat{y}_i$ on the present theory, one needs either data or assumptions about the frequency of occurrence of the contaminant of interest above the level of interest; the number of samples taken from each system; the number of sampling locations within systems; and temporal and spatial variability of contaminant occurrence across sampling locations. Such data will be available once the sampling program is complete, and more accurate and conservative confidence intervals can be computed at that time.

Appendix B

Expected and Total Number of Systems Selected for Assessment Monitoring

Appendix B. Probability of Selection, with Expected and Initial SMP Systems Selected for Assessment Monitoring

Total Number of Systems	State/Territory	System Type	System Size	Source Type	Probability	Cumulative Probability	Expected # of Systems	Actual # of Systems
4	Alaska	CWS	25-500	GW	0.103141	0.103141	0	1
	Alaska	CWS	25-500	SW	0.527185	0.630325	1	2
	Alaska	CWS	501-3300	GW	0.112833	0.743158	1	1
	Alaska	CWS	501-3300	SW	0.061396	0.804554	0	0
	Alaska	CWS	3301-10000	GW	0.068704	0.873258	1	0
	Alaska	CWS	3301-10000	SW	0.126742	1.000000	1	0
	Alaska	NTNCWS	25-500	GW	0.000000	1.000000	0	0
	Alaska	NTNCWS	25-500	SW	0.000000	1.000000	0	0
	Alaska	NTNCWS	501-3300	GW	0.000000	1.000000	0	0
	Alaska	NTNCWS	501-3300	SW	0.000000	1.000000	0	0
	Alaska	NTNCWS	3301-10000	GW	0.000000	1.000000	0	0
	Alaska	NTNCWS	3301-10000	SW	0.000000	1.000000	0	0
14	Alabama	CWS	25-500	GW	0.012354	0.012354	0	0
	Alabama	CWS	25-500	SW	0.003231	0.015585	0	1
	Alabama	CWS	501-3300	GW	0.274297	0.289882	4	2
	Alabama	CWS	501-3300	SW	0.023398	0.313280	0	1
	Alabama	CWS	3301-10000	GW	0.538540	0.851820	8	10
	Alabama	CWS	3301-10000	SW	0.111429	0.963250	2	1
	Alabama	NTNCWS	25-500	GW	0.001197	0.964446	0	0
	Alabama	NTNCWS	25-500	SW	0.009440	0.973886	0	0
	Alabama	NTNCWS	501-3300	GW	0.006425	0.980312	0	0
	Alabama	NTNCWS	501-3300	SW	0.019688	1.000000	0	0
	Alabama	NTNCWS	3301-10000	GW	0.000000	1.000000	0	0
	Alabama	NTNCWS	3301-10000	SW	0.000000	1.000000	0	0
13	Arkansas	CWS	25-500	GW	0.048335	0.048335	1	1
	Arkansas	CWS	25-500	SW	0.037493	0.085827	0	1
	Arkansas	CWS	501-3300	GW	0.281970	0.367797	4	3
	Arkansas	CWS	501-3300	SW	0.065464	0.433261	1	0
	Arkansas	CWS	3301-10000	GW	0.380083	0.813343	5	5
	Arkansas	CWS	3301-10000	SW	0.165064	0.978408	2	3
	Arkansas	NTNCWS	25-500	GW	0.001920	0.980327	0	0
	Arkansas	NTNCWS	25-500	SW	0.012133	0.992460	0	0
	Arkansas	NTNCWS	501-3300	GW	0.002293	0.994752	0	0
	Arkansas	NTNCWS	501-3300	SW	0.005248	1.000000	0	0
	Arkansas	NTNCWS	3301-10000	GW	0.000000	1.000000	0	0
	Arkansas	NTNCWS	3301-10000	SW	0.000000	1.000000	0	0
2	American Samoa	CWS	25-500	GW	0.278403	0.278403	1	1

Appendix B. Probability of Selection, with Expected and Initial SMP Systems Selected for Assessment Monitoring

Total Number of Systems	State/Territory	System Type	System Size	Source Type	Probability	Cumulative Probability	Expected # of Systems	Actual # of Systems
	American Samoa	CWS	25-500	SW	0.636275	0.914677	1	1
	American Samoa	CWS	501-3300	GW	0.000000	0.914677	0	0
	American Samoa	CWS	501-3300	SW	0.085323	1.000000	0	0
	American Samoa	CWS	3301-10000	GW	0.000000	1.000000	0	0
	American Samoa	CWS	3301-10000	SW	0.000000	1.000000	0	0
	American Samoa	NTNCWS	25-500	GW	0.000000	1.000000	0	0
	American Samoa	NTNCWS	25-500	SW	0.000000	1.000000	0	0
	American Samoa	NTNCWS	501-3300	GW	0.000000	1.000000	0	0
	American Samoa	NTNCWS	501-3300	SW	0.000000	1.000000	0	0
	American Samoa	NTNCWS	3301-10000	GW	0.000000	1.000000	0	0
	American Samoa	NTNCWS	3301-10000	SW	0.000000	1.000000	0	0
12	Arizona	CWS	25-500	GW	0.108010	0.108010	1	2
	Arizona	CWS	25-500	SW	0.058390	0.166401	0	0
	Arizona	CWS	501-3300	GW	0.284651	0.451052	3	2
	Arizona	CWS	501-3300	SW	0.023234	0.474286	0	1
	Arizona	CWS	3301-10000	GW	0.366545	0.840831	4	7
	Arizona	CWS	3301-10000	SW	0.016569	0.857400	0	0
	Arizona	NTNCWS	25-500	GW	0.021645	0.879045	0	0
	Arizona	NTNCWS	25-500	SW	0.019254	0.898299	0	0
	Arizona	NTNCWS	501-3300	GW	0.077477	0.975776	1	0
	Arizona	NTNCWS	501-3300	SW	0.005127	0.980903	0	0
	Arizona	NTNCWS	3301-10000	GW	0.019097	1.000000	0	0
	Arizona	NTNCWS	3301-10000	SW	0.000000	1.000000	0	0
48	California	CWS	25-500	GW	0.091801	0.091801	4	6
	California	CWS	25-500	SW	0.145704	0.237505	0	10
	California	CWS	501-3300	GW	0.170920	0.408425	8	7
	California	CWS	501-3300	SW	0.058824	0.467249	3	2
	California	CWS	3301-10000	GW	0.280015	0.747264	13	10
	California	CWS	3301-10000	SW	0.129795	0.877059	6	8
	California	NTNCWS	25-500	GW	0.022186	0.899245	1	1

Appendix B. Probability of Selection, with Expected and Initial SMP Systems Selected for Assessment Monitoring

Total Number of Systems	State/Territory	System Type	System Size	Source Type	Probability	Cumulative Probability	Expected # of Systems	Actual # of Systems
	California	NTNCWS	25-500	SW	0.020841	0.920085	1	0
	California	NTNCWS	501-3300	GW	0.022424	0.942510	1	2
	California	NTNCWS	501-3300	SW	0.011769	0.954278	1	1
	California	NTNCWS	3301-10000	GW	0.012763	0.967041	1	0
	California	NTNCWS	3301-10000	SW	0.032959	1.000000	2	1
10	Colorado	CWS	25-500	GW	0.089138	0.089138	0	0
	Colorado	CWS	25-500	SW	0.188764	0.277903	0	1
	Colorado	CWS	501-3300	GW	0.166154	0.444056	2	1
	Colorado	CWS	501-3300	SW	0.138157	0.582213	1	3
	Colorado	CWS	3301-10000	GW	0.129963	0.712176	1	2
	Colorado	CWS	3301-10000	SW	0.213830	0.926007	2	2
	Colorado	NTNCWS	25-500	GW	0.002338	0.928344	0	0
	Colorado	NTNCWS	25-500	SW	0.008918	0.937263	0	0
	Colorado	NTNCWS	501-3300	GW	0.001276	0.938538	0	0
	Colorado	NTNCWS	501-3300	SW	0.001898	0.940436	0	0
	Colorado	NTNCWS	3301-10000	GW	0.000000	0.940436	0	0
	Colorado	NTNCWS	3301-10000	SW	0.059564	1.000000	1	1
6	Connecticut	CWS	25-500	GW	0.195981	0.195981	0	1
	Connecticut	CWS	25-500	SW	0.006058	0.202039	0	0
	Connecticut	CWS	501-3300	GW	0.166513	0.368552	1	0
	Connecticut	CWS	501-3300	SW	0.037219	0.405771	0	1
	Connecticut	CWS	3301-10000	GW	0.101240	0.507011	1	0
	Connecticut	CWS	3301-10000	SW	0.176568	0.683578	1	2
	Connecticut	NTNCWS	25-500	GW	0.153652	0.837230	1	0
	Connecticut	NTNCWS	25-500	SW	0.000000	0.837230	0	0
	Connecticut	NTNCWS	501-3300	GW	0.162770	1.000000	1	2
	Connecticut	NTNCWS	501-3300	SW	0.000000	1.000000	0	0
	Connecticut	NTNCWS	3301-10000	GW	0.000000	1.000000	0	0
	Connecticut	NTNCWS	3301-10000	SW	0.000000	1.000000	0	0
2	Delaware	CWS	25-500	GW	0.177268	0.177268	0	1
	Delaware	CWS	25-500	SW	0.000000	0.177268	0	0
	Delaware	CWS	501-3300	GW	0.381717	0.558986	1	0
	Delaware	CWS	501-3300	SW	0.000000	0.558986	0	0
	Delaware	CWS	3301-10000	GW	0.239315	0.798300	1	1
	Delaware	CWS	3301-10000	SW	0.000000	0.798300	0	0
	Delaware	NTNCWS	25-500	GW	0.060765	0.859066	0	0
	Delaware	NTNCWS	25-500	SW	0.000000	0.859066	0	0

