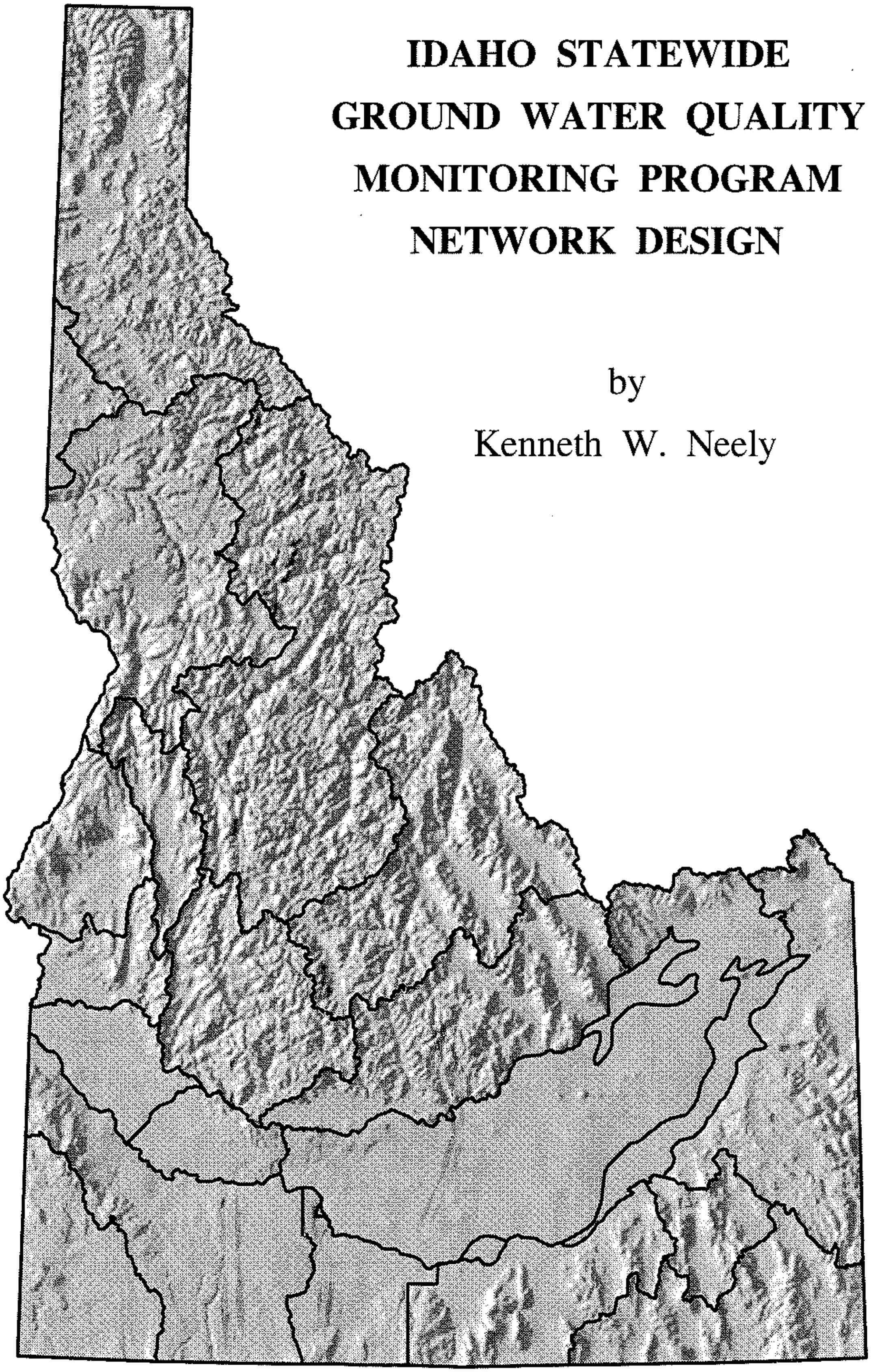
IDAHO STATEWIDE GROUND WATER QUALITY MONITORING PROGRAM NETWORK DESIGN

by

Kenneth W. Neely



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ABSTRACT

This Water Information Bulletin presents the network design for Idaho's Statewide Ground Water Quality Monitoring Program. It describes the need for a monitoring network, development and implementation of the network, verification of the network design and plans for the future.

The Ground Water Quality Protection Act of 1989 authorized development of a comprehensive ground water quality monitoring network. Idaho's Ground Water Quality Plan outlines a three-part monitoring program which includes statewide, regional and local monitoring. The Idaho Department of Water Resources (IDWR), in cooperation with other agencies, was tasked with developing the statewide ground water quality monitoring program. Currently, the program's primary objective is to characterize the existing ground water quality in the state's aquifers. To accomplish this objective, a sophisticated monitoring network design was developed.

Stratified random sampling was selected as the statistical method for the network design. The state's ground water basins were grouped and stratified into 22 hydrogeologic subareas, which are regions characterized by fairly homogeneous hydrogeology. Twenty of the 22 hydrogeologic subareas were used for the network; two subareas were not used because the ground water in these subareas is used by very few people and the aquifer systems are isolated from other major aquifers.

The Neyman optimal allocation method was modified and used to assign the number of monitoring sites per subarea. The subareas were overlain with a township grid. Each year, the appropriate number of townships are selected randomly for each subarea. Primary monitoring sites (existing wells and springs) are picked randomly for each selected township and reviewed for suitability (well construction and aquifer information). Alternate sites are selected for the primary sites. Primary and alternate sites are inspected by field technicians prior to sampling.

Since 1990, IDWR and the U.S. Geological Survey (USGS) have selected and sampled about 1,200 monitoring sites. Ground water samples are collected and tested for field parameters, major inorganics, trace elements, volatile organic compounds, pesticides, bacteria and radioactivity.

Statistical tests were conducted to determine if the stratified random sampling technique was working as predicted. The Student's t-test (parametric) and the Wilcoxon signed rank test (non-parametric) were used to test for significant differences between the mean values of specific conductance, calcium and chloride data. The tests were conducted for each subarea on the data collected in 1991 and 1992. The test results were: 1) there was no significant difference in the means for 17 of the 20 subareas at the 86 percent confidence interval, 2) there was a significant difference in the means for one subarea according to the t-tests and for a second subarea according to the Wilcoxon tests, and 3) the results were inconclusive for one subarea. These results confirm that stratified random sampling is a valid method for Idaho's statewide ground water quality monitoring program.

Clustering of monitoring sites and data gaps are two problems that have been identified with the site selection process. These problems are due to: 1) the nature of random selection, 2) the distribution of sites in the databases, and 3) the lack of existing sites in some geographic areas.

Future plans include: 1) sampling more monitoring sites until about 1,600 sites have been added to the network, 2) modifying the selection process to minimize clustering, 3) filling in data gaps with individually-selected sites, 4) conducting comprehensive analyses after 1,600 sites have been sampled, and 5) beginning trend and seasonal monitoring.

INTRODUCTION

Prior to the 1960's, very little geochemical data existed regarding the overall ground water quality of Idaho's aquifers. Reconnaissance ground water studies, conducted from 1960 to 1986 by the U.S. Geological Survey (USGS), the Idaho Department of Water Resources (IDWR), and the Idaho Department of Health and Welfare, Division of Environmental Quality (IDHW-DEQ) provided some baseline geochemical data and interpretations. However, large portions of aquifer systems remained untested for most constituents, including many potential contaminants. In recent years, discoveries of ground water contamination have become more frequent in Idaho, especially in the state's urban and agricultural areas.

In response to the need to understand and protect the state's ground water resources, the Idaho Legislature passed the Ground Water Quality Protection Act in 1989. One of the act's provisions stated that IDWR, in cooperation with IDHW-DEQ and the Idaho Department of Agriculture (IDA), would design and maintain a statewide ground water quality monitoring network. The objectives of the statewide program are to: 1) characterize the ground water quality, 2) analyze for trends, and 3) identify areas where concentrations of constituents are anomalous. In 1990, IDWR and USGS began collecting ground water quality samples from wells and springs throughout the state. Only cold water (≤ 26° Celsius) aquifers are sampled because the program is focussed primarily on ground water used for human consumption.

The purpose of this report is to describe the design and implementation of Idaho's statewide ground water quality monitoring network. Specifically, the report discusses the following technical elements of the network design: 1) the design criteria, 2) the statistical methodology, 3) the sample strata (hydrogeologic subareas), 4) the method for determining sample sizes, and 5) the site selection criteria and procedures. The report also presents discussions regarding the verification of the network design, problems related to the site selection process and future plans for the network.

PROGRAM OVERVIEW

Legislative Authority

Concerns about the state's ground water quality prompted the Idaho Legislature to take a proactive role in understanding and protecting the state's ground water resources. In 1989, the Legislature passed the Ground Water Quality Protection Act. The primary goals of the Act are: 1) "to maintain the existing high quality of the state's ground water..." and 2) "to prevent contamination of ground water from any source to the maximum extent practical" (State of Idaho,

Idaho State Legislature, 1989). As directed in the act, a 22-member Ground Water Quality Council was appointed by the Governor. The Council developed the Idaho Ground Water Quality Plan (Ground Water Quality Council, 1992), which was passed by the Legislature in 1992. The plan calls for a three-part monitoring program which includes statewide, regional and local monitoring. IDWR, in cooperation with other agencies, was tasked to develop and administrate the statewide ground water quality monitoring network.

Program Objectives

The objectives of any monitoring program must be clear so that the type of the information sought is readily apparent (Ward and others, 1986; Ward and Loftis, 1989). The Idaho Ground Water Quality Plan outlines the objectives for comprehensive ground water quality monitoring and the responsible state agencies. The specific objectives for the statewide monitoring program, as developed by IDWR, are:

1) Characterize the ground water quality of the state's aquifers.
2) Identify trends and changes in ground water quality within the state's aquifers.
3) Identify potential problem areas.

Since base-level geochemical data were lacking for most of the aquifers in the state, the initial efforts focussed on objective one and the network was designed accordingly. After the ground water quality has been characterized, the statewide monitoring program can address long-term and seasonal trends (objective two). Potential problem areas (objective three) are being identified with the current network. The results and any potential health implications are communicated to the site owner and to IDHW-DEQ and/or IDA for follow-up study.

Monitoring Results

Since 1990, about 1,200 monitoring sites have been selected and sampled for ground water quality. The ground water from each site is tested for the occurrence and concentration of approximately 100 constituents and chemical properties (Appendix A). The results so far indicate that most of the ground water quality in the state is acceptable for human consumption since most constituent concentrations were less than the Maximum Contaminant Level (MCLs) established or proposed by the Environmental Protection Agency (IDWR, 1991; IDWR, 1992; IDWR, 1993). However, about nine percent of the sites have one or more constituents whose concentrations exceed the MCLs. Nitrates, volatile organic compounds (VOCs), inorganic constituents and uranium have been detected above MCLs or at levels of concern (IDHW-DEQ and IDWR, 1991; IDWR, 1991; IDWR, 1992; IDWR, 1993; IDHW-DEQ, in press; Crockett, in press). Nitrate detections that exceed the MCL have been found mainly in southern Idaho (Figure 1A). Volatile organic compounds (VOCs), such as tetrachloroethylene, trichloroethylene, dichloropropane, ethylene dibromide and others have been detected at sites throughout the state (Figure 1B). Inorganic constituents, such as arsenic, cadmium, fluoride and selenium have exceeded

