BASELINE GROUND WATER QUALITY CONDITIONS AT IN SITU URANIUM WELLFIELDS IN WYOMING[1]

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Abstract: Interest in the ground water quality distributions at uranium in situ mining wellfields has increased because of the need to address differences in federal and state water quality standards and restoration requirements. There has been considerable discussion about the water quality distributions at *individual* wellfields because of specific operators' concerns (e.g., modifying a monitoring program). However, this is one of the first *overviews* of water quality distributions at wellfields in Wyoming. Three water quality parameters (Total Dissolved Solids (TDS), uranium, and radium) were evaluated at nine wellfields. These parameters were selected for information on overall water quality (TDS) and on water quality in the vicinity of the production zones (uranium and radium). Box and Whisker Plots were used to compare the TDS and Uranium concentrations in each production zone and surrounding monitor ring. Visually, the plots indicate that it is difficult to distinguish between TDS concentrations in a production zone and surrounding monitor ring, and the TDS concentrations are all below 1,200 milligrams per liter (mg/l) with the majority below 500 mg/l. In contrast, it is much easier to distinguish the uranium concentrations in a production zone because they are generally much higher than the concentrations in the surrounding monitor ring. This is confirmed by statistical analyses. Even so, the uranium concentrations in the production zone often do not exceed 0.03 mg/l, the Maximum Concentration Limit for uranium established by the U.S. Environmental Protection Agency for drinking water. Frequency histograms of radium concentrations in the production zones show scattered data, and most of the concentrations exceed 100 picoCuries per liter (pCi/l). In contrast, the majority of the radium concentrations in the monitor rings are less than 100 pCi/l, with most less than 20 pCi/l, and the higher concentrations are only in a few wells in the ring (generally in areas where the ore trend extends beyond the mining area). The limited contrast in TDS concentrations, as compared to the generally significant contrasts in uranium and radium concentrations, inside and outside a production zone must be taken into consideration in efforts to harmonize federal and state ground water quality standards and restoration criteria.

Additional Key Words: water quality monitoring, graphical analyses, statistical analyses.

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[1] Paper was presented at the 2006 Billings Land Reclamation Symposium, June 4-8, 2006, Billings MT and jointly published by BLRS and ASMR, R.I. Barnhisel (ed.) 3134 Montavesta Rd., Lexington, KY 40502.

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Proceedings America Society of Mining and Reclamation, 2006 pp 246-259
DOI: 10.21000/JASMR06010246
http://dx.doi.org/10.21000/JASMR06010246

Introduction

Attention to the water quality distributions at uranium in situ mining wellfields has increased in the last few years because of the rekindled interest in uranium mining and the need to address two primary regulatory concerns:

- ✓ Separate federal and state approaches to ground water quality standards; and
- ✓ Different federal and state ground water restoration requirements.

There has been considerable discussion about the water quality distributions in the vicinity of *individual* wellfields because of operator requests to modify monitoring programs, add new wellfields, and obtain approval of restoration efforts from the Land Quality Division (LQD) of the Wyoming Department of Environmental Quality (WDEQ). However, there has not been a comparable *overview* of water quality distributions at wellfields in Wyoming to address the broader concerns listed above. In addition, questions about water quality distributions at wellfields were raised at various meetings of the Environmental Quality Council and respective Advisory Boards for the LQD and the WDEQ Water Quality Division (WQD). However, those questions could generally not be answered with the evaluations available at the time.

From a technical standpoint, the purpose of this paper is to provide an overview of the distribution of three water quality parameters (Total Dissolved Solids (TDS), uranium, and radium) at nine commercial wellfields prior to mining. The three parameters were selected to provide information on overall water quality (TDS) and on water quality in the vicinity of uranium ore zones (uranium and radium). The nine wellfields were selected to include both older and newer wellfields at the three largest in situ mines that are either in operation or in restoration in Wyoming. The nine wellfields (or mine units) at the respective mines are:

- $ Wellfields B, E, and I at Power Resources Inc. Highlands Project (LQD Permit No. 603);
- $ Mine Units 2 North, 4, and 6 at COGEMA Mining, Inc.'s Christensen Ranch Project (LQD Permit No. 478); and
- $ Wellfields 2, 4, and 15 at PRI's Smith Ranch Project (LQD Permit No. 633).

For simpler reference in the text, the mine names have been abbreviated (Highlands - H; Christensen Ranch - CR; and Smith Ranch - SR), and the terms 'wellfield' and 'mine unit' omitted. For example, Wellfield "B" at PRI Highlands is abbreviated as H-B.

From a regulatory standpoint, the purpose of this paper is to provide a preliminary basis for evaluating whether the current federal and state in situ mining regulations adequately take into account the baseline water quality distributions.