Appendix B. Probability of Selection, with Expected and Initial SMP Systems Selected for Assessment Monitoring

Total Number of Systems	State/Territory	System Type	System Size	Source Type	Probability	Cumulative Probability	Expected # of Systems	Actual # of Systems
	Delaware	NTNCWS	501-3300	GW	0.078519	0.937585	0	0
	Delaware	NTNCWS	501-3300	SW	0.062415	1.000000	0	0
	Delaware	NTNCWS	3301-10000	GW	0.000000	1.000000	0	0
	Delaware	NTNCWS	3301-10000	SW	0.000000	1.000000	0	0
32	Florida	CWS	25-500	GW	0.107618	0.107618	0	3
	Florida	CWS	25-500	SW	0.000000	0.107618	0	0
	Florida	CWS	501-3300	GW	0.350597	0.458215	11	8
	Florida	CWS	501-3300	SW	0.001696	0.459910	0	0
	Florida	CWS	3301-10000	GW	0.394205	0.854115	13	17
	Florida	CWS	3301-10000	SW	0.016435	0.870550	1	0
	Florida	NTNCWS	25-500	GW	0.058549	0.929099	2	2
	Florida	NTNCWS	25-500	SW	0.000000	0.929099	0	0
	Florida	NTNCWS	501-3300	GW	0.060849	0.989949	2	1
	Florida	NTNCWS	501-3300	SW	0.000000	0.989949	0	0
	Florida	NTNCWS	3301-10000	GW	0.010051	1.000000	0	1
	Florida	NTNCWS	3301-10000	SW	0.000000	1.000000	0	0
22	Georgia	CWS	25-500	GW	0.123473	0.123473	0	3
	Georgia	CWS	25-500	SW	0.075460	0.198932	0	5
	Georgia	CWS	501-3300	GW	0.216882	0.415814	5	3
	Georgia	CWS	501-3300	SW	0.076029	0.491843	2	1
	Georgia	CWS	3301-10000	GW	0.205910	0.697753	5	4
	Georgia	CWS	3301-10000	SW	0.233809	0.931562	5	4
	Georgia	NTNCWS	25-500	GW	0.014761	0.946323	0	1
	Georgia	NTNCWS	25-500	SW	0.016129	0.962453	0	1
	Georgia	NTNCWS	501-3300	GW	0.017752	0.980205	0	0
	Georgia	NTNCWS	501-3300	SW	0.017194	0.997399	0	0
	Georgia	NTNCWS	3301-10000	GW	0.002601	1.000000	0	0
	Georgia	NTNCWS	3301-10000	SW	0.000000	1.000000	0	0
1	Guam	CWS	25-500	GW	0.000000	0.000000	0	0
	Guam	CWS	25-500	SW	0.000000	0.000000	0	0
	Guam	CWS	501-3300	GW	0.000000	0.000000	0	0
	Guam	CWS	501-3300	SW	0.000000	0.000000	0	0
	Guam	CWS	3301-10000	GW	0.000000	0.000000	0	0
	Guam	CWS	3301-10000	SW	1.000000	1.000000	1	1
	Guam	NTNCWS	25-500	GW	0.000000	1.000000	0	0
	Guam	NTNCWS	25-500	SW	0.000000	1.000000	0	0
	Guam	NTNCWS	501-3300	GW	0.000000	1.000000	0	0

Appendix B. Probability of Selection, with Expected and Initial SMP Systems Selected for Assessment Monitoring

Total Number of Systems	State/Territory	System Type	System Size	Source Type	Probability	Cumulative Probability	Expected # of Systems	Actual # of Systems
	Guam	NTNCWS	501-3300	SW	0.000000	1.000000	0	0
	Guam	NTNCWS	3301-10000	GW	0.000000	1.000000	0	0
	Guam	NTNCWS	3301-10000	SW	0.000000	1.000000	0	0
3	Hawaii	CWS	25-500	GW	0.044055	0.044055	0	0
	Hawaii	CWS	25-500	SW	0.013192	0.057247	0	0
	Hawaii	CWS	501-3300	GW	0.348328	0.405574	1	1
	Hawaii	CWS	501-3300	SW	0.018984	0.424558	0	0
	Hawaii	CWS	3301-10000	GW	0.442170	0.866728	1	2
	Hawaii	CWS	3301-10000	SW	0.086899	0.953627	1	0
	Hawaii	NTNCWS	25-500	GW	0.029826	0.983453	0	0
	Hawaii	NTNCWS	25-500	SW	0.002279	0.985732	0	0
	Hawaii	NTNCWS	501-3300	GW	0.014268	1.000000	0	0
	Hawaii	NTNCWS	501-3300	SW	0.000000	1.000000	0	0
	Hawaii	NTNCWS	3301-10000	GW	0.000000	1.000000	0	0
	Hawaii	NTNCWS	3301-10000	SW	0.000000	1.000000	0	0
16	Iowa	CWS	25-500	GW	0.108789	0.108789	0	2
	Iowa	CWS	25-500	SW	0.009389	0.118178	0	1
	Iowa	CWS	501-3300	GW	0.421654	0.539832	7	9
	Iowa	CWS	501-3300	SW	0.022059	0.561891	1	3
	Iowa	CWS	3301-10000	GW	0.338653	0.900544	5	1
	Iowa	CWS	3301-10000	SW	0.061586	0.962131	1	0
	Iowa	NTNCWS	25-500	GW	0.016414	0.978545	0	0
	Iowa	NTNCWS	25-500	SW	0.003658	0.982203	0	0
	Iowa	NTNCWS	501-3300	GW	0.017797	1.000000	0	0
	Iowa	NTNCWS	501-3300	SW	0.000000	1.000000	0	0
	Iowa	NTNCWS	3301-10000	GW	0.000000	1.000000	0	0
	Iowa	NTNCWS	3301-10000	SW	0.000000	1.000000	0	0
8	Idaho	CWS	25-500	GW	0.124816	0.124816	0	1
	Idaho	CWS	25-500	SW	0.199402	0.324217	0	1
	Idaho	CWS	501-3300	GW	0.181250	0.505467	1	0
	Idaho	CWS	501-3300	SW	0.050444	0.555911	1	1
	Idaho	CWS	3301-10000	GW	0.245922	0.801833	2	5
	Idaho	CWS	3301-10000	SW	0.036241	0.838074	0	0
	Idaho	NTNCWS	25-500	GW	0.044504	0.882578	1	0
	Idaho	NTNCWS	25-500	SW	0.037115	0.919693	0	0
	Idaho	NTNCWS	501-3300	GW	0.042032	0.961725	0	0
	Idaho	NTNCWS	501-3300	SW	0.008380	0.970105	0	0

Appendix B. Probability of Selection, with Expected and Initial SMP Systems Selected for Assessment Monitoring