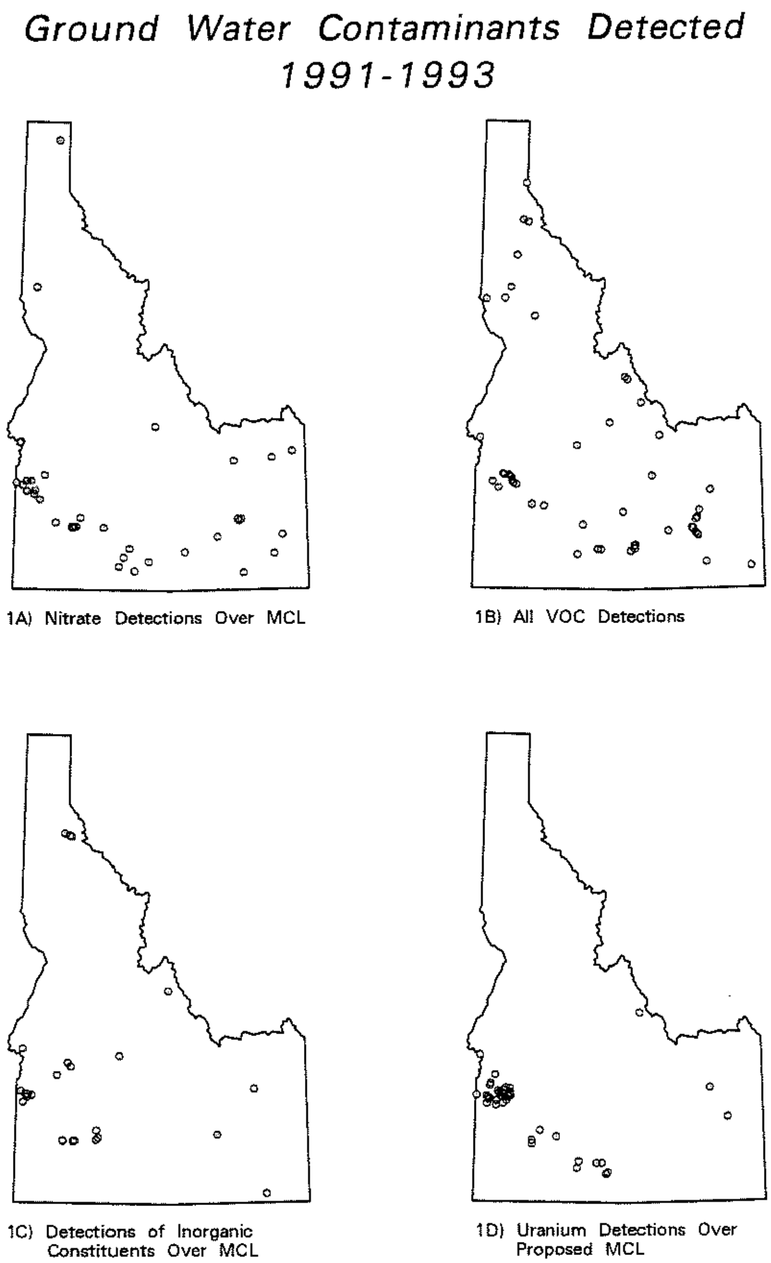

Figure 1. Detections of ground water contamination, 1991-1993 statewide ground water monitoring program.

MCLs mainly in southern Idaho (Figure 1C). Uranium, a radioactive element, has been detected above the proposed MCL at sites primarily in southwestern and southcentral Idaho (Figure 1D). Radon also exceeded the proposed MCL at about eighty percent of the sites (the proposed MCL for radon is currently under review by EPA). Figure 2 shows that many of the detections occurred in areas that have been mapped previously as vulnerable to ground water contamination by Rupert and others (1991).

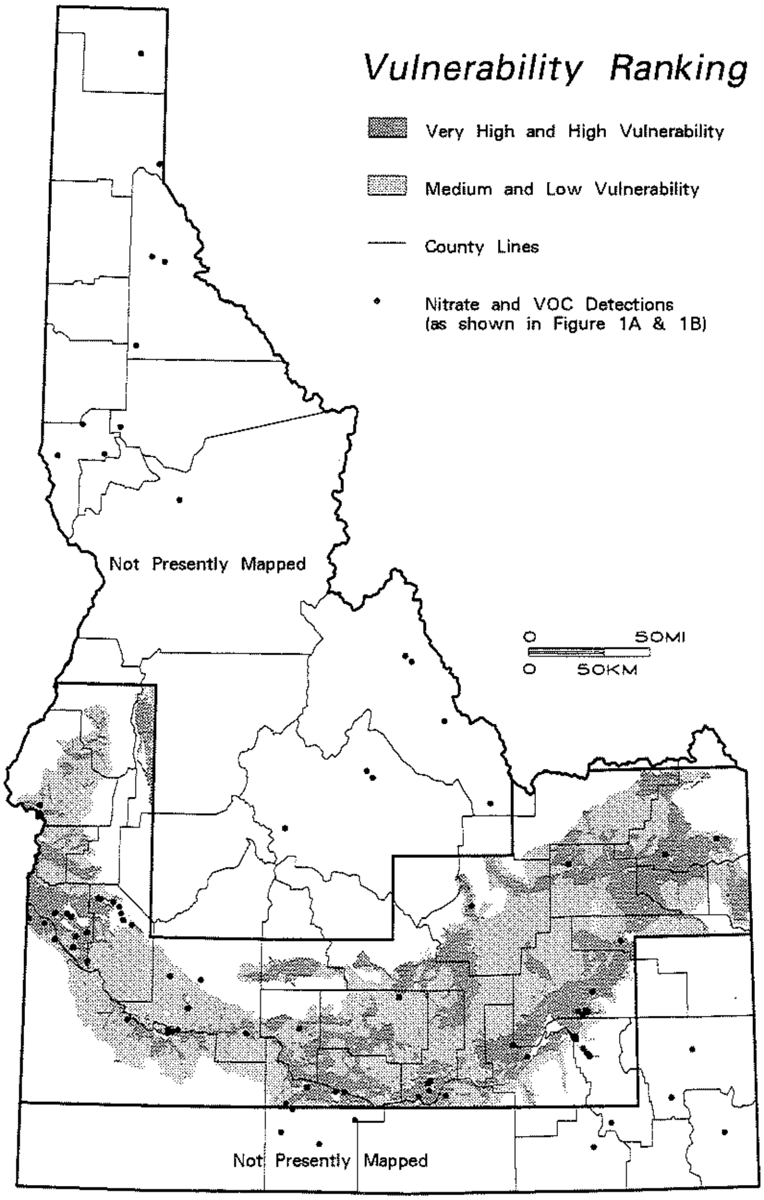

Figure 2. Locations of detections in relation to vulnerability mapping.

NETWORK DESIGN

Design Criteria

IDWR conducted a technical workshop in 1990 to determine the elements critical for an acceptable statewide network design. The workshop attendees developed recommendations for the number of monitoring sites, the constituents to be tested and the computer storage of the data. The Monitoring Subcommittee of the Ground Water Quality Council made additional recommendations regarding the distribution of sites, sampling techniques and data interpretation.

After the workshop and subcommittee recommendations were compiled, IDWR reviewed the following existing or proposed statewide networks: Kansas (Spruill, 1990), Iowa (Detroy and others, 1988), Illinois (O'Hearn and Schock, 1985; McKenna and others, 1989; Voelker, 1989), Oklahoma (Scott, 1990), and Idaho (Whitehead and Parliman, 1979).

Based on the recommendations and literature reviews, IDWR developed the following design criteria for the statewide ground water quality monitoring network:

1. The network would characterize the overall ground water quality throughout the state.
2. The network would be designed using a statistical methodology to minimize bias in site selection and to allow for accurate data interpretations (The original network design for Idaho (Whitehead and Parliman, 1979) was not used because the monitoring sites were selected subjectively. The network designs for Kansas and Illinois were applicable to Idaho primarily because they used *statistical site selection methodologies*).
3. Sample sizes would be large enough to permit statistical analyses.
4. Monitoring sites would be existing wells and springs.
5. Monitoring would be focussed in areas where ground water was used primarily for domestic and public supply and irrigation.
6. Only cold water ($\leq$ 26° Celsius) aquifers would be sampled since thermal water (>26°Celsius) is not commonly used for human consumption in Idaho.
7. Areas with higher population would receive more monitoring sites than areas with lower population so that more knowledge could be gained regarding those aquifers used by the majority of Idaho citizens.
8. A well log would be mandatory for all network wells.
9. Wells would be open to a single aquifer.
10. Ground water samples would be collected by experienced field personnel.
11. Samples would be tested for a variety of field parameters and constituents with the focus on (but not limited to) those analytes with established or proposed MCLs.
12. Samples would be collected during the summer months of each year to minimize seasonality effects.
13. The network design would be flexible to allow for changes as necessary, such as the addition of more sites to areas where anomalous results are discovered.

These criteria were grouped into four key areas related to the statewide network design: 1) the statistical methodology, 2) the sample strata-hydrogeologic subareas, 3) the sample size, and 4) the site selection.

Statistical Method

The statistical method distributes monitoring sites in a manner that will best achieve the objective of characterizing the ground water quality. In the Kansas and Illinois network designs, random sampling was the primary statistical method. Five types of random sampling, described in detail by McKenna and others (1989), were considered for Idaho's monitoring network: simple, systematic, cluster, stratified random and double sampling.

Simple random sampling is the method that selects n units (the sample size) from N (the total population). Systematic random sampling divides N into k subpopulations. A unit is selected randomly from the first k subpopulation. A unit in the same sequential position is selected from the other subpopulations. Both simple and systematic random sampling require that a complete list exists for N. Neither method was selected because a complete list of all of the wells in Idaho does not exist.

Cluster sampling divides the population into units or clusters. A specified number of clusters is selected randomly from the list of clusters. Cluster sampling was not selected because the data required to divide the population into clusters were not available.

Double sampling is the method that collects a second, smaller set of samples based on the results of the collection of an initial, larger set. Double sampling was not selected because this approach goes beyond the initial objective of characterization. However, this technique may prove useful in future design considerations for trend monitoring.

Stratified random sampling divides a large population into a number of small subpopulations called strata (McKenna and others, 1989; Snedecor and Cochran, 1967). Within each stratum, sample sites are selected randomly. This method is useful when the total population is heterogeneous. Stratifying the population creates more homogeneous subpopulations which allow for more accurate statistical analyses. Stratified random sampling was selected as the best approach for Idaho's statewide monitoring program because of state's heterogeneous hydrogeology. The design for Kansas' ground water quality monitoring network is based on a similar stratification method (Spruill, 1990).

Sample Strata--Hydrogeologic Subareas

Idaho's major aquifer types are unconsolidated alluvium, Columbia River basalt, Snake River Plain basalt and mixed sedimentary/volcanic rocks. Graham and Campbell (1981) used surface water basins called "hydrologic units" (USGS, 1975) and existing hydrogeologic data to define 70 ground water basins in Idaho. A new aquifer map (Figure 3) was created for the statewide program using Graham and Campbell's (1981) ground water basins map and other existing hydrologic and geologic data (Dion, 1969; Ralston and Chapman, 1969; Ralston and Chapman, 1970; Ralston and Young, 1971; USGS, 1975; Castelin, 1976; Young and others, 1977; Whitehead and Parliman, 1979; Parliman and others, 1980; Parliman, 1982; Yee and Souza, 1984; Parliman, 1986; Lindholm and others, 1987; Young and others, 1989). The new aquifer map is more refined than Graham and Campbell's (1981) ground water basins map in some areas because of more recent data. However, the new aquifer map does not include some of the very small intermontane aquifer systems since it was decided not to include these basins in the network.

Despite the overall heterogeneity in aquifer types throughout Idaho, the hydrogeology of some large regions is relatively homogeneous. After carefully reviewing the existing data, it was determined that certain hydrologic units and ground water basins could be combined to form ground water regions with mostly homogeneous hydrogeology. This combination process resulted in the delineation of 22 ground water regions called hydrogeologic subareas (Figure 4). Hydrogeologic subareas are the strata used in the stratified random site selection process. Moni-

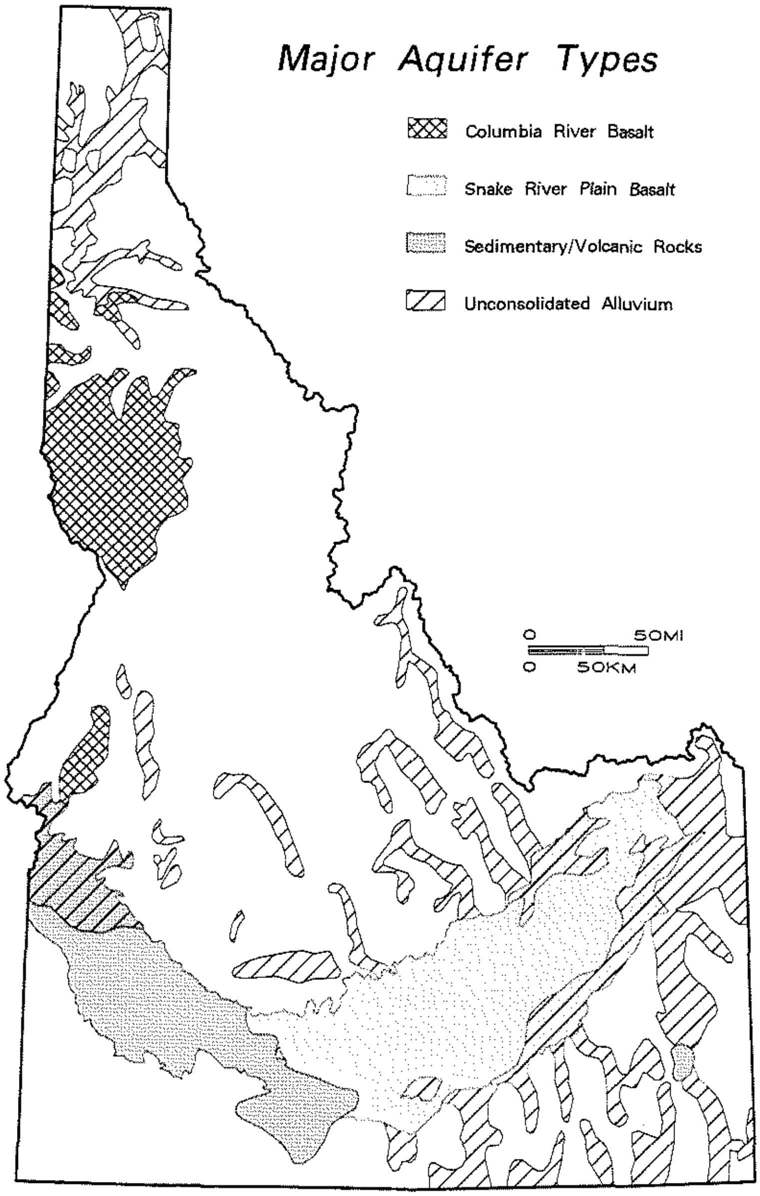

Figure 3. Major aquifer types in Idaho.

toring sites are selected randomly from each subarea. Subareas one through 20 were considered viable for ground water monitoring; subareas 21 and 22 were not used because the ground water in these subareas is used by very few people and the aquifer systems are isolated from other major aquifers.