Collection of Baseline Ground Water Quality Data

At in situ uranium mines, baseline data is collected from monitoring wells to provide information for evaluating both mining efficiency and environmental impacts. This data is then used by the operators and WDEQ to evaluate proposed mining activities, mining impacts, and ground water restoration success. The monitoring wells are generally located:

- < On the perimeter of the wellfield from wells in the monitor ring, which is designed to detect horizontal excursions from the production zone; and

< Among the production and injection wells to evaluate water quality changes in the production zone during mining and restoration.

Baseline data is also collected from overlying and/or underlying sandstones to detect vertical excursions, if there are no thick shale layers (e.g., >50 feet thick) between the ore zone and those sandstones. The data from overlying and underlying sandstones was not evaluated for this paper because of the focus on the conditions in the sandstones containing ore zones.

In general during baseline sampling, three samples are collected from each monitoring well for the same set of parameters over a period of a few weeks. For the following analyses, 'non-detect' concentrations were assigned the value of the detection limit for that sample.

Range & Distribution of Baseline TDS, Uranium, and Radium Concentrations

To illustrate the typical layout of an in situ uranium mine, the locations of all the wellfields at one of the mines is shown on Fig. 1. In general, the uranium wellfields are long and narrow, following the trend of the roll-front ore deposits common in Wyoming . Wellfields may separated along an ore trend because of 'gaps' in the occurrence of *economically recoverable* ore or other practical reasons such as development schedules. However, there may still be increased uranium concentrations in those gaps relative to areas outside the ore trend, especially as the assessment of economically recoverability varies with time. Some wellfields are isolated, again based on the distribution of economically recoverable ore. In general, overlapping wellfields are due to the occurrence of ore zones in different sandstone layers. The permit boundary generally encompasses much more area than just the wellfields due to leasing considerations and other practical issues, as well as potential future development.

Well averages were used for mapping the baseline concentration distributions because the well averages are used by WQD to classify the baseline ground water quality per Table I in Chapter 8 of the WQD Rules. This classification is critical because it forms the basis for the ground water restoration requirements.

For space considerations, maps of the baseline well locations and associated TDS, uranium, and radium concentrations are presented for three of the nine wellfields evaluated for this paper, rather than all nine. The three wellfields were selected to illustrate how varied the distributions may be, particularly the distributions of uranium and radium.

TDS

The highest average baseline TDS concentration in any of the wells in the nine wellfields was just under 1,200 milligrams per liter (mg/l), substantially less than the 5,000 mg/l upper limit for Class III - Livestock ground water per WQD Chapter 8. In six of the nine wellfields, almost all of the TDS concentrations were less than the 500 mg/l upper limit for Class I - Domestic ground water. Therefore, the TDS distributions shown on the maps (Figures 2a through 2c) were separated on the basis of concentrations less than 500 mg/l and concentrations between 500 and 1,200 mg/l.