Total Number of Systems	State/Territory	System Type	System Size	Source Type	Probability	Cumulative Probability	Expected # of Systems	Actual # of Systems
	Idaho	NTNCWS	3301-10000	GW	0.029895	1.000000	0	0
	Idaho	NTNCWS	3301-10000	SW	0.000000	1.000000	0	0
28	Illinois	CWS	25-500	GW	0.072244	0.072244	0	0
	Illinois	CWS	25-500	SW	0.010088	0.082331	0	0
	Illinois	CWS	501-3300	GW	0.320482	0.402813	9	10
	Illinois	CWS	501-3300	SW	0.036115	0.438927	1	1
	Illinois	CWS	3301-10000	GW	0.360524	0.799451	10	15
	Illinois	CWS	3301-10000	SW	0.105342	0.904793	3	1
	Illinois	NTNCWS	25-500	GW	0.020272	0.925065	1	0
	Illinois	NTNCWS	25-500	SW	0.010566	0.935631	0	0
	Illinois	NTNCWS	501-3300	GW	0.020635	0.956266	1	1
	Illinois	NTNCWS	501-3300	SW	0.005094	0.961359	0	0
	Illinois	NTNCWS	3301-10000	GW	0.006049	0.967408	0	0
	Illinois	NTNCWS	3301-10000	SW	0.032592	1.000000	1	0
20	Indiana	CWS	25-500	GW	0.046374	0.046374	0	1
	Indiana	CWS	25-500	SW	0.001670	0.048044	0	0
	Indiana	CWS	501-3300	GW	0.292420	0.340464	6	2
	Indiana	CWS	501-3300	SW	0.015509	0.355973	0	0
	Indiana	CWS	3301-10000	GW	0.424877	0.780850	8	14
	Indiana	CWS	3301-10000	SW	0.076221	0.857071	2	1
	Indiana	NTNCWS	25-500	GW	0.063461	0.920532	2	1
	Indiana	NTNCWS	25-500	SW	0.021198	0.941730	0	0
	Indiana	NTNCWS	501-3300	GW	0.054268	0.995998	1	1
	Indiana	NTNCWS	501-3300	SW	0.004002	1.000000	0	0
	Indiana	NTNCWS	3301-10000	GW	0.000000	1.000000	0	0
	Indiana	NTNCWS	3301-10000	SW	0.000000	1.000000	0	0
12	Kansas	CWS	25-500	GW	0.079950	0.079950	0	2
	Kansas	CWS	25-500	SW	0.060355	0.140304	0	0
	Kansas	CWS	501-3300	GW	0.370682	0.510986	4	4
	Kansas	CWS	501-3300	SW	0.113083	0.624069	2	1
	Kansas	CWS	3301-10000	GW	0.174180	0.798249	2	4
	Kansas	CWS	3301-10000	SW	0.169657	0.967906	2	1
	Kansas	NTNCWS	25-500	GW	0.007580	0.975485	0	0
	Kansas	NTNCWS	25-500	SW	0.009514	0.984999	0	0
	Kansas	NTNCWS	501-3300	GW	0.015001	1.000000	0	0
	Kansas	NTNCWS	501-3300	SW	0.000000	1.000000	0	0
	Kansas	NTNCWS	3301-10000	GW	0.000000	1.000000	0	0

Appendix B. Probability of Selection, with Expected and Initial SMP Systems Selected for Assessment Monitoring

Total Number of Systems	State/Territory	System Type	System Size	Source Type	Probability	Cumulative Probability	Expected # of Systems	Actual # of Systems
	Kansas	NTNCWS	3301-10000	SW	0.000000	1.000000	0	0
9	Kentucky	CWS	25-500	GW	0.018156	0.018156	0	0
	Kentucky	CWS	25-500	SW	0.057626	0.075782	0	1
	Kentucky	CWS	501-3300	GW	0.088308	0.164090	1	0
	Kentucky	CWS	501-3300	SW	0.124368	0.288458	1	2
	Kentucky	CWS	3301-10000	GW	0.139996	0.428453	1	2
	Kentucky	CWS	3301-10000	SW	0.509989	0.938442	5	4
	Kentucky	NTNCWS	25-500	GW	0.008458	0.946900	0	0
	Kentucky	NTNCWS	25-500	SW	0.027535	0.974435	0	0
	Kentucky	NTNCWS	501-3300	GW	0.004291	0.978726	0	0
	Kentucky	NTNCWS	501-3300	SW	0.021274	1.000000	0	0
	Kentucky	NTNCWS	3301-10000	GW	0.000000	1.000000	0	0
	Kentucky	NTNCWS	3301-10000	SW	0.000000	1.000000	0	0
27	Louisiana	CWS	25-500	GW	0.070882	0.070882	0	3
	Louisiana	CWS	25-500	SW	0.013489	0.084371	0	1
	Louisiana	CWS	501-3300	GW	0.360128	0.444499	10	12
	Louisiana	CWS	501-3300	SW	0.018921	0.463420	1	0
	Louisiana	CWS	3301-10000	GW	0.414728	0.878148	11	6
	Louisiana	CWS	3301-10000	SW	0.058840	0.936988	2	1
	Louisiana	NTNCWS	25-500	GW	0.005874	0.942862	0	0
	Louisiana	NTNCWS	25-500	SW	0.013111	0.955973	0	0
	Louisiana	NTNCWS	501-3300	GW	0.013590	0.969562	0	0
	Louisiana	NTNCWS	501-3300	SW	0.005822	0.975385	0	0
	Louisiana	NTNCWS	3301-10000	GW	0.000000	0.975385	0	0
	Louisiana	NTNCWS	3301-10000	SW	0.024615	1.000000	1	4
12	Massachusetts	CWS	25-500	GW	0.030041	0.030041	0	0
	Massachusetts	CWS	25-500	SW	0.006699	0.036740	0	0
	Massachusetts	CWS	501-3300	GW	0.144887	0.181627	2	2
	Massachusetts	CWS	501-3300	SW	0.024759	0.206386	0	1
	Massachusetts	CWS	3301-10000	GW	0.603425	0.809810	7	7
	Massachusetts	CWS	3301-10000	SW	0.100924	0.910734	1	1
	Massachusetts	NTNCWS	25-500	GW	0.037313	0.948048	1	0
	Massachusetts	NTNCWS	25-500	SW	0.000000	0.948048	0	0
	Massachusetts	NTNCWS	501-3300	GW	0.048693	0.996741	1	1
	Massachusetts	NTNCWS	501-3300	SW	0.000000	0.996741	0	0
	Massachusetts	NTNCWS	3301-10000	GW	0.003259	1.000000	0	0
	Massachusetts	NTNCWS	3301-10000	SW	0.000000	1.000000	0	0

Appendix B. Probability of Selection, with Expected and Initial SMP Systems Selected for Assessment Monitoring

Total Number of Systems	State/Territory	System Type	System Size	Source Type	Probability	Cumulative Probability	Expected # of Systems	Actual # of Systems
8	Maryland	CWS	25-500	GW	0.098108	0.098108	0	1
	Maryland	CWS	25-500	SW	0.062991	0.161098	0	0
	Maryland	CWS	501-3300	GW	0.233629	0.394727	2	3
	Maryland	CWS	501-3300	SW	0.035363	0.430090	0	0
	Maryland	CWS	3301-10000	GW	0.163664	0.593754	1	0
	Maryland	CWS	3301-10000	SW	0.096850	0.690604	1	1
	Maryland	NTNCWS	25-500	GW	0.113191	0.803794	1	1
	Maryland	NTNCWS	25-500	SW	0.008687	0.812481	0	0
	Maryland	NTNCWS	501-3300	GW	0.174751	0.987232	1	0
	Maryland	NTNCWS	501-3300	SW	0.000000	0.987232	0	0
	Maryland	NTNCWS	3301-10000	GW	0.012768	1.000000	0	2
	Maryland	NTNCWS	3301-10000	SW	0.000000	1.000000	0	0
6	Maine	CWS	25-500	GW	0.080051	0.080051	0	0
	Maine	CWS	25-500	SW	0.080540	0.160591	1	1
	Maine	CWS	501-3300	GW	0.210100	0.370691	0	1
	Maine	CWS	501-3300	SW	0.133374	0.504065	1	0
	Maine	CWS	3301-10000	GW	0.125473	0.629538	1	0
	Maine	CWS	3301-10000	SW	0.149065	0.778603	1	1
	Maine	NTNCWS	25-500	GW	0.122935	0.901537	1	3
	Maine	NTNCWS	25-500	SW	0.058997	0.960535	0	0
	Maine	NTNCWS	501-3300	GW	0.027121	0.987656	0	0
	Maine	NTNCWS	501-3300	SW	0.012344	1.000000	0	0
	Maine	NTNCWS	3301-10000	GW	0.000000	1.000000	0	0
	Maine	NTNCWS	3301-10000	SW	0.000000	1.000000	0	0
24	Michigan	CWS	25-500	GW	0.088378	0.088378	0	2
	Michigan	CWS	25-500	SW	0.009233	0.097611	0	0
	Michigan	CWS	501-3300	GW	0.286533	0.384144	7	10
	Michigan	CWS	501-3300	SW	0.023687	0.407831	1	1
	Michigan	CWS	3301-10000	GW	0.256976	0.664808	6	5
	Michigan	CWS	3301-10000	SW	0.063746	0.728554	2	2
	Michigan	NTNCWS	25-500	GW	0.159639	0.888193	4	3
	Michigan	NTNCWS	25-500	SW	0.000000	0.888193	0	0
	Michigan	NTNCWS	501-3300	GW	0.096246	0.984439	2	1
	Michigan	NTNCWS	501-3300	SW	0.000000	0.984439	0	0
	Michigan	NTNCWS	3301-10000	GW	0.015561	1.000000	0	0
	Michigan	NTNCWS	3301-10000	SW	0.000000	1.000000	0	0
16	Minnesota	CWS	25-500	GW	0.097146	0.097146	0	2