Throughout most of Idaho, the hydrogeologic subareas contain one predominant aquifer system. However, at least two areas contain tiered aquifer systems where a deep aquifer of one rock type is overlain by a shallow aquifer of a different rock type. In these two areas, two hydrogeologic subareas were delineated. The Boise Valley is one of these tiered systems where a deep aquifer consisting of thin, fine-grained sands interbedded with thick clays is overlain by

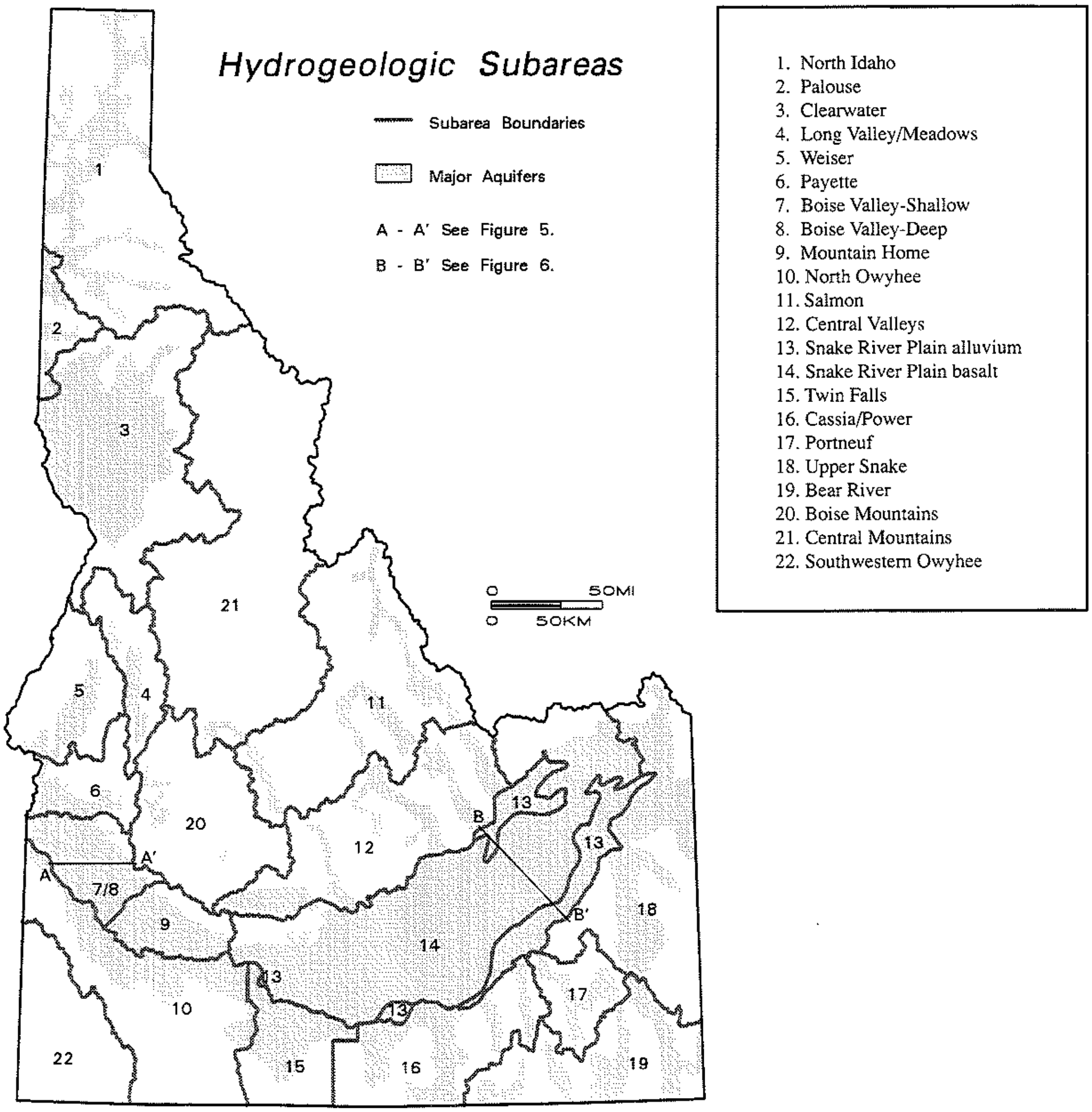

Figure 4. Twenty-two hydrogeologic subareas for the statewide monitoring program.

widespread deposits of coarse river gravels and other fluvial/alluvial sediments (Dion, 1972; Newton, 1989; Squires and others, 1992). Figure 5 shows how the Boise Valley was stratified into two hydrogeologic subareas.

The Eastern Snake River Plain is another ground water basin where two distinctly separate aquifer systems exist. The Snake River Plain basalt is the regional aquifer system and is designated as subarea 14. Along portions of the Plain's periphery, the basalt is overlain by a thin (10 to 200 feet) veneer of unconsolidated alluvial sediments (Figure 6). These sediments are called the Snake River Plain alluvium and are designated as subarea 13. The two aquifer systems (subareas 13 and 14) are separated by up to several hundred feet of unsaturated basalt.

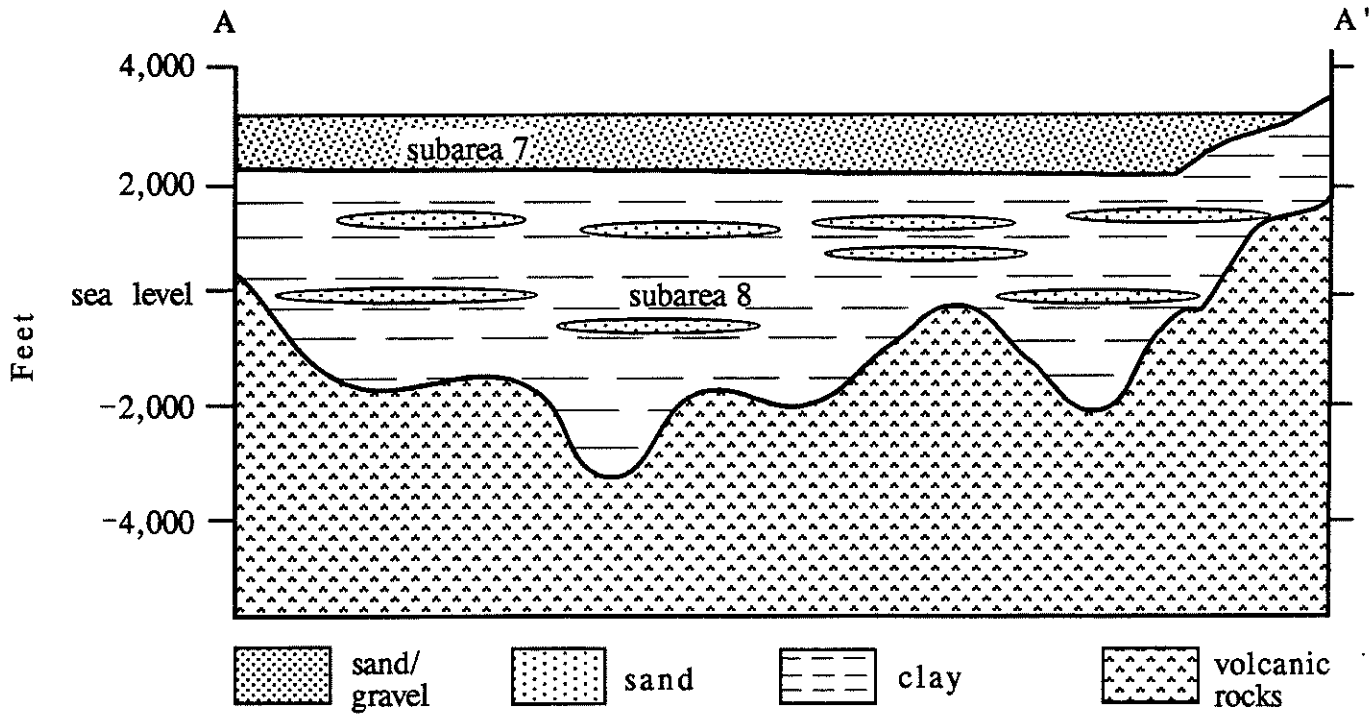

Figure 5. Conceptual model of the Boise Valley basin (subareas 7 and 8). (Modified from Newton, 1989)

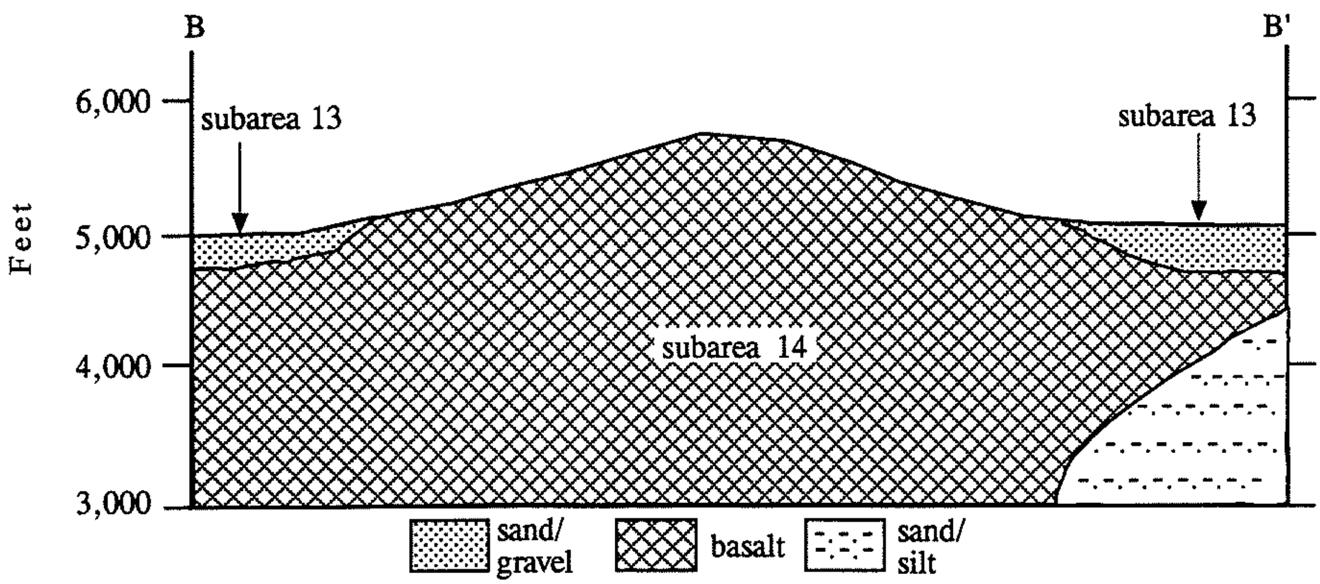

Figure 6. Conceptual model of a portion of the Eastern Snake River Plain basin (subareas 13 and 14) (modified from Whitehead, 1986).

Sample Size

Determining the sample size (i.e., the number of monitoring sites) needed to characterize the ground water quality for an entire state is a challenging task. The 1990 technical workshop group recommended that the network contain 375 monitoring sites. After the first year of ground water sampling, IDWR and the Monitoring Subcommittee decided that the number of network monitoring sites would have to be more than 375 to determine the ground water quality. Therefore, IDWR proposed to sample 400 sites annually for four years followed by a complete data analysis. This plan was approved by the Monitoring Subcommittee and the Ground Water Quality Council.