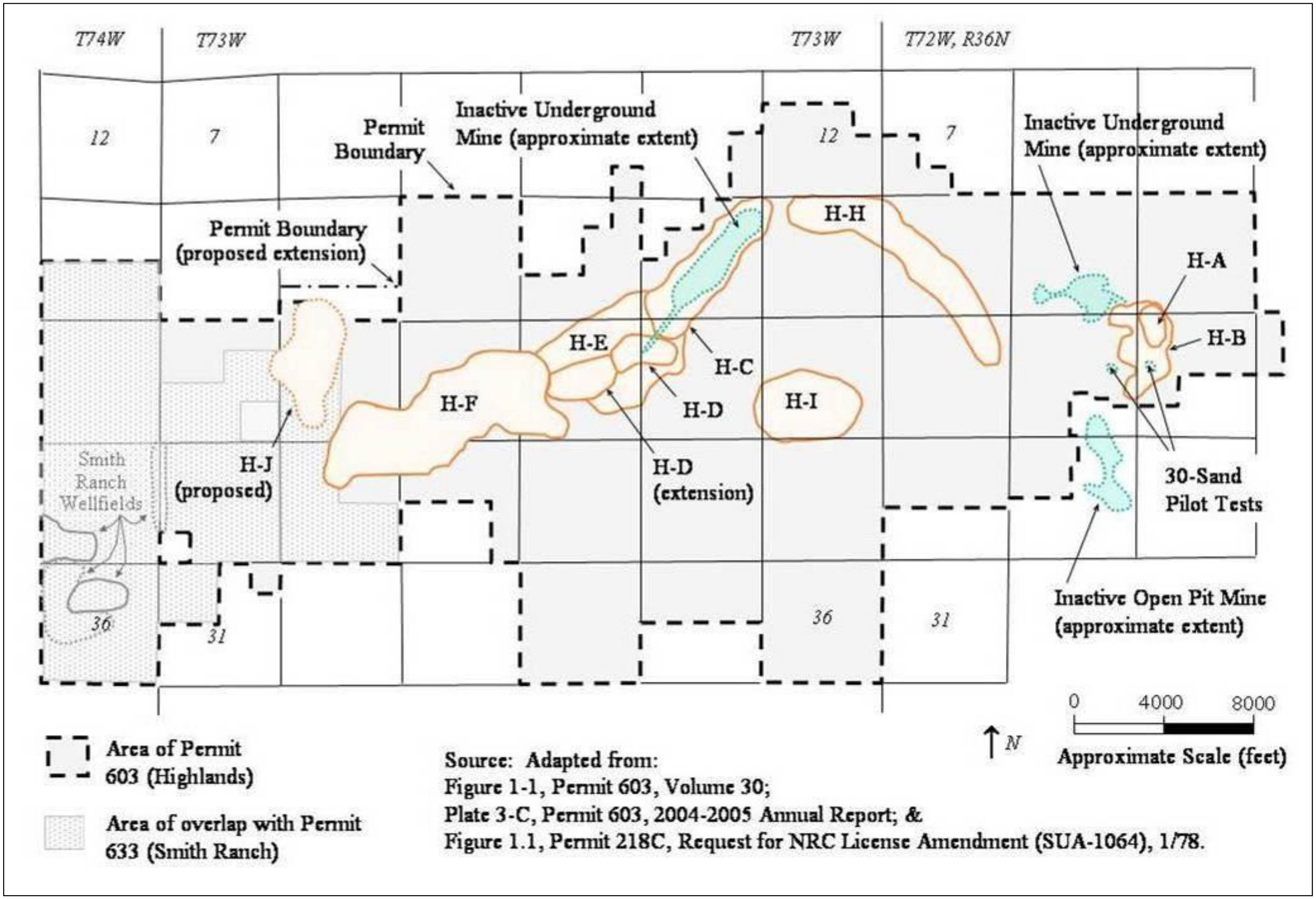


Figure 1. Location Map - Wellfields at PRI's Highland Uranium Project in Wyoming.

In general, higher TDS concentrations are associated with specific wellfields, not scattered throughout the wellfields. For example, none of the TDS concentrations in H-B exceeded 500 mg/l, and most concentrations were on order of 350 mg/l. In contrast, all of the TDS concentrations in CR-6 exceeded 500 mg/l, with most concentrations on the order of 875 mg/l. Therefore, elevated TDS concentrations are not a good 'indicator' of a uranium ore zone in a given area, as discussed in more detail in the section on statistical analyses.

Uranium

The range in uranium concentrations in the nine wellfields is extensive - from non-detect, at a detection limit of 0.003 mg/l, to 0.6 mg/l, with a single exception of 12 mg/l. The exceptionally high values are possible considering the depositional history of the uranium ore, although their presence may also indicate laboratory error (particular if only a single sample is available for a well) or uranium dissolution due to oxidized conditions resulting from exploration drilling, research projects, or other uranium mining activities such as underground mining (Figure 1).

Despite the wide range in the uranium concentrations, the uranium concentrations *even in the production zone* are not always high enough to be of concern from a water quality perspective. The distributions of uranium concentrations shown on the maps were separated on the basis of concentrations less than or greater than the Maximum Contaminant Limit (MCL) of 0.03 mg/l dissolved uranium set by the U.S. Environmental Protection Agency (EPA) for public drinking water supplies. In only one wellfield of the nine wellfields did *all* the baseline concentrations in the *production zone* exceed 0.03 mg/l. In three other of the wellfields, over half the concentrations in the production zone exceeded 0.03 mg/l. However, in the remainder, half or less of the concentrations in the production zone exceeded 0.03 mg/l.

In almost all the monitor ring wells, the baseline uranium concentrations were less than 0.03 mg/l. In some wellfields, the elevated uranium concentrations in the monitor ring wells are apparently associated with the ore trends. For example, in H-E, the only elevated uranium concentration is to southwest of the production zone, following the southwest-northeast ore trend (Fig. 2a). In other wellfields, the reason for an elevated uranium concentration in a monitor ring well is not apparent. For example, in CR-4, the only elevated uranium concentration in the monitor ring is relatively isolated (Fig. 2b). In all but one wellfield, only four or fewer of the monitor ring wells had uranium concentrations greater than 0.03 mg/l, and in two wellfields, none of the concentrations in the monitor ring exceeded 0.03 mg/l. The one exception was in SR-15 in which just over half of the wells had uranium concentrations over 0.03 mg/l (Fig. 2c). Because this wellfield is isolated, the reason for the elevated uranium concentrations, such as location within an ore trend, is not readily apparent.

Even though the uranium concentrations in the production zones and monitor rings are not consistently high from a water quality perspective, there is generally a significant difference in the concentrations in a production zone as compared to its corresponding monitor ring. This difference is further discussed in the section on statistical analyses.

Radium

Similar to the uranium concentrations, the range in radium concentrations is extensive - from less than 1 picoCuries per liter (pCi/l) to almost 2,000 pCi/