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Total Number of Systems	State/Territory	System Type	System Size	Source Type	Probability	Cumulative Probability	Expected # of Systems	Actual # of Systems
	Minnesota	CWS	25-500	SW	0.002208	0.099353	0	0
	Minnesota	CWS	501-3300	GW	0.457793	0.557147	7	5
	Minnesota	CWS	501-3300	SW	0.010180	0.567327	0	0
	Minnesota	CWS	3301-10000	GW	0.324204	0.891531	5	7
	Minnesota	CWS	3301-10000	SW	0.058047	0.949578	1	0
	Minnesota	NTNCWS	25-500	GW	0.033979	0.983557	1	2
	Minnesota	NTNCWS	25-500	SW	0.001830	0.985387	0	0
	Minnesota	NTNCWS	501-3300	GW	0.005726	0.991113	0	0
	Minnesota	NTNCWS	501-3300	SW	0.008887	1.000000	0	0
	Minnesota	NTNCWS	3301-10000	GW	0.000000	1.000000	0	0
	Minnesota	NTNCWS	3301-10000	SW	0.000000	1.000000	0	0
20	Missouri	CWS	25-500	GW	0.089997	0.089997	0	3
	Missouri	CWS	25-500	SW	0.047255	0.137252	0	0
	Missouri	CWS	501-3300	GW	0.307287	0.444539	6	7
	Missouri	CWS	501-3300	SW	0.046065	0.490604	1	0
	Missouri	CWS	3301-10000	GW	0.331344	0.821948	7	5
	Missouri	CWS	3301-10000	SW	0.109887	0.931835	2	3
	Missouri	NTNCWS	25-500	GW	0.012704	0.944539	0	2
	Missouri	NTNCWS	25-500	SW	0.021993	0.966532	0	0
	Missouri	NTNCWS	501-3300	GW	0.030450	0.996982	1	0
	Missouri	NTNCWS	501-3300	SW	0.000000	0.996982	0	0
	Missouri	NTNCWS	3301-10000	GW	0.003018	1.000000	0	0
	Missouri	NTNCWS	3301-10000	SW	0.000000	1.000000	0	0
2	Marianna Islands	CWS	25-500	GW	0.424375	0.424375	0	1
	Marianna Islands	CWS	25-500	SW	0.000000	0.424375	0	0
	Marianna Islands	CWS	501-3300	GW	0.575625	1.000000	1	1
	Marianna Islands	CWS	501-3300	SW	0.000000	1.000000	0	0
	Marianna Islands	CWS	3301-10000	GW	0.000000	1.000000	0	0
	Marianna Islands	CWS	3301-10000	SW	0.000000	1.000000	0	0
	Marianna Islands	NTNCWS	25-500	GW	0.000000	1.000000	0	0
	Marianna Islands	NTNCWS	25-500	SW	0.000000	1.000000	0	0

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Total Number of Systems	State/Territory	System Type	System Size	Source Type	Probability	Cumulative Probability	Expected # of Systems	Actual # of Systems
	Marianna Islands	NTNCWS	501-3300	GW	0.000000	1.000000	0	0
	Marianna Islands	NTNCWS	501-3300	SW	0.000000	1.000000	0	0
	Marianna Islands	NTNCWS	3301-10000	GW	0.000000	1.000000	0	0
	Marianna Islands	NTNCWS	3301-10000	SW	0.000000	1.000000	0	0
30	Mississippi	CWS	25-500	GW	0.054848	0.054848	0	2
	Mississippi	CWS	25-500	SW	0.000395	0.055243	0	0
	Mississippi	CWS	501-3300	GW	0.536246	0.591489	16	20
	Mississippi	CWS	501-3300	SW	0.000000	0.591489	0	0
	Mississippi	CWS	3301-10000	GW	0.355742	0.947231	11	6
	Mississippi	CWS	3301-10000	SW	0.000000	0.947231	0	0
	Mississippi	NTNCWS	25-500	GW	0.010244	0.957475	0	0
	Mississippi	NTNCWS	25-500	SW	0.000000	0.957475	0	0
	Mississippi	NTNCWS	501-3300	GW	0.025558	0.983032	1	2
	Mississippi	NTNCWS	501-3300	SW	0.000000	0.983032	0	0
	Mississippi	NTNCWS	3301-10000	GW	0.016968	1.000000	0	0
	Mississippi	NTNCWS	3301-10000	SW	0.000000	1.000000	0	0
6	Montana	CWS	25-500	GW	0.176760	0.176760	0	1
	Montana	CWS	25-500	SW	0.109912	0.286672	0	1
	Montana	CWS	501-3300	GW	0.225216	0.511888	1	1
	Montana	CWS	501-3300	SW	0.081293	0.593181	0	0
	Montana	CWS	3301-10000	GW	0.147776	0.740957	1	1
	Montana	CWS	3301-10000	SW	0.146475	0.887433	1	1
	Montana	NTNCWS	25-500	GW	0.059815	0.947248	1	0
	Montana	NTNCWS	25-500	SW	0.024406	0.971654	0	0
	Montana	NTNCWS	501-3300	GW	0.028346	1.000000	0	1
	Montana	NTNCWS	501-3300	SW	0.000000	1.000000	0	0
	Montana	NTNCWS	3301-10000	GW	0.000000	1.000000	0	0
	Montana	NTNCWS	3301-10000	SW	0.000000	1.000000	0	0
22	North Carolina	CWS	25-500	GW	0.156723	0.156723	4	3
	North Carolina	CWS	25-500	SW	0.045023	0.201746	0	1
	North Carolina	CWS	501-3300	GW	0.195084	0.396830	4	2
	North Carolina	CWS	501-3300	SW	0.052233	0.449063	1	2
	North Carolina	CWS	3301-10000	GW	0.227239	0.676301	5	6
	North Carolina	CWS	3301-10000	SW	0.163587	0.839889	4	6
	North Carolina	NTNCWS	25-500	GW	0.061479	0.901368	1	0

Appendix B. Probability of Selection, with Expected and Initial SMP Systems Selected for Assessment Monitoring

Total Number of Systems	State/Territory	System Type	System Size	Source Type	Probability	Cumulative Probability	Expected # of Systems	Actual # of Systems
	North Carolina	NTNCWS	25-500	SW	0.009916	0.911284	0	1
	North Carolina	NTNCWS	501-3300	GW	0.066654	0.977938	1	0
	North Carolina	NTNCWS	501-3300	SW	0.020225	0.998163	1	1
	North Carolina	NTNCWS	3301-10000	GW	0.001837	1.000000	0	0
	North Carolina	NTNCWS	3301-10000	SW	0.000000	1.000000	0	0
4	North Dakota	CWS	25-500	GW	0.107831	0.107831	1	0
	North Dakota	CWS	25-500	SW	0.014230	0.122061	0	1
	North Dakota	CWS	501-3300	GW	0.511024	0.633085	2	3
	North Dakota	CWS	501-3300	SW	0.049591	0.682676	0	0
	North Dakota	CWS	3301-10000	GW	0.220790	0.903466	1	0
	North Dakota	CWS	3301-10000	SW	0.079568	0.983034	0	0
	North Dakota	NTNCWS	25-500	GW	0.001980	0.985014	0	0
	North Dakota	NTNCWS	25-500	SW	0.014986	1.000000	0	0
	North Dakota	NTNCWS	501-3300	GW	0.000000	1.000000	0	0
	North Dakota	NTNCWS	501-3300	SW	0.000000	1.000000	0	0
	North Dakota	NTNCWS	3301-10000	GW	0.000000	1.000000	0	0
	North Dakota	NTNCWS	3301-10000	SW	0.000000	1.000000	0	0
8	Nebraska	CWS	25-500	GW	0.152090	0.152090	0	1
	Nebraska	CWS	25-500	SW	0.000000	0.152090	0	0
	Nebraska	CWS	501-3300	GW	0.426111	0.578202	3	3
	Nebraska	CWS	501-3300	SW	0.014720	0.592922	0	0
	Nebraska	CWS	3301-10000	GW	0.307693	0.900615	3	3
	Nebraska	CWS	3301-10000	SW	0.044192	0.944807	1	0
	Nebraska	NTNCWS	25-500	GW	0.024216	0.969023	0	1
	Nebraska	NTNCWS	25-500	SW	0.000000	0.969023	0	0
	Nebraska	NTNCWS	501-3300	GW	0.016591	0.985614	0	0
	Nebraska	NTNCWS	501-3300	SW	0.000000	0.985614	0	0
	Nebraska	NTNCWS	3301-10000	GW	0.014386	1.000000	0	0
	Nebraska	NTNCWS	3301-10000	SW	0.000000	1.000000	0	0
6	New Hampshire	CWS	25-500	GW	0.179653	0.179653	0	1
	New Hampshire	CWS	25-500	SW	0.059689	0.239342	0	0
	New Hampshire	CWS	501-3300	GW	0.211377	0.450719	1	1
	New Hampshire	CWS	501-3300	SW	0.082279	0.532998	0	2
	New Hampshire	CWS	3301-10000	GW	0.100470	0.633468	1	1