The sample size for each subarea (stratum) was calculated using a modified Neyman optimal allocation method. The Neyman method can be used to distribute a fixed number of sampling sites to a specific number of strata. The sites are distributed based on a weighting factor which is assigned to each stratum (Nelson and Ward, 1981). Spruill (1990) used the Neyman method to distribute 250 ground water sampling sites in 19 strata for the Kansas' ground water monitoring program. Other equations can be used to determine the sample size if the variance for one or more water quality variables is known (Snedecor and Cochran, 1967; Gilbert, 1987). However, the existing ground water quality data for Idaho were too incomplete to use in these equations.

The Neyman optimal allocation equation is:

$$n_i = N \frac{W_i S_i}{\sum_{i=1}^{L} W_i S_i}$$

where:

n_i = number of samples in stratum i;
N = total number of sample points annually;
W_i = weighting factor for stratum i;
S_i = standard deviation of a water quality variable in stratum i; and
L = total number of strata.

In the initial calculations using the Neyman equation, N equaled 400, which is the maximum number of samples that can be sampled annually with the current funding. W_i was a function of the population and the size of the aquifer area for subarea i, S_i was the standard deviation for the historical specific conductance data for subarea i, and L equaled 20.

The weighting factor (W_i) for each subarea was determined using population and aquifer area percentages. Population (P) was weighted three times more than aquifer area (AA), generally causing the more populated subareas to receive more monitoring sites. There are three reasons for weighting population higher than aquifer area. First, the concentration of monitoring sites in populated subareas will provide more information about the aquifers used by a large percentage of the population. Second, the areas with higher populations will generally correlate with greater potential impacts to the aquifer. Third, this weighting method will prevent oversampling of some large, but sparsely populated, subareas such as the Clearwater and the Upper Snake River (Figure 4-subareas 3 and 18).

The Geographic Information System (GIS) at IDWR was used to determine population, to calculate aquifer areas and to assign specific conductance data to the appropriate subareas. Population was determined for each subarea using the 1988 population estimates from the Idaho Department of Commerce. Aquifer area was calculated for each subarea using the aquifer boundaries in Figure 3 and the subarea boundaries in Figure 4. S_i was based on statistical calculations from about 4,000 specific conductance (SC) readings collected historically by the USGS. The SC data were used because they were considered the best representative ground water quality parameter collected by previous sampling. However, the SC database does contain some biases because the data is a compilation of many studies, some of which were conducted in areas of known ground water contamination.

The number of samples per subarea (n_i) using the original Neyman equation is given in Table 1, column 6. Subareas 2, 4, 5, 10 and 20 had sample sizes too small for viable statistical analyses even after four years of sampling. Subsequent calculations were conducted by modifying W_i (using a variety of weighting ratios for population and aquifer area), but these changes did not significantly increase the small sample sizes. Thus, S_i (the standard deviation for specific conductance) was determined to be the most sensitive variable in the low number of samples. This is because S_i is a very small number for some subareas, apparently due to the low variability in specific conductance (for those subareas). The low variability indicates that these subareas will not require as many sampling points as the those subareas with high variability. However, all subareas will be required to have at least 30 sampling sites so that statistical analyses will be viable.

To resolve the problem of small sample sizes, W_i was modified to include S_i, which allowed SC to be weighted like population and aquifer area. Thus, the influence of S_i in the Neyman equation could be reduced, which is a reasonable approach considering the potential biases in the SC database. The Neyman equation then became:

$$n_i = N \frac{W_{i\text{-}mod}}{\sum_{i=1}^{L} W_{i\text{-}mod}}$$

where:

$W_{i\text{-}mod}$ = modified weighting factor for stratum *i*.

Since the summation of $W_{i\text{-}mod}$ equals 1.0, the modified Neyman equation became:

$$n_i = NW_{i\text{-}mod}$$

In the final calculation, population was weighted three times more than aquifer area and six times more than specific conductance ($W_{i\text{-}mod} = 6P + 3AA + S_i$). Using this modified Neyman equation, more subareas will have greater numbers of samples for statistical analysis after four years of sampling (Table 1, column 9).

The data collected in the first four years will be analyzed to determine if the number of sites per subarea needs to be adjusted to achieve better precision. The variance for specific conductance and other variables will be calculated and used to determine the number of samples required for a specified level of precision for each subarea. Some subareas may need additional sites if the ground water quality is more variable than was predicted from the historic specific conductance data.

Table 1
Annual Allocation of 400 Monitoring Sites in 20 Hydrogeologic Subareas For Idaho's Statewide Ground Water Quality Monitoring Network

1 Subarea (# and Name) (Fig. 5)	2 Aquifer Type[a]	3 S_i[b]	4 W_i[c] (Original)	5 S_iW_i	6 n_i[d] (Original)	7 $W_{i\text{-}mod}$[e] (Modified)	8 $n_{i\text{-}mod}$[f] (Modified)	9 # of samples after 4 years $(n_{i\text{-}mod})(4)$	10 # of samples as of 1/1/94
1 North Idaho	UA	159	.100	15.9	25	.091	36	144	110
2 Palouse	B^{CR}	63	.022	1.4	2	.022	9	36	29
3 Clearwater	B^{CR}	93	.063	5.9	9	.058	23	92	55
4 Long Valley/New Meadows	UA	45	.009	0.4	1	.009	4	16	18
5 Weiser Basin	UA/B^{CR}	102	.013	1.3	2	.018	7	28	23
6 Payette River Basin	UA	341	.024	8.2	13	.029	12	48	31
7 Boise Valley-Shallow	UA	307	.098	30.1	48	.094	38	152	108
8 Boise Valley-Deep	SV	260	.109	28.3	45	.104	42	168	113
9 Mountain Home	SV	459	.024	11.0	18	.029	12	48	39
10 North Owyhee	SV	129	.026	3.4	5	.028	11	44	28
11 Salmon River Basin	UA	587	.021	12.3	20	.025	10	40	33
12 Central Valleys	UA	243	.031	7.5	12	.032	13	52	39
13 Snake River Plain Alluvium	UA	270	.055	14.9	24	.057	23	92	67
14 Snake River Plain Basalt	B^{SR}	207	.199	41.2	66	.179	72	288	198
15 Twin Falls	SV	534	.049	26.2	42	.058	23	92	72
16 Cassia/Power	UA/SV	474	.036	17.1	27	.045	18	72	53
17 Portneuf	UA	246	.050	12.3	20	.051	20	80	51
18 Upper Snake River Basin	UA/SV	218	.037	8.1	13	.039	16	64	57
19 Bear River Basin	UA	191	.028	5.4	9	.032	13	52	43
20 Boise Mountains	UA	54	.005	0.3	0	.006	2	8	11

[a] = Aquifer Type; UA = unconsolidated alluvium, B^{CR} = Columbia River basalt, SV = sedimentary and volcanic, B^{SR} Snake River Plain basalt.

[b] S_i = standard deviation for specific conductance readings in subarea *i*.

[c] W_i = weighting factor assigned to subarea *i* (original Neyman equation).

[d] n_i = sample size for subarea *i* (original Neyman equation).

[e] $W_{i\text{-}mod}$ = weighting factor assigned to subarea *i* (modified Neyman equation).

[f] $n_{i\text{-}mod}$ = sample size for subarea *i* (modified Neyman equation).

Site Selection

A six step process is used to select the primary and alternate monitoring sites annually:

1. The subareas are overlain with a township grid.
2. Potential monitoring areas (townships) are selected randomly from the township grid.
3. Primary monitoring sites are selected randomly for each selected township.
4. Nearby alternate sites are selected for each primary site.
5. An office review is conducted on each primary and alternate site.
6. The suitability of each site is verified by a field inspection prior to sampling.

Step 1 was completed during the first year and is not repeated during the subsequent years; steps 2 through 6 are repeated for each year of site selections. The Geographic Information System (GIS) was used to complete steps 1 through 4. Figures 7 through 10 illustrate how the site selection process works for an individual subarea. Figure 11 shows the logic flowpath of the site selection process.

1. The subareas are overlain with a township grid. Most townships cover 36 square miles (6 miles per side); however, some are smaller due to survey adjustments (Figure 7). The township grid was selected because: 1) it was an existing GIS coverage, thus eliminating the need to create a new coverage, 2) township sizes were assumed to be an appropriate scale for

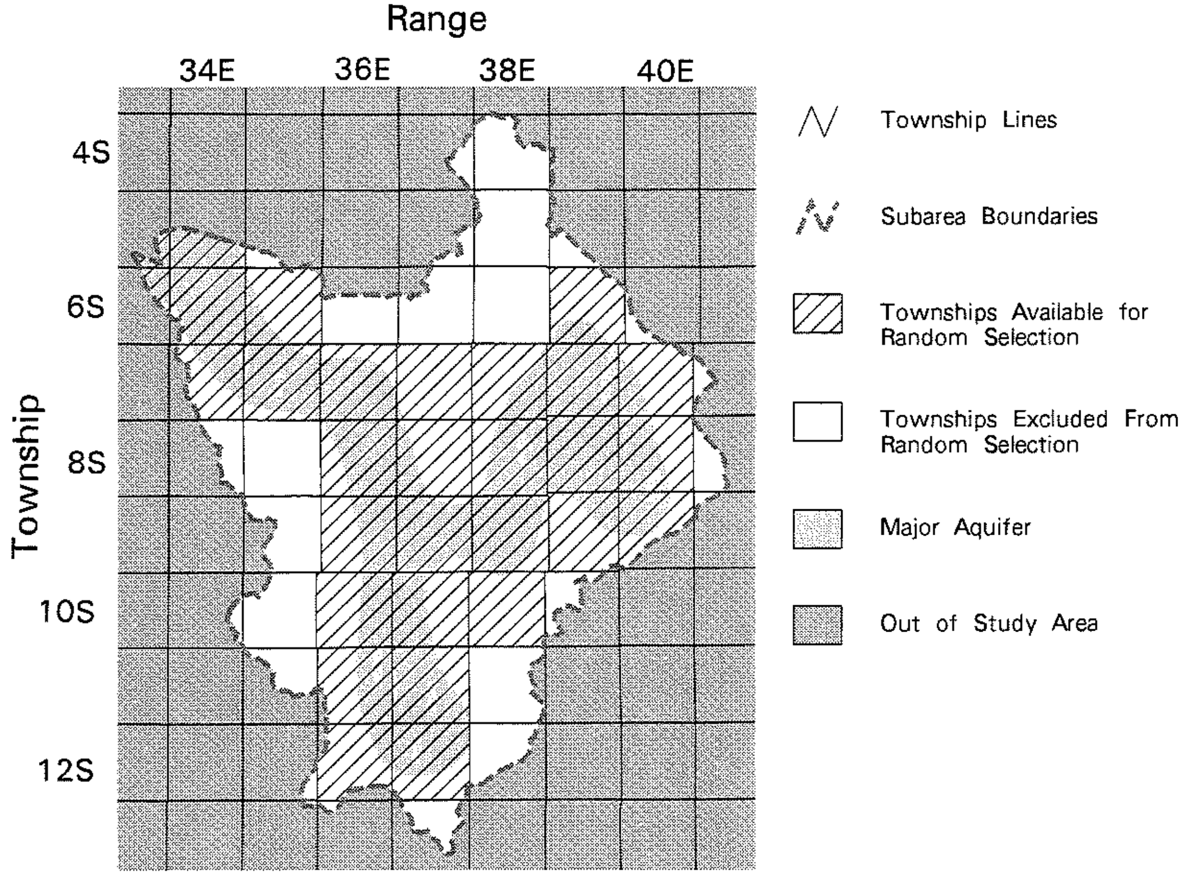

Figure 7. Township grid overlying the Portneuf subarea.

selecting monitoring areas for a state the size of Idaho, and 3) the locational data for most wells and springs are in the public land survey system coordinates (township-range-section).

2. Potential monitoring areas (townships) are selected randomly from the township grid. The appropriate number of townships for each subarea (based on the modified Neyman equation) are selected randomly (Figure 8). Only townships that occur within a subarea's boundaries and are underlain by at least 640 acres of the aquifer are considered for selection. All townships that meet these minimum criteria have an equal chance of being selected, regardless of the number of aquifer acres that they contain. This approach is acceptable because of the uncertainty regarding the exact location of subarea and aquifer boundaries.