Appendix B. Probability of Selection, with Expected and Initial SMP Systems Selected for Assessment Monitoring

Total Number of Systems	State/Territory	System Type	System Size	Source Type	Probability	Cumulative Probability	Expected # of Systems	Actual # of Systems
	New Hampshire	CWS	3301-10000	SW	0.134734	0.768202	1	0
	New Hampshire	NTNCWS	25-500	GW	0.129265	0.897467	1	0
	New Hampshire	NTNCWS	25-500	SW	0.000000	0.897467	0	0
	New Hampshire	NTNCWS	501-3300	GW	0.102533	1.000000	1	1
	New Hampshire	NTNCWS	501-3300	SW	0.000000	1.000000	0	0
	New Hampshire	NTNCWS	3301-10000	GW	0.000000	1.000000	0	0
	New Hampshire	NTNCWS	3301-10000	SW	0.000000	1.000000	0	0
16	New Jersey	CWS	25-500	GW	0.041427	0.041427	0	1
	New Jersey	CWS	25-500	SW	0.000000	0.041427	0	0
	New Jersey	CWS	501-3300	GW	0.180334	0.221761	3	4
	New Jersey	CWS	501-3300	SW	0.006606	0.228367	0	0
	New Jersey	CWS	3301-10000	GW	0.435798	0.664165	7	7
	New Jersey	CWS	3301-10000	SW	0.043850	0.708015	1	2
	New Jersey	NTNCWS	25-500	GW	0.105685	0.813700	2	2
	New Jersey	NTNCWS	25-500	SW	0.001010	0.814710	0	0
	New Jersey	NTNCWS	501-3300	GW	0.140774	0.955484	2	0
	New Jersey	NTNCWS	501-3300	SW	0.018795	0.974279	0	0
	New Jersey	NTNCWS	3301-10000	GW	0.025721	1.000000	0	0
	New Jersey	NTNCWS	3301-10000	SW	0.000000	1.000000	0	0
8	New Mexico	CWS	25-500	GW	0.147242	0.147242	0	1
	New Mexico	CWS	25-500	SW	0.069756	0.216998	0	2
	New Mexico	CWS	501-3300	GW	0.268916	0.485914	2	3
	New Mexico	CWS	501-3300	SW	0.044185	0.530099	1	0
	New Mexico	CWS	3301-10000	GW	0.310844	0.840944	2	0
	New Mexico	CWS	3301-10000	SW	0.077038	0.917981	1	0
	New Mexico	NTNCWS	25-500	GW	0.020732	0.938713	0	0
	New Mexico	NTNCWS	25-500	SW	0.024464	0.963178	0	0
	New Mexico	NTNCWS	501-3300	GW	0.031415	0.994593	0	2
	New Mexico	NTNCWS	501-3300	SW	0.005407	1.000000	0	0
	New Mexico	NTNCWS	3301-10000	GW	0.000000	1.000000	0	0
	New Mexico	NTNCWS	3301-10000	SW	0.000000	1.000000	0	0
4	Nevada	CWS	25-500	GW	0.096624	0.096624	1	0
	Nevada	CWS	25-500	SW	0.061023	0.157648	0	0

Appendix B. Probability of Selection, with Expected and Initial SMP Systems Selected for Assessment Monitoring

Total Number of Systems	State/Territory	System Type	System Size	Source Type	Probability	Cumulative Probability	Expected # of Systems	Actual # of Systems
	Nevada	CWS	501-3300	GW	0.316982	0.474630	1	3
	Nevada	CWS	501-3300	SW	0.025688	0.500317	0	0
	Nevada	CWS	3301-10000	GW	0.301061	0.801378	1	0
	Nevada	CWS	3301-10000	SW	0.064865	0.866243	1	0
	Nevada	NTNCWS	25-500	GW	0.030812	0.897055	0	0
	Nevada	NTNCWS	25-500	SW	0.028647	0.925702	0	1
	Nevada	NTNCWS	501-3300	GW	0.032687	0.958389	0	0
	Nevada	NTNCWS	501-3300	SW	0.011499	0.969888	0	0
	Nevada	NTNCWS	3301-10000	GW	0.030112	1.000000	0	0
	Nevada	NTNCWS	3301-10000	SW	0.000000	1.000000	0	0
29	New York	CWS	25-500	GW	0.105270	0.105270	0	1
	New York	CWS	25-500	SW	0.119826	0.225096	0	1
	New York	CWS	501-3300	GW	0.212439	0.437535	6	8
	New York	CWS	501-3300	SW	0.099139	0.536674	3	1
	New York	CWS	3301-10000	GW	0.128412	0.665086	4	4
	New York	CWS	3301-10000	SW	0.182485	0.847570	5	6
	New York	NTNCWS	25-500	GW	0.025672	0.873242	1	4
	New York	NTNCWS	25-500	SW	0.012511	0.885754	1	0
	New York	NTNCWS	501-3300	GW	0.039152	0.924905	1	2
	New York	NTNCWS	501-3300	SW	0.013069	0.937975	0	0
	New York	NTNCWS	3301-10000	GW	0.007687	0.945661	0	0
	New York	NTNCWS	3301-10000	SW	0.054339	1.000000	2	2
28	Ohio	CWS	25-500	GW	0.060154	0.060154	0	1
	Ohio	CWS	25-500	SW	0.021562	0.081715	0	0
	Ohio	CWS	501-3300	GW	0.247273	0.328989	0	6
	Ohio	CWS	501-3300	SW	0.045966	0.374955	1	0
	Ohio	CWS	3301-10000	GW	0.308339	0.683294	9	12
	Ohio	CWS	3301-10000	SW	0.141144	0.824438	4	4
	Ohio	NTNCWS	25-500	GW	0.071715	0.896153	2	2
	Ohio	NTNCWS	25-500	SW	0.004899	0.901052	0	0
	Ohio	NTNCWS	501-3300	GW	0.056505	0.957557	2	1
	Ohio	NTNCWS	501-3300	SW	0.035977	0.993534	1	0
	Ohio	NTNCWS	3301-10000	GW	0.006466	1.000000	0	2
	Ohio	NTNCWS	3301-10000	SW	0.000000	1.000000	0	0
15	Oklahoma	CWS	25-500	GW	0.053578	0.053578	0	3
	Oklahoma	CWS	25-500	SW	0.129226	0.182804	0	0
	Oklahoma	CWS	501-3300	GW	0.235046	0.417850	3	1

Appendix B. Probability of Selection, with Expected and Initial SMP Systems Selected for Assessment Monitoring

Total Number of Systems	State/Territory	System Type	System Size	Source Type	Probability	Cumulative Probability	Expected # of Systems	Actual # of Systems
	Oklahoma	CWS	501-3300	SW	0.135236	0.553087	2	2
	Oklahoma	CWS	3301-10000	GW	0.110855	0.663942	2	3
	Oklahoma	CWS	3301-10000	SW	0.310569	0.974511	5	6
	Oklahoma	NTNCWS	25-500	GW	0.004712	0.979223	0	0
	Oklahoma	NTNCWS	25-500	SW	0.016061	0.995284	0	0
	Oklahoma	NTNCWS	501-3300	GW	0.000876	0.996160	0	0
	Oklahoma	NTNCWS	501-3300	SW	0.000000	0.996160	0	0
	Oklahoma	NTNCWS	3301-10000	GW	0.003840	1.000000	0	0
	Oklahoma	NTNCWS	3301-10000	SW	0.000000	1.000000	0	0
11	Oregon	CWS	25-500	GW	0.105427	0.105427	0	0
	Oregon	CWS	25-500	SW	0.124548	0.229975	0	1
	Oregon	CWS	501-3300	GW	0.189055	0.419030	2	3
	Oregon	CWS	501-3300	SW	0.126690	0.545720	2	1
	Oregon	CWS	3301-10000	GW	0.136664	0.682384	2	1
	Oregon	CWS	3301-10000	SW	0.194845	0.877229	2	3
	Oregon	NTNCWS	25-500	GW	0.057707	0.934936	1	2
	Oregon	NTNCWS	25-500	SW	0.012444	0.947380	0	0
	Oregon	NTNCWS	501-3300	GW	0.025242	0.972622	0	0
	Oregon	NTNCWS	501-3300	SW	0.027378	1.000000	0	0
	Oregon	NTNCWS	3301-10000	GW	0.000000	1.000000	0	0
	Oregon	NTNCWS	3301-10000	SW	0.000000	1.000000	0	0
37	Pennsylvania	CWS	25-500	GW	0.090515	0.090515	0	4
	Pennsylvania	CWS	25-500	SW	0.064085	0.154600	1	3
	Pennsylvania	CWS	501-3300	GW	0.200824	0.355424	8	4
	Pennsylvania	CWS	501-3300	SW	0.064166	0.419591	0	3
	Pennsylvania	CWS	3301-10000	GW	0.183790	0.603380	7	4
	Pennsylvania	CWS	3301-10000	SW	0.172501	0.775881	6	8
	Pennsylvania	NTNCWS	25-500	GW	0.082633	0.858514	3	5
	Pennsylvania	NTNCWS	25-500	SW	0.023604	0.882118	1	1
	Pennsylvania	NTNCWS	501-3300	GW	0.080900	0.963018	3	4
	Pennsylvania	NTNCWS	501-3300	SW	0.029903	0.992921	1	1
	Pennsylvania	NTNCWS	3301-10000	GW	0.007079	1.000000	0	0
	Pennsylvania	NTNCWS	3301-10000	SW	0.000000	1.000000	0	0
9	Puerto Rico	CWS	25-500	GW	0.030068	0.030068	0	0
	Puerto Rico	CWS	25-500	SW	0.367728	0.397797	0	2
	Puerto Rico	CWS	501-3300	GW	0.096501	0.494298	1	0
	Puerto Rico	CWS	501-3300	SW	0.126482	0.620780	1	1

Appendix B. Probability of Selection, with Expected and Initial SMP Systems Selected for Assessment Monitoring

Total Number of Systems	State/Territory	System Type	System Size	Source Type	Probability	Cumulative Probability	Expected # of Systems	Actual # of Systems
	Puerto Rico	CWS	3301-10000	GW	0.163618	0.784398	2	3
	Puerto Rico	CWS	3301-10000	SW	0.140299	0.924697	1	2
	Puerto Rico	NTNCWS	25-500	GW	0.002643	0.927340	0	0
	Puerto Rico	NTNCWS	25-500	SW	0.013930	0.941269	0	0
	Puerto Rico	NTNCWS	501-3300	GW	0.034820	0.976089	1	1
	Puerto Rico	NTNCWS	501-3300	SW	0.000000	0.976089	0	0
	Puerto Rico	NTNCWS	3301-10000	GW	0.023911	1.000000	0	0
	Puerto Rico	NTNCWS	3301-10000	SW	0.000000	1.000000	0	0
2	Rhode Island	CWS	25-500	GW	0.102141	0.102141	0	0
	Rhode Island	CWS	25-500	SW	0.000000	0.102141	0	0
	Rhode Island	CWS	501-3300	GW	0.119044	0.221185	0	1
	Rhode Island	CWS	501-3300	SW	0.075209	0.296394	0	0
	Rhode Island	CWS	3301-10000	GW	0.166570	0.462964	1	1
	Rhode Island	CWS	3301-10000	SW	0.151757	0.614721	1	0
	Rhode Island	NTNCWS	25-500	GW	0.139146	0.753868	0	0
	Rhode Island	NTNCWS	25-500	SW	0.000000	0.753868	0	0
	Rhode Island	NTNCWS	501-3300	GW	0.144328	0.898196	0	0
	Rhode Island	NTNCWS	501-3300	SW	0.000000	0.898196	0	0
	Rhode Island	NTNCWS	3301-10000	GW	0.101804	1.000000	0	0
	Rhode Island	NTNCWS	3301-10000	SW	0.000000	1.000000	0	0
11	South Carolina	CWS	25-500	GW	0.074769	0.074769	0	0
	South Carolina	CWS	25-500	SW	0.000000	0.074769	0	0
	South Carolina	CWS	501-3300	GW	0.219103	0.293873	2	3
	South Carolina	CWS	501-3300	SW	0.054199	0.348072	1	0
	South Carolina	CWS	3301-10000	GW	0.272259	0.620330	3	0
	South Carolina	CWS	3301-10000	SW	0.277753	0.898083	3	6
	South Carolina	NTNCWS	25-500	GW	0.012816	0.910900	0	0
	South Carolina	NTNCWS	25-500	SW	0.005474	0.916373	0	1
	South Carolina	NTNCWS	501-3300	GW	0.011296	0.927669	0	0
	South Carolina	NTNCWS	501-3300	SW	0.015615	0.943284	0	1
	South Carolina	NTNCWS	3301-10000	GW	0.000000	0.943284	0	0
	South Carolina	NTNCWS	3301-10000	SW	0.056716	1.000000	1	0
4	South Dakota	CWS	25-500	GW	0.123446	0.123446	1	0
	South Dakota	CWS	25-500	SW	0.114364	0.237810	1	1
	South Dakota	CWS	501-3300	GW	0.336164	0.573974	0	2
	South Dakota	CWS	501-3300	SW	0.065505	0.639479	0	0
	South Dakota	CWS	3301-10000	GW	0.271831	0.911310	1	1

Appendix B. Probability of Selection, with Expected and Initial SMP Systems Selected for Assessment Monitoring

Total Number of Systems	State/Territory	System Type	System Size	Source Type	Probability	Cumulative Probability	Expected # of Systems	Actual # of Systems
	South Dakota	CWS	3301-10000	SW	0.067799	0.979109	0	0
	South Dakota	NTNCWS	25-500	GW	0.003200	0.982309	0	0
	South Dakota	NTNCWS	25-500	SW	0.016996	0.999305	0	0
	South Dakota	NTNCWS	501-3300	GW	0.000695	1.000000	0	0
	South Dakota	NTNCWS	501-3300	SW	0.000000	1.000000	0	0
	South Dakota	NTNCWS	3301-10000	GW	0.000000	1.000000	0	0
	South Dakota	NTNCWS	3301-10000	SW	0.000000	1.000000	0	0
14	Tennessee	CWS	25-500	GW	0.010921	0.010921	0	0
	Tennessee	CWS	25-500	SW	0.039598	0.050519	0	2
	Tennessee	CWS	501-3300	GW	0.132222	0.182741	2	2
	Tennessee	CWS	501-3300	SW	0.091572	0.274314	2	0
	Tennessee	CWS	3301-10000	GW	0.172997	0.447311	2	0
	Tennessee	CWS	3301-10000	SW	0.527512	0.974823	7	10
	Tennessee	NTNCWS	25-500	GW	0.001157	0.975979	0	0
	Tennessee	NTNCWS	25-500	SW	0.004805	0.980785	0	0
	Tennessee	NTNCWS	501-3300	GW	0.000531	0.981316	0	0
	Tennessee	NTNCWS	501-3300	SW	0.018684	1.000000	0	0
	Tennessee	NTNCWS	3301-10000	GW	0.000000	1.000000	0	0
	Tennessee	NTNCWS	3301-10000	SW	0.000000	1.000000	0	0
7	Tribes	CWS	25-500	GW	0.202971	0.202971	2	2
	Tribes	CWS	25-500	SW	0.147933	0.350904	0	2
	Tribes	CWS	501-3300	GW	0.338683	0.689587	2	1
	Tribes	CWS	501-3300	SW	0.046713	0.736299	0	0
	Tribes	CWS	3301-10000	GW	0.170082	0.906381	1	0
	Tribes	CWS	3301-10000	SW	0.055832	0.962213	1	1
	Tribes	NTNCWS	25-500	GW	0.017954	0.980167	0	0
	Tribes	NTNCWS	25-500	SW	0.000000	0.980167	0	0
	Tribes	NTNCWS	501-3300	GW	0.019833	1.000000	0	1
	Tribes	NTNCWS	501-3300	SW	0.000000	1.000000	0	0
	Tribes	NTNCWS	3301-10000	GW	0.000000	1.000000	0	0
	Tribes	NTNCWS	3301-10000	SW	0.000000	1.000000	0	0
71	Texas	CWS	25-500	GW	0.080530	0.080530	0	8
	Texas	CWS	25-500	SW	0.032271	0.112801	0	3
	Texas	CWS	501-3300	GW	0.336133	0.448935	24	19
	Texas	CWS	501-3300	SW	0.034461	0.483395	2	0
	Texas	CWS	3301-10000	GW	0.346726	0.830121	25	29
	Texas	CWS	3301-10000	SW	0.102709	0.932830	7	4

Appendix B. Probability of Selection, with Expected and Initial SMP Systems Selected for Assessment Monitoring