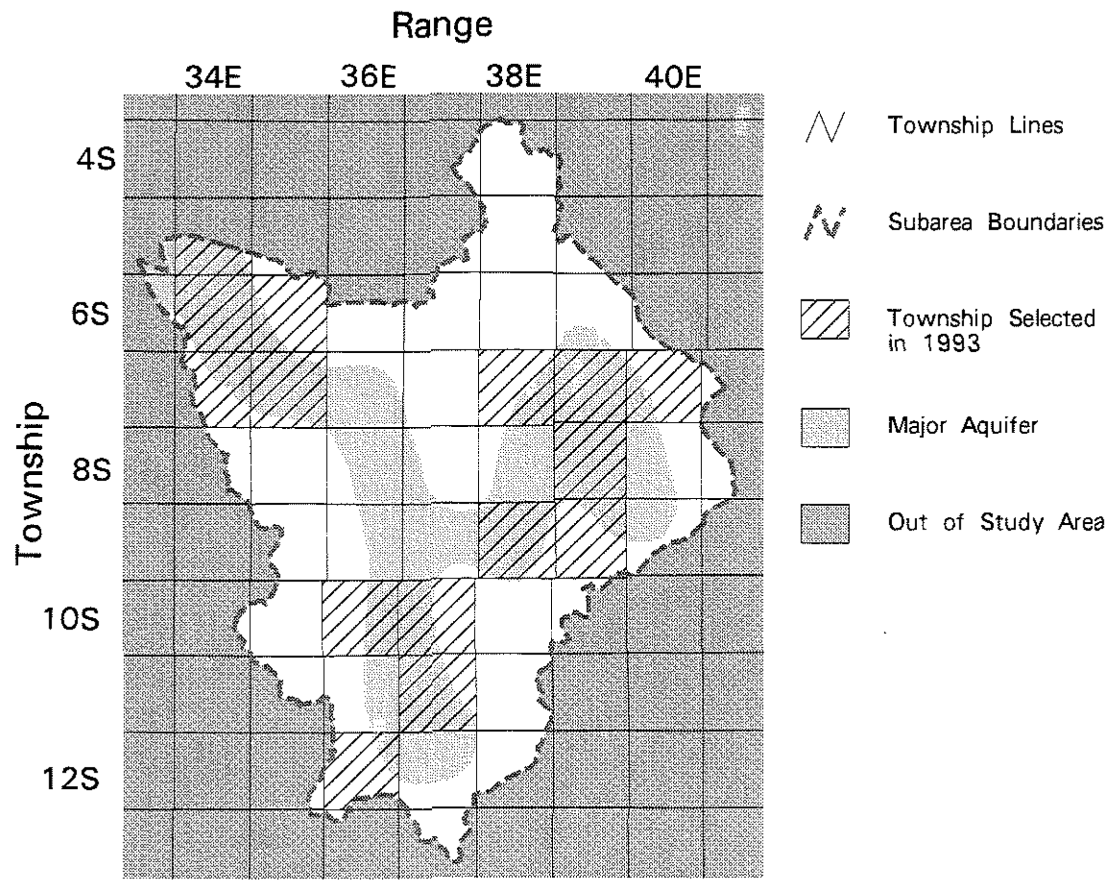

Figure 8. Townships selected as potential monitoring areas for the Portneuf subarea in 1993.

3. Primary monitoring sites are selected randomly for each selected township. An attempt is made to find a usable monitoring site (an existing well or spring) for each selected township. Monitoring sites are selected from one of the two lists of existing wells and springs. The first list is the Ground Water Site Inventory (GWSI) which is a computerized database maintained by the USGS. GWSI contains location, well construction, hydrogeologic and other site information for about 19,000 wells and springs in Idaho (Tungate, 1994, personal communication). However, due to missing well construction information, geothermal temperatures and other restrictions, only about 7,000 wells and springs are suitable for selection. The second list is the well log library which is maintained by IDWR and contains about 60,000 well logs in microfiche files.

Initially, GWSI is searched for a usable monitoring site for each randomly-selected township (Figure 9). If several sites exist in GWSI for a selected township, the random selection program picks one of those sites. GWSI is used as the first choice because: 1) the database is computerized, and 2) each site has been inspected previously by an experienced USGS field technician who recorded specific information about the site.

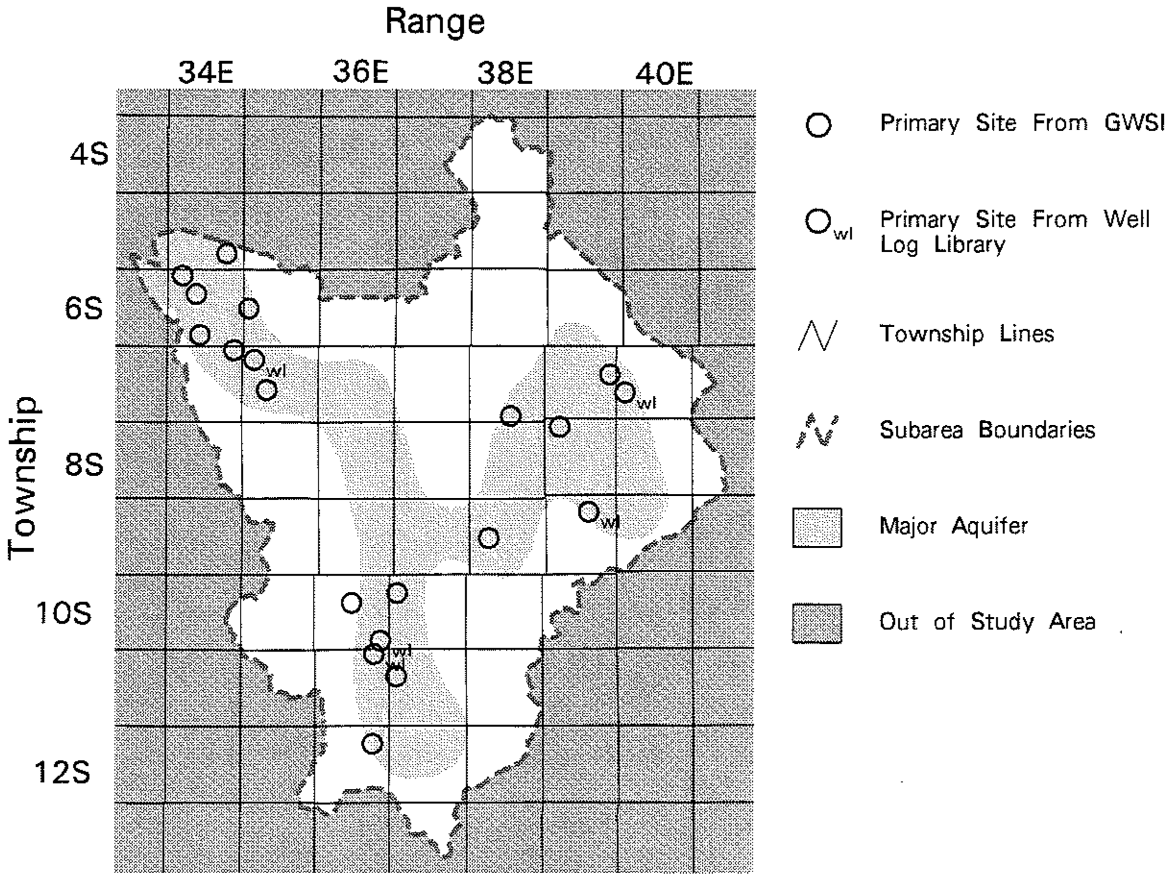

Figure 9. Primary sites selected from GWSI and the well log library for the Portneuf subarea in 1993.

When there are no wells or springs in GWSI for a selected township, a well is selected randomly from the well log library (Figure 9). The well log library is not used as the primary source for selecting sites, despite containing more records than GWSI, because the library: 1) was not computerized when the statewide monitoring program began and is currently only partially computerized, and 2) contains locational data that is less accurate than the locational data for the sites in GWSI.

Occasionally, no sites exist in either GWSI or the well log library for a selected township. For example, many townships in the Eastern Snake River Plain are underlain by the basalt aquifer, but do not have any wells because the overlying land is undeveloped. In these situations, the township is eliminated as a potential monitoring area even though it is underlain by an aquifer.

4. Nearby alternate sites are selected for each primary site. Alternate sites are wells or springs that are close to the primary site and are completed in the same aquifer (Figure 10).

Alternate sites are chosen because some primary sites are unusable for reasons such as incomplete or missing well logs, poor well construction or the well is no longer in use. Therefore, alternate sites are selected for all primary sites to avoid lost time in the field. GWSI is used as the first choice for selecting alternate sites. When there are no alternate sites available in GWSI, well logs from the well log library are provided as alternates.

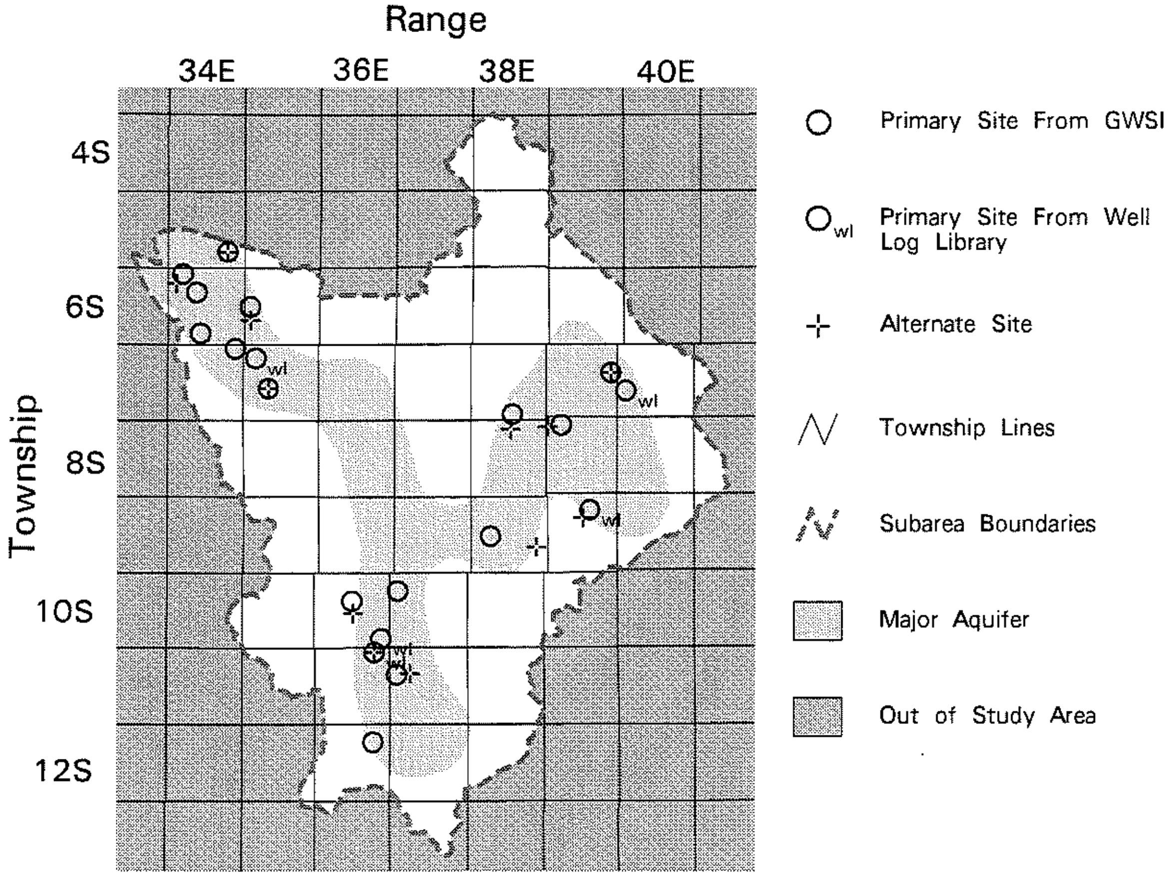

Figure 10. Alternate sites selected from GWSI for the Portneuf subarea in 1993.

5. An office review is conducted on each primary and alternate site. Each well or spring selected from GWSI or from the well log library is checked for suitability as a monitoring site. Only sites with temperatures ≤ 26° Celsius are accepted because geothermal wells and springs are not typically used for human consumption. Well construction information (depth, casing and open intervals) and hydrogeologic data (aquifer type) are reviewed and checked to assure that the ground water collected is not being drawn from multiple aquifers.

6. The suitability of each site is verified by a field inspection prior to sampling. During the spring months, USGS field technicians inspect each monitoring site to verify well construction, to record nearby land use data and to get the owner's permission for the sampling which occurs in the summer. Sites that do not appear to be representative because of well construction problems or local impacts are replaced with alternates. The field inspections, the actual sampling and some of the laboratory analyses are performed by the USGS as part of a state-federal joint funding contractual agreement.

Flowpath for the Site Selection Process

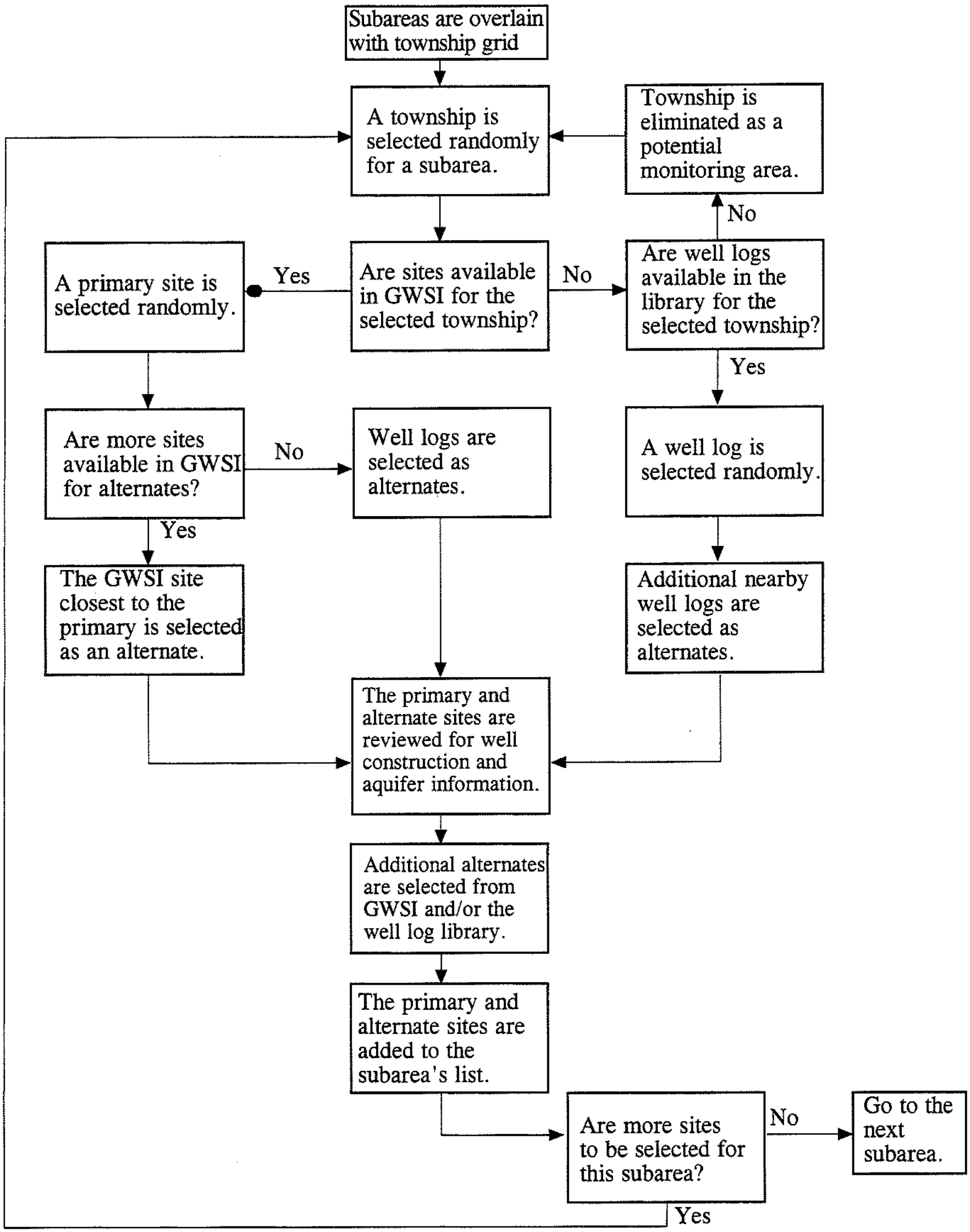

Figure 11. Flowpath for the site selection process.

NETWORK DESIGN VERIFICATION

Parametric and non-parametric statistical tests were conducted on the first two years of ground water quality data to verify that the stratified random technique was working as predicted. The tests showed that the mean values of three constituents (specific conductance, calcium and chloride) collected in 1992 were not significantly different than the water chemistries collected in 1991 for at least 17 of the 20 subareas at the 86 percent confidence interval. This evaluation indicates that stratified random sampling is a valid sampling approach for the statewide monitoring program. Additional verification testing is planned for the future when more data become available.

The network design verification contained seven steps:

1. Null and alternate hypotheses were established.
2. Statistical tests were selected.
3. Data were checked for normality.
4. Data were checked for equal variances.
5. Data were transformed to simulate more normal-shaped distributions.
6. Hypotheses were tested using the Student's t-test (parametric).
7. Hypotheses were tested using the Wilcoxon signed rank test (non-parametric).

1. Null and alternate hypotheses were established. To determine whether the stratified random approach was working properly, the mean values for three ground water quality constituents from sites sampled in 1991 and 1992 were tested for significant differences. The null hypothesis (H_o) was that the mean value for constituent x, subarea i, for 1991 was not significantly different than the mean value for constituent x, subarea i, for 1992 at the 95 percent confidence interval (CI). The alternate hypothesis (H_a) was that the mean values were significantly different at the CI equal to 95 percent. An equivalent way of writing these hypotheses is:

$$H_o: \mu_{\text{constituent } x,\text{ subarea } i, 1991} = \mu_{\text{constituent } x,\text{ subarea } i, 1992}$$
$$H_a: \mu_{\text{constituent } x,\text{ subarea } i, 1991} \neq \mu_{\text{constituent } x,\text{ subarea } i, 1992}$$

The null hypothesis was based on two assumptions: 1) for each subarea, the ground water collected in 1991 came from the same aquifer as the ground water collected in 1992, and 2) the overall water chemistry did not change significantly between 1991 and 1992 for any of the subareas. Specific conductance, calcium, and chloride were selected as the ground water quality variables for testing because they represent a field parameter, a cation and an anion, respectively. These variables were also selected because the data contained very few non-detections. The cumulative confidence interval is 86 percent, which is the product of the confidence intervals for the three individual tests (95 percent x 95 percent x 95 percent).

2. Statistical tests were selected. The Student's t-test and the Wilcoxon signed rank test were selected for testing the hypotheses because these tests are valid for ground water quality analyses (Rovers and McBean, 1981; Harris, Loftis, and Montgomery, 1987; Montgomery and Loftis, 1987). The Student's t-test is a parametric test used when the sample sizes are significantly smaller than the total population (Hoel, 1971). The assumptions of the Student's t-test are: 1) the data are independent (nonautocorrelated), 2) the distributions are normal or Gaussian, and 3) the data sets have equal variances (Rovers and McBean, 1981; Harris and others, 1987; Helsel and Hirsch, 1988). When these assumptions are violated, non-parametric tests, such as the Mann-Whitney U Statistic or the Wilcoxon signed rank test can be used (Rovers and McBean, 1981; Wilkinson and others, 1992).

3. Data were checked for normality. Montgomery and others (1987) concluded that the distribution of many ground water quality variables is not Gaussian (normal), but is skewed to the right. Therefore, the assumption of normality was tested using probability plots, and skewness and kurtosis statistics. The data were grouped and analyzed by individual subareas. About 65 percent of the subareas had distributions for specific conductance and calcium data that were normal or near-normal (Figure 12a); the remainder of the subareas had distributions that were skewed highly to the right (Figure 12b). Only about 26 percent of the subareas had chloride data with normal or near-normal distributions; the remainder were skewed highly to the right (Figure 12c). The assumption of normality is violated for about 48 percent of the data.

4. Data were checked for equal variances. The assumption of equal variances was tested using the variance ratio (F) test (Rovers and McBean, 1981) where

$$F = \frac{\text{greater estimate of the variance of constituent } x_{\text{subarea i, year a}}}{\text{lesser estimate of the variance of constituent } x_{\text{subarea i, year b}}}$$

Each F value is compared to a table of variance ratios (Rovers and McBean, 1981) to determine if a significant difference exists between the variances. The F tests indicate that significant differences in the variances exist for specific conductance (45 percent of the subareas), calcium (35 percent of the subareas) and chloride (75 percent of the subareas). The assumption of equal variances is violated for about 52 percent of the data.

5. Data were transformed to simulate more normal-shaped distributions. The raw data for specific conductance, calcium and chloride were transformed by computing the log of each measurement. The transformed data were checked for normality and for equal variances as described in steps 3 and 4. The log transformations were successful in converting about 64 percent of the non-normal distributions into normal shapes (Figure 13a) and in reducing the F values. However, about 17 percent of the distributions were still right-skewed (Figure 13b) and about 7 percent of the F test results indicated unequal variances.

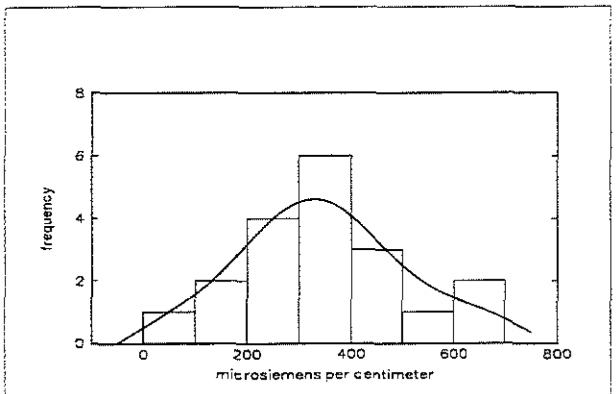

Figure 12a. An example showing a normal data distribution for specific conductance data for Subarea 18 in 1991.

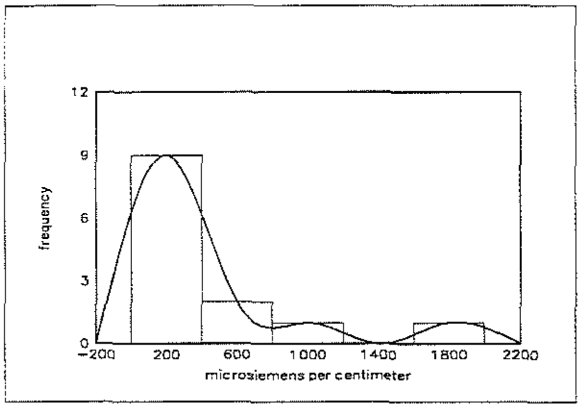

Figure 12b. An example showing a right-skewed data distribution for specific conductance data for Subarea 9 in 1991.

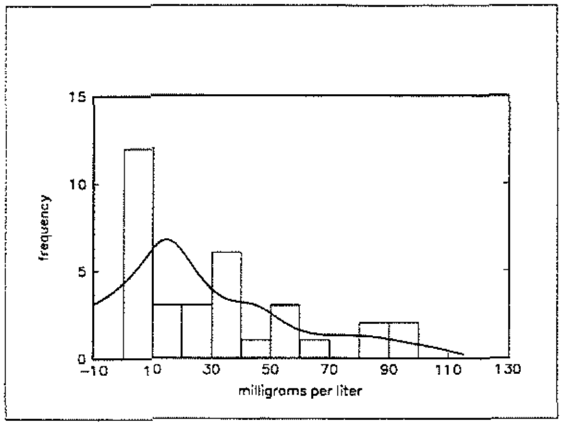

Figure 12c. An example showing a right-skewed data distribution for chloride data for Subarea 8 in 1992.

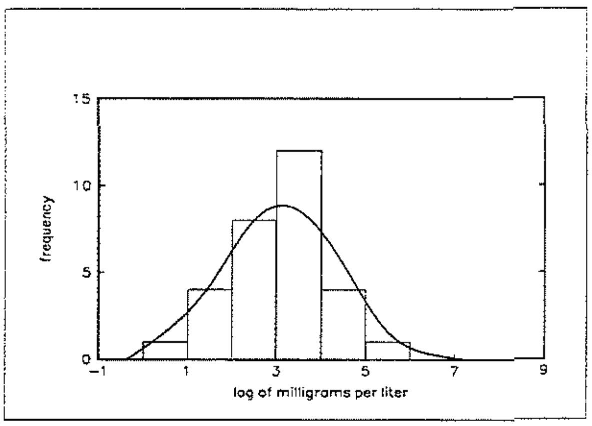

Figure 13a. An example showing that the chloride data from Figure 12c was changed to a normal distribution using the log transformation.