Total Number of Systems	State/Territory	System Type	System Size	Source Type	Probability	Cumulative Probability	Expected # of Systems	Actual # of Systems
	Texas	NTNCWS	25-500	GW	0.009594	0.942424	1	1
	Texas	NTNCWS	25-500	SW	0.011363	0.953787	1	1
	Texas	NTNCWS	501-3300	GW	0.012236	0.966023	1	2
	Texas	NTNCWS	501-3300	SW	0.013273	0.979297	1	1
	Texas	NTNCWS	3301-10000	GW	0.004174	0.983471	0	0
	Texas	NTNCWS	3301-10000	SW	0.016529	1.000000	1	3
7	Utah	CWS	25-500	GW	0.097464	0.097464	0	0
	Utah	CWS	25-500	SW	0.089084	0.186548	0	1
	Utah	CWS	501-3300	GW	0.292421	0.478969	2	2
	Utah	CWS	501-3300	SW	0.042900	0.521869	0	0
	Utah	CWS	3301-10000	GW	0.322360	0.844229	2	2
	Utah	CWS	3301-10000	SW	0.100653	0.944882	1	2
	Utah	NTNCWS	25-500	GW	0.011787	0.956669	0	0
	Utah	NTNCWS	25-500	SW	0.011496	0.968165	0	0
	Utah	NTNCWS	501-3300	GW	0.011412	0.979577	0	0
	Utah	NTNCWS	501-3300	SW	0.000000	0.979577	0	0
	Utah	NTNCWS	3301-10000	GW	0.020423	1.000000	0	0
	Utah	NTNCWS	3301-10000	SW	0.000000	1.000000	0	0
16	Virginia	CWS	25-500	GW	0.110551	0.110551	0	4
	Virginia	CWS	25-500	SW	0.098994	0.209545	0	1
	Virginia	CWS	501-3300	GW	0.126866	0.336411	2	5
	Virginia	CWS	501-3300	SW	0.084950	0.421361	1	0
	Virginia	CWS	3301-10000	GW	0.056914	0.478275	1	0
	Virginia	CWS	3301-10000	SW	0.209323	0.687598	3	2
	Virginia	NTNCWS	25-500	GW	0.088632	0.776230	2	1
	Virginia	NTNCWS	25-500	SW	0.018261	0.794490	0	0
	Virginia	NTNCWS	501-3300	GW	0.139405	0.933895	2	0
	Virginia	NTNCWS	501-3300	SW	0.052778	0.986673	1	3
	Virginia	NTNCWS	3301-10000	GW	0.013327	1.000000	0	0
	Virginia	NTNCWS	3301-10000	SW	0.000000	1.000000	0	0
2	Virgin Islands	CWS	25-500	GW	0.000000	0.000000	0	0
	Virgin Islands	CWS	25-500	SW	0.203449	0.203449	0	1
	Virgin Islands	CWS	501-3300	GW	0.000000	0.203449	0	0
	Virgin Islands	CWS	501-3300	SW	0.009623	0.213072	0	0
	Virgin Islands	CWS	3301-10000	GW	0.000000	0.213072	0	0
	Virgin Islands	CWS	3301-10000	SW	0.007027	0.220099	0	0
	Virgin Islands	NTNCWS	25-500	GW	0.000000	0.220099	0	0

Appendix B. Probability of Selection, with Expected and Initial SMP Systems Selected for Assessment Monitoring

Total Number of Systems	State/Territory	System Type	System Size	Source Type	Probability	Cumulative Probability	Expected # of Systems	Actual # of Systems
	Virgin Islands	NTNCWS	25-500	SW	0.298099	0.518198	1	1
	Virgin Islands	NTNCWS	501-3300	GW	0.000000	0.518198	0	0
	Virgin Islands	NTNCWS	501-3300	SW	0.189741	0.707939	0	0
	Virgin Islands	NTNCWS	3301-10000	GW	0.000000	0.707939	0	0
	Virgin Islands	NTNCWS	3301-10000	SW	0.292061	1.000000	1	0
4	Vermont	CWS	25-500	GW	0.151019	0.151019	0	1
	Vermont	CWS	25-500	SW	0.168637	0.319656	0	0
	Vermont	CWS	501-3300	GW	0.228719	0.548375	1	2
	Vermont	CWS	501-3300	SW	0.150632	0.699007	0	0
	Vermont	CWS	3301-10000	GW	0.144298	0.843305	0	0
	Vermont	CWS	3301-10000	SW	0.156398	0.999702	1	1
	Vermont	NTNCWS	25-500	GW	0.000298	1.000000	0	0
	Vermont	NTNCWS	25-500	SW	0.000000	1.000000	0	0
	Vermont	NTNCWS	501-3300	GW	0.000000	1.000000	0	0
	Vermont	NTNCWS	501-3300	SW	0.000000	1.000000	0	0
	Vermont	NTNCWS	3301-10000	GW	0.000000	1.000000	0	0
	Vermont	NTNCWS	3301-10000	SW	0.000000	1.000000	0	0
17	Washington	CWS	25-500	GW	0.199296	0.199296	4	4
	Washington	CWS	25-500	SW	0.063516	0.262812	0	1
	Washington	CWS	501-3300	GW	0.307767	0.570579	5	4
	Washington	CWS	501-3300	SW	0.048778	0.619357	1	1
	Washington	CWS	3301-10000	GW	0.252023	0.871380	4	4
	Washington	CWS	3301-10000	SW	0.047768	0.919148	1	0
	Washington	NTNCWS	25-500	GW	0.015331	0.934479	0	0
	Washington	NTNCWS	25-500	SW	0.018754	0.953233	0	0
	Washington	NTNCWS	501-3300	GW	0.014947	0.968180	0	1
	Washington	NTNCWS	501-3300	SW	0.031820	1.000000	1	2
	Washington	NTNCWS	3301-10000	GW	0.000000	1.000000	0	0
	Washington	NTNCWS	3301-10000	SW	0.000000	1.000000	0.0	0
21	Wisconsin	CWS	25-500	GW	0.080289	0.080289	0	0
	Wisconsin	CWS	25-500	SW	0.000000	0.080289	0	0
	Wisconsin	CWS	501-3300	GW	0.325307	0.405597	7	8
	Wisconsin	CWS	501-3300	SW	0.001226	0.406822	0	0
	Wisconsin	CWS	3301-10000	GW	0.413393	0.820215	9	11
	Wisconsin	CWS	3301-10000	SW	0.007789	0.828004	0	0
	Wisconsin	NTNCWS	25-500	GW	0.105799	0.933804	2	2
	Wisconsin	NTNCWS	25-500	SW	0.000000	0.933804	0	0

Appendix B. Probability of Selection, with Expected and Initial SMP Systems Selected for Assessment Monitoring

Total Number of Systems	State/Territory	System Type	System Size	Source Type	Probability	Cumulative Probability	Expected # of Systems	Actual # of Systems
	Wisconsin	NTNCWS	501-3300	GW	0.066196	1.000000	1	0
	Wisconsin	NTNCWS	501-3300	SW	0.000000	1.000000	0	0
	Wisconsin	NTNCWS	3301-10000	GW	0.000000	1.000000	0	0
	Wisconsin	NTNCWS	3301-10000	SW	0.000000	1.000000	0	0
10	West Virginia	CWS	25-500	GW	0.049667	0.049667	0	0
	West Virginia	CWS	25-500	SW	0.061836	0.111503	0	0
	West Virginia	CWS	501-3300	GW	0.154994	0.266497	2	0
	West Virginia	CWS	501-3300	SW	0.232457	0.498954	2	5
	West Virginia	CWS	3301-10000	GW	0.083186	0.582140	1	0
	West Virginia	CWS	3301-10000	SW	0.328074	0.910214	3	4
	West Virginia	NTNCWS	25-500	GW	0.011075	0.921289	0	0
	West Virginia	NTNCWS	25-500	SW	0.010705	0.931994	0	0
	West Virginia	NTNCWS	501-3300	GW	0.003917	0.935911	0	0
	West Virginia	NTNCWS	501-3300	SW	0.009707	0.945618	0	1
	West Virginia	NTNCWS	3301-10000	GW	0.000000	0.945618	0	0
	West Virginia	NTNCWS	3301-10000	SW	0.054382	1.000000	1	0
3	Wyoming	CWS	25-500	GW	0.125408	0.125408	0	0
	Wyoming	CWS	25-500	SW	0.187899	0.313306	0	1
	Wyoming	CWS	501-3300	GW	0.145051	0.458358	1	1
	Wyoming	CWS	501-3300	SW	0.105977	0.564335	0	0
	Wyoming	CWS	3301-10000	GW	0.087057	0.651392	0	0
	Wyoming	CWS	3301-10000	SW	0.228394	0.879786	1	0
	Wyoming	NTNCWS	25-500	GW	0.008824	0.888609	0	0
	Wyoming	NTNCWS	25-500	SW	0.091474	0.980084	0	1
	Wyoming	NTNCWS	501-3300	GW	0.003474	0.983557	0	0
	Wyoming	NTNCWS	501-3300	SW	0.016443	1.000000	0	0
	Wyoming	NTNCWS	3301-10000	GW	0.000000	1.000000	0	0
	Wyoming	NTNCWS	3301-10000	SW	0.000000	1.000000	0	0

Appendix C

Acronyms

CCL	- Contaminant Candidate List
CFR	- Code of Federal Regulations
CWS	- community water system
EPA	- Environmental Protection Agency
EPTDS	- Entry Point to the Distribution System
GW	- ground water
GUDI	- ground water under the direct influence (of surface water)
NAWQA	- National Water Quality Assessment Program
NCOD	- National Drinking Water Contaminant Occurrence Database
NTNCWS	- non-transient non-community water system
PA	- Partnership agreement
PWS	- Public Water System
SDWA	- Safe Drinking Water Act
SDWIS	- Safe Drinking Water Information System
SDWIS FED	- the Federal Safe Drinking Water Information System
SMP	- State monitoring plan
SW	- surface water
TNCWS	- transient non-community water system
UCMR	- Unregulated Contaminant Monitoring Regulation/Rule
USEPA	- United States Environmental Protection Agency

Appendix D

Definitions

Assessment Monitoring means sampling, testing, and reporting of listed contaminants that have available analytical methods and for which preliminary data indicate their possible occurrence in drinking water. Assessment Monitoring will be conducted for the UCMR (1999) List 1 contaminants.