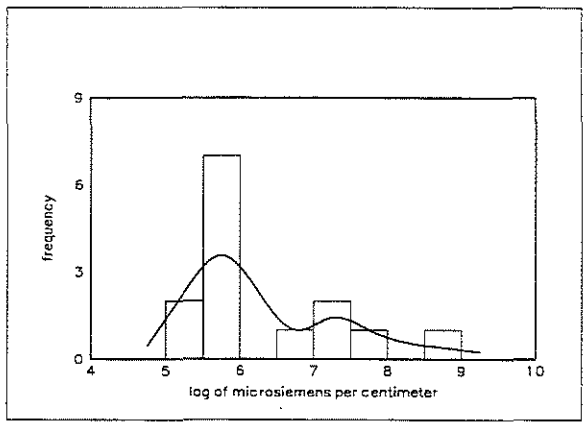

Figure 13b. An example showing that the specific conductance data from Figure 12b is still right-skewed after the log transformation.

The violations related to the assumptions of normality and equal variances suggest that the Student's t-test may not be a valid statistical test for most of the raw data and for some of the transformed data. However, Student t-tests are considered to be robust (valid) even when some of the assumptions are violated (Harris and others, 1987, Montgomery and Loftis, 1987, Montgomery and Loftis, 1988). Therefore, t-tests were performed on both the raw and transformed data.

6. Hypotheses were tested using the Student's t-test (parametric). The Student's t-test was used to calculate t values for both the raw and transformed data. A small positive or negative t value confirms the null hypothesis; a large positive or negative value causes the null hypothesis to be rejected. The t values for raw and transformed data are small enough to accept the null hypothesis (mean values are equal) at the 86 percent confidence interval for all of the subareas except subarea 14-Snake River Plain Basalt and possibly subarea 8-Boise Valley-Deep (Table 2).

Table 2
Results for Student t-Tests and Wilcoxon Tests Conducted on Specific Conductance (SC), Calcium (Ca) and Chloride (Cl) Data Collected for the Statewide Monitoring Program in 1991 and 1992.

Subarea (# and Name) (Fig. 5)	Student's t-test Raw data			Student's t-test Transformed Data			Wilcoxon		
	SC	Ca	Cl	SC	Ca	Cl	SC	Ca	Cl
1 North Idaho	A	A	A	A	A	A	A	A	A
2 Palouse	A	A	A	A	A	A	A	A	A
3 Clearwater	A	A	A	A	A	A	A	A	A
4 Long Valley/New Meadows	A	A	A	A	A	A	A	A	A
5 Weiser Basin	A	A	A	A	A	A	**R**	A	A
6 Payette River Basin	A	A	A	A	A	A	A	A	A
7 Boise Valley-Shallow	A	A	A	A	A	A	A	A	A
8 Boise Valley-Deep	A	**R**	A	A	**R**	A	**R**	**R**	**R**
9 Mountain Home	A	A	A	A	A	A	A	A	A
10 North Owyhee	A	A	A	A	A	A	A	A	A
11 Salmon River Basin	A	A	A	A	A	A	A	A	A
12 Central Valleys	A	A	A	A	A	A	A	A	A
13 Snake River Plain Alluvium	A	A	A	A	A	A	A	A	A
14 Snake River Plain Basalt	A	**R**	A	**R**	**R**	**R**	A	A	A
15 Twin Falls	A	A	A	A	A	A	A	A	A
16 Cassia/Power	A	A	A	A	A	A	A	A	A
17 Pocatello/Portneuf	A	A	A	A	A	A	A	A	A
18 Upper Snake River Basin	A	A	A	A	A	A	A	A	A
19 Bear River Basin	A	A	A	A	A	A	A	A	A
20 Boise Mountains	A	A	A	A	A	A	A	A	A

A = Null hypothesis is accepted at the 95 percent confidence interval.
R = *Null hypothesis is rejected at the 95 percent confidence interval.*

7. Hypotheses were tested using the Wilcoxon signed rank test (non-parametric). The Wilcoxon test overcomes the problem of unequal variances and non-normality. However, non-parametric tests, such as the Wilcoxon test, do not have the discrimination power of the t-test (e.g., the ability to distinguish between sets of data) because they use the rank of the data as opposed to the actual data value (Rovers and McBean, 1981).

The results from the Wilcoxon tests indicate that the null hypothesis is accepted for all of the subareas with the exception of subarea 8-Boise Valley-Deep and possibly subarea 5-the Weiser Basin (Table 2). Some of the ground water quality data collected in subarea 8 in 1992 is highly right-skewed and similar statistically to the data collected from sites in subarea 7 (Boise Valley-Shallow) in 1991 and 1992. In general, maximum concentrations for specific conductance, calcium and chloride were significantly higher for subarea 8 in 1992 than for subarea 8 in 1991. These high values may be caused by local aquifer conditions, well bore impacts or wells being assigned incorrectly to subarea 8. Further studies will be conducted to determine the cause of the anomalous values.

Conclusions of Network Design Verification. The results of Student t-tests and Wilcoxon tests on specific conductance, calcium and chloride indicate that the null hypothesis (mean values are equal) is accepted for 17 of the 20 subareas sampled in 1991 and 1992. Since each test has a 95 percent confidence interval, the cumulative level of confidence for the testing is 86 percent. The Wilcoxon test indicates clearly that the null hypothesis is rejected for subarea 8-Boise Valley-Deep. The null hypothesis is also rejected for subarea 14-Snake River Plain Basalt according to the Student t-test (log transformed data), but the null hypothesis is accepted for the same subarea using the Wilcoxon test. The results for subarea 5 (Weiser) indicate that the null hypothesis is accepted with exception of one test (Wilcoxon, specific conductance).

The test results indicate that the stratified random sampling approach is valid for Idaho's statewide ground water quality monitoring program. However, additional verification testing is needed to confirm these results and to investigate the inconsistencies between the tests for subareas 5, 8 and 14. As more data become available in the future, additional statistical analyses, including multivariant testing, will be performed.

PROBLEMS RELATED TO THE SITE SELECTION PROCESS

Clustering of sites and data gaps are two problems that have been recognized with the site selection process. Clustering of sites is not desirable because sites that are located within very small distances of each other could have water chemistries so similar that they are essentially identical. Clustering may cause a reduction in efficiency since the objective of the statewide monitoring program is to characterize the overall ground water quality as opposed to delineating local variations.

Clustering of network sites can occur because of the existing list of sites in the GWSI database. For example, the sites listed in GWSI for a selected township may be limited to a small area of that township (Figure 14). This pattern is caused by either: 1) the existing wells and springs are only in certain areas of a township, or 2) previous studies by the USGS were conducted in a limited area of a township (resulting in only those wells being entered into GWSI). In either case, the selection of monitoring sites will be biased toward those areas of a township where the GWSI sites are located (Figure 15). Clustering can occur because there is no restriction as to how close a site can be to a previously-sampled network site.

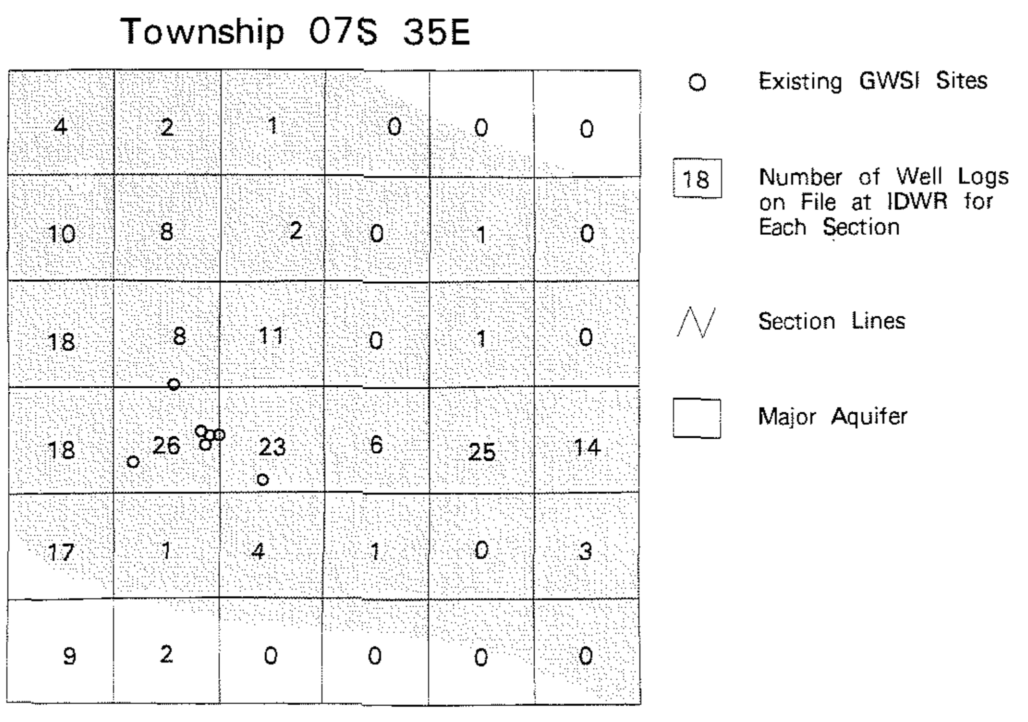

Figure 14. An example from the Portneuf subarea showing that GWSI sites can be limited to a small area of a township.

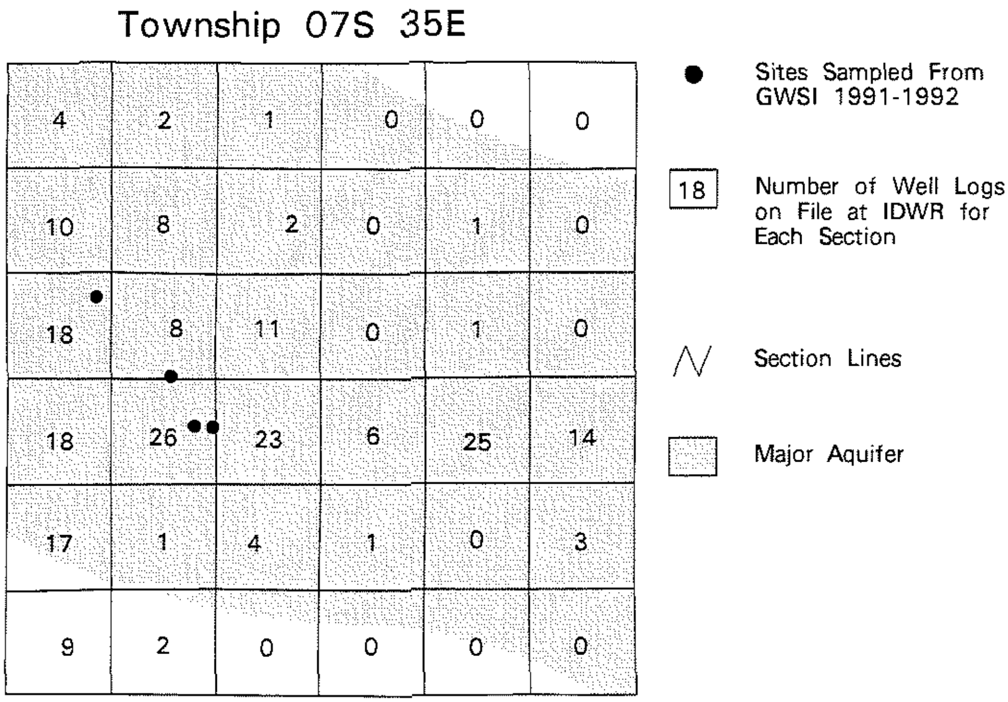

Figure 15. An example from the Portneuf subarea showing how clustering of monitoring sites can occur because of the locations of sites in GWSI.

Data gaps are the second problem with the site selection process. Data gaps can be caused by either: 1) the lack of sites in some geographic areas, 2) the nature of the random selection process, or 3) the distribution of sites in GWSI and/or the well log library. Data gaps caused by the lack of sites can not be avoided because the current funding permits the sampling of existing sites only.

A data gap caused by the nature of random selection is called a Type A data gap. Some townships are simply not selected by the process even after multiple years of selections. Figure 16 shows a Type A data gap that has occurred in the Portneuf subarea after three years of site selections.

Type B data gaps are caused by the distribution of sites within townships. Type B data gaps occur when: 1) only a couple sites are in GWSI for a selected township, or 2) GWSI sites are clustered in a small area of the township. Frequently, there are other wells available within a Type B data gap according to the well log library. However, these wells will not be selected as long as GWSI sites are available for selection. Figure 16 shows Type B data gaps for the Portneuf subarea.

Proposed solutions to these problems are discussed in the following section.