Index Systems means a limited number of small CWSs and NTNCWSs, selected from the Assessment Monitoring systems in State Plans, that will be required to provide more detailed and frequent monitoring for the UCMR (1999) List 1 contaminants (§141.40(a)(6)). The Index Systems will be selected to geographically coincide with watersheds and areas studied under the United States Geological Survey's National Water Quality Assessment program. In addition to the reporting information required for Assessment Monitoring, the Index Systems must also report information on system operating conditions (such as water source, pumping rates, and environmental setting) (§141.40(a)(6)). These systems must monitor each year of the 5-year UCMR cycle, with EPA paying for all reasonable monitoring costs (§141.40(a)(4)(i)(A)). This more detailed and frequent monitoring will provide important information with which EPA can more fully evaluate the conditions under which small systems operate.

Listed contaminant means a contaminant identified as an analyte in Table 1, 141.40(a)(3) of the Unregulated Contaminant Monitoring Regulation (UCMR). To distinguish the current 1999 UCMR listed contaminants from potential future UCMR listed contaminants, all references to UCMR contaminant lists will identify the appropriate year in parenthesis immediately following the acronym UCMR and before the referenced list. For example, the contaminants included in the UCMR (1999) List include the component lists identified as UCMR (1999) List 1, UCMR (1999) List 2 and UCMR (1999) List 3 contaminants.

Listing cycle means the 5-year period for which each revised UCMR list is effective and during which no more than 30 unregulated contaminants from the list may be required to be monitored. EPA is mandated to develop and promulgate a new UCMR List every 5 years.

Monitored systems means all community water systems serving more than 10,000 people, and the national representative sample of community and non-transient non-community water systems serving 10,000 or fewer people that are selected to be part of a State Plan for the UCMR. (Note that for this round of Assessment Monitoring, systems that purchase their primary source of water are not included in the monitoring.)

Monitoring (as distinct from Assessment Monitoring) means all aspects of determining the quality of drinking water relative to the listed contaminants. These aspects include drinking water sampling and testing, and the reviewing, reporting, and submission to EPA of analytical results.

*Most vulnerable systems (*or *Systems most vulnerable)* means a subset of 5 to not more than 25 systems of all monitored systems in a State that are determined by that State in consultation with the EPA Regional Office to be most likely to have the listed contaminants occur in their drinking waters, considering the characteristics of the listed contaminants, precipitation, system operation, and environmental conditions (soils, geology and land use).

Pre-Screen Testing means sampling, testing, and reporting of the listed contaminants that may have newly emerged as drinking water concerns and, in most cases, for which methods are in an early stage of development. Pre-Screen Testing will be conducted by a limited number of systems (up to 200). States will nominate up to 25 of the most vulnerable systems per State for Pre-Screen Testing. The actual Pre-Screen Testing systems will be selected from the list of nominated systems through the use of a random number generator. Pre-Screen Testing will be performed to determine whether a listed contaminant occurs in sufficient frequency in the most vulnerable systems or sampling locations to warrant its being included in future Assessment Monitoring or Screening Surveys. Pre-Screen Testing will be conducted for the UCMR (1999) List 3 contaminants.

Random Sampling is a statistical sampling method by which each member of the population has an equal probability (an equal random chance) of being selected as part of a sample (the sample being a small subset of the population which represents the population as a whole).

Representative Sample (or *National Representative Sample*) means a small subset of all community and non-transient non-community water systems serving 10,000 or fewer people which EPA selects using a random number generator. The systems in the representative sample are selected using a stratified random sampling process that ensures that this small subset of systems will proportionally reflect (is "representative" of) the actual number of size- and water type-categories of all small systems nationally. In finalizing State Plans, a State may substitute a system from the replacement list for a system selected as part of the original representative sample, if a system on the representative sample list in the State Plan is closed, merged or purchases water from another system.

Sampling means the act of collecting water from the appropriate location in a public water system (from the applicable point from an intake or well to the end of a distribution line, or in some limited cases, a residential tap) following proper methods for the particular contaminant or group of contaminants.

Sampling Point means a unique location where samples are to be collected.

Screening Survey means sampling, testing, and reporting of the List 2 contaminants. These contaminants have analytical methods which have been recently developed, and have uncertain potential for occurrence in drinking water. Under the final List 2 Rule (66 FR 2273), two Screening Surveys will be conducted by a subset of approximately 180 small systems from the 800 small systems conducting Assessment Monitoring. Screening Survey one will be conducted by small systems during 2001 for the List 2 chemical contaminants. Screening Survey two will be conducted by small systems during 2003 for the List 2 microbiological contaminant, *Aeromonas*.

State means each of the fifty States, the District of Columbia, U.S. Territories, and Tribal lands. For the national representative sample, Guam, the Commonwealth of Puerto Rico, the Northern Mariana Islands, the Virgin Islands, American Samoa, and the Trust Territories of the Pacific Islands are each treated as an individual State. All Tribal water systems in the U.S. which have status as a State under Section 1451 of the Safe Drinking Water Act for this program will be considered collectively as one State for the purposes of selecting a representative sample of small systems.

*State Monitoring Plan (*or *State Plan)* means a State's portion of the national representative sample of CWSs and NTNCWSs serving 10,000 or fewer people which must monitor for unregulated contaminants (Assessment Monitoring, Screening Survey(s) and Index Systems) and all large systems (systems serving greater than 10,000 people) which are required to monitor for Screening Survey contaminants. A State Plan may be developed by a State's acceptance of EPA's representative sample for that State, or by a State's selection of systems from a replacement list for systems specified in the first list that are closed, are merged, or purchase water from another system. A State Plan also includes the process by which the State will inform each public water system of its selection for the plan and of its responsibilities to monitor. A State Plan will also include the systems required to conduct Pre-Screen Testing, selected from the State's designation of vulnerable systems. The State Plan may be part of the Partnership Agreement (PA) between the State and EPA.

Stratified Random Sampling is a procedure to draw a random sample from a population that has been divided into subpopulations or strata, with each stratum comprised of a population subset sharing common characteristics. Random samples are selected from each stratum proportional to that stratum's proportion of the entire population. The aggregate random sample (compiled from all the strata samples) provides a random sample of the entire population that reflects the proportional distribution of characteristics of the population. In the context of the UCMR, the population served by public water systems was stratified by size (with size categories of 500 or fewer people served, 501 to 3,300 people served, and 3,301 to 10,000 people served) and by water source type supplying the water system (ground water or surface water). This stratification was done to ensure that systems randomly selected as nationally representative sample systems would proportionally reflect the actual number of size and water type categories nationally.

Testing means, for the purposes of the UCMR and distinct from *Pre-Screen Testing*, the submission and/or shipment of samples following appropriate preservation practices to protect the integrity of the sample; the chemical, radiological, physical and/or microbiological analysis of samples; and the reporting of the sample's analytical results for evaluation. Testing is a subset of activities defined as *monitoring*.

Unregulated contaminants means chemical, microbiological, radiological and other substances that occur in drinking water or sources of drinking water that are not currently regulated under the federal drinking water program. EPA has not issued standards for these substances in drinking water (i.e., maximum contaminant levels or treatment technology requirements). EPA is required by Congress to establish a program to monitor for selected unregulated contaminants in public water systems to determine whether they should be considered for future regulation to protect public health. The selected contaminants are listed in 141.40(a)(3), Table 1, the UCMR List.

Vulnerable time (or *vulnerable period*) means the time (or, in some cases, the 3-month quarter) of the year determined as the most likely to have the listed group of contaminants present at their highest concentrations or densities in drinking water. The vulnerable determination, in the case of the UCMR, is made by the EPA or by the State (under arrangement with the EPA) for a system, subset of systems, or all systems in a State. The vulnerable determination is based on characteristics of the contaminants, precipitation, system operations, and environmental conditions such as soil types, geology, and land use. This determination does not indicate or imply that the listed contaminants will be identified in the drinking water with certainty, but only that sampling conducted during the vulnerable period presumably has the highest likelihood of identifying those contaminants in higher concentrations relative to other sampling times of the year, if and when the contaminants occur.