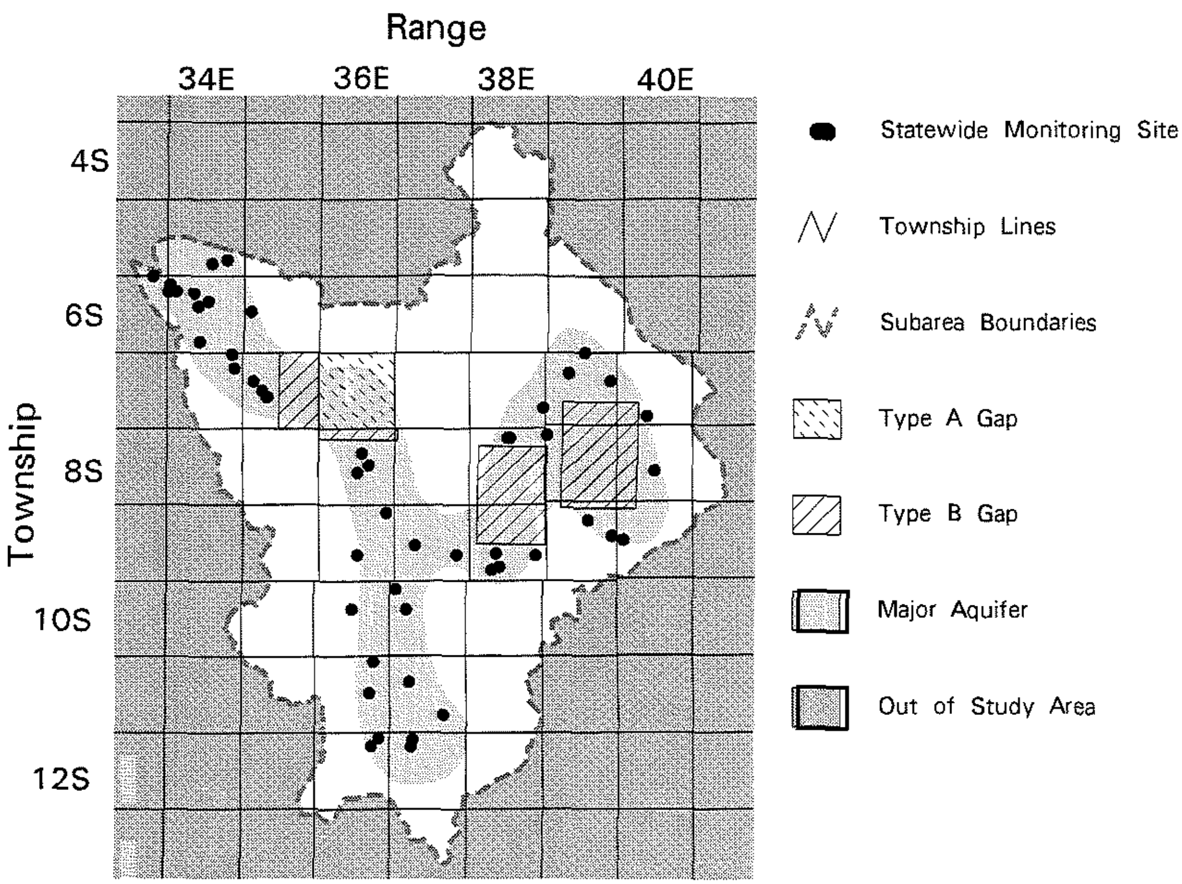

Figure 16. An example from the Portneuf subarea showing Type A and Type B data gaps.

FUTURE PLANS

Additional monitoring sites will be added to the network in 1994 and 1995 until about 1,600 sites have been sampled. In 1995, a complete analysis will be conducted to determine whether objective 1, the characterization of the ground water quality, has been achieved. Depending on the analytical results, the number of monitoring sites will be adjusted as necessary for each subarea.

As mentioned in the "Problems Related To The Site Selection Process" section, clustering of monitoring sites has occurred in some areas. To minimize clustering, the selection process was modified in 1994 so that additional sites will not be selected in sections where a network site has been previously selected and sampled (Figure 17). Areas where clustering has already occurred will be reviewed on a case by case basis to see if a single site can be used to represent the ground water quality.

Data gap problems will be solved in two ways. First, the site selection process was modified in 1994 so that sections are now selected as potential monitoring areas from the list of randomly-selected townships. This change allows more well logs from the well log library to be included in the site selection process. Second, some sites will be added selectively to the net-

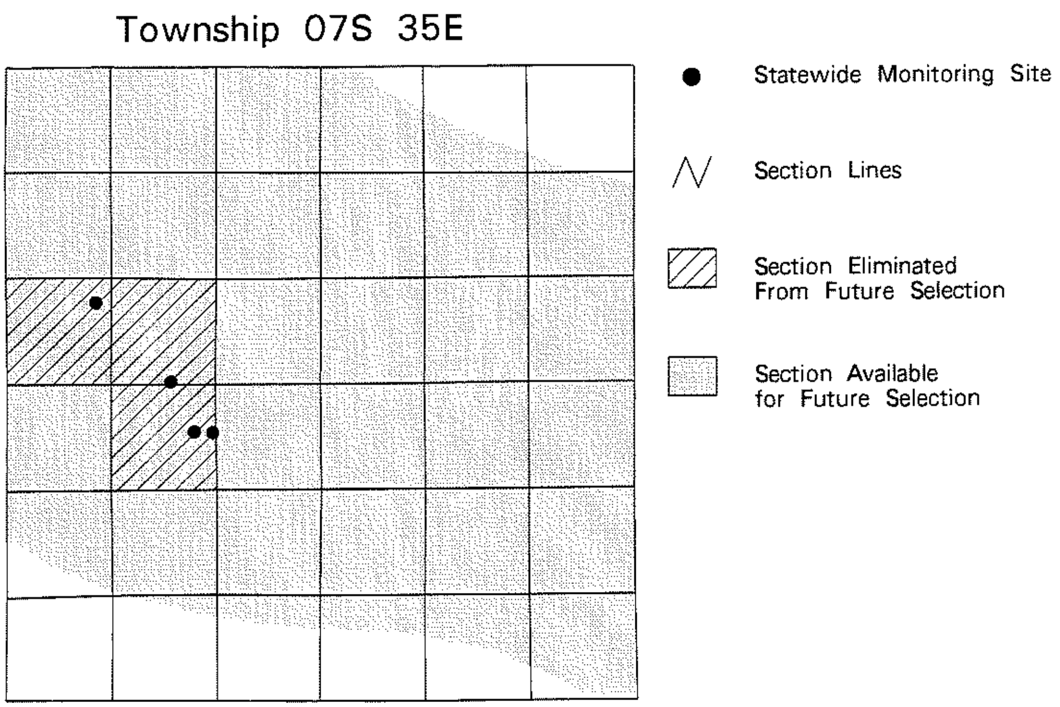

Figure 17. An example showing how sections with existing network sites are eliminated from future selections.

work to fill in specific data gaps. The sites will be added so that the objective of characterizing the ground water quality can be fully accomplished while introducing minimum bias.

IDWR held a technical workshop in October 1994. The attendees reviewed the current network design and provided input for trend monitoring. It is anticipated that trend monitoring will begin in 1995.

SUMMARY AND CONCLUSIONS

The Ground Water Quality Protection Act of 1989 authorized development of a comprehensive ground water quality monitoring network. Idaho's Ground Water Quality Plan outlines a three-part monitoring plan which includes statewide, regional and local monitoring. The Idaho Department of Water Resources, in cooperation with other agencies, was tasked with developing the statewide ground water quality monitoring network. Currently, the program's primary focus is to characterize the existing ground water quality in the state's aquifers. To accomplish this objective, a complex network design was developed.

The design for the monitoring network is based on a stratified random sampling technique which uses 20 hydrogeologic subareas as the sampling strata. The Neyman optimal allocation method was modified and used to assign the number of sites per subarea. Each year, the appropriate number of townships are selected randomly for each subarea. Primary monitoring sites are picked randomly for each selected township, reviewed for suitability (well construction and aquifer information), and verified by field inspections prior to sampling. Since 1990, about 1,200 monitoring sites (wells and springs) have been selected and sampled. Ground water samples are collected and tested for field parameters, major inorganics, trace elements, volatile organic compounds, pesticides, bacteria and radioactivity.

Ground water quality data collected in 1991 and 1992 were used to test whether the network design is working properly. The Student's t-test (parametric) and the Wilcoxon signed rank test (non-parametric) were used to test for significance differences between the mean values of specific conductance, calcium and chloride data within individual subareas. The Wilcoxon test was considered more reliable because almost one-half of the data violate the assumptions of the t-test.

The test results indicate that the mean values for the three water quality variables were not statistically different for 17 of the 20 hydrogeologic subareas at the 86 percent confidence interval. Stratified random sampling is a valid approach for the statewide monitoring program. These results are preliminary because the statistics were conducted on only three constituents from 800 monitoring sites. A more comprehensive analysis is planned after about 1,600 monitoring sites have been sampled.

Clustering of monitoring sites and data gaps are two problems that have been identified with the site selection process. These problems are due to the nature of random selection and to the distribution of sites naturally and in the databases.

Future plans for the statewide ground water quality monitoring program include: 1) adding more sites to the network until about 1,600 sites have been sampled, 2) modifying the site selection process to minimize clustering, 3) filling in data gaps with individually-selected sites, 4) conducting comprehensive analyses after 1,600 sites have been sampled, and 5) beginning trend and seasonal monitoring.

APPENDIX

Constituents tested by Idaho's Statewide Ground Water Quality Monitoring Program

FIELD PARAMETERS

specific conductance, pH, temperature, alkalinity

LABORATORY PARAMETERS

Common Ions

calcium, magnesium, sodium, potassium, bicarbonate, carbonate, alkalinity, hardness, sulfate, chloride, fluoride, silica, dissolved solids

Nutrients

nitrogen (NO_2+NO_3), nitrogen (ammonia), phosphorus

Trace Elements

arsenic, cadmium, chromium, copper, cyanide, iron, lead, manganese, mercury, selenium, zinc

Radioactivity/Radionuclides

gross alpha, gross beta, radon, (selected sites are also tested for radium 226, uranium-total, uranium 233 and 234, uranium 235, uranium 238, and strontium 90)

Bacteria

fecal coliform

Pesticides

Immunoassay scans for 2,4-D, alachlor, aldicarb, atrazine, carbofuran, cyanazine, and metolachor. Gas chromatography on selected sites for 2,4-D, alachlor, aldicarb, atrazine, bromacil, carbofuran, dacthal, dicamba, diclofop, disulfoton, eptc, ethoprop, ethyl_para, fonofos, lindane, methoxychor, metribuzin, pcp, phorate, picloram, terbufos, toxaphene, triallate, and trifluraln.

Trihalomethanes (THMs)

bromodichloromethane, bromoform, chloroform, dibromochloromethane

Regulated Volatile Organic Compounds (VOCs)

benzene, carbon tetrachloride, 1,4-dichlorobenzene, 1,2-dichloroethane, 1,1-dichloroethene, 1,1,1-trichloroethane, trichloroethylene, vinyl chloride

Unregulated Volatile Organic Compounds (VOCs)

bromobenzene, bromochloromethane, bromodichloromethane, bromoform, bromomethane, n-butylbenzene, sec-butylbenzene, tert-butylbenzene, chlorobenzene, chloroethane, chloromethane, 2-chlorotoluene, 4-chlorotoluene, 1,2-dibromo-3-chloropropane (DBCP), ethylene dibromide (EDB), dibromochloromethane, dibromomethane, 1,2-dichlorobenzene, 1,3-dichlorobenzene, 1,4-dichlorobenzene, dichlorodifluoromethane, 1,1-dichloroethane, 1,1-dichloroethene, cis-1,2-dichloroethane, trans-1,2-dichloroethane, 1,2-dichloropropane, 1,3-dichloropropane, 2,2-dichloropropane, 1,1-dichloropropene, cis-1,3-dichloropropene, trans-1,3-dichloropropene, dimethylbenzene, ethylbenzene, hexachlorobutadiene, isopropylbenzene, methylene chloride, naphthalene, n-butylbenzene, n-propylbenzene, ortho-chlorotoluene, ortho-xylene, para-chlorotoluene, para-isopropyltoluene, sec_butylbenzene, styrene, tert_butylbenzene, 1,1,1,2-tetrachloroethane, 1,1,2,2-tetrachloroethane, tetrachloroethylene, toluene, 1,2,3-trichlorobenzene, 1,2,4-trichlorobenzene, 1,1,1-trichloroethane, 1,1,2-trichloroethane, trichlorofluoromethane, 1,2,3-trichloropropane, 1,2,4-trimethylbenzene, 1,3,5-trimethylbenzene, meta-xylene + para-xylene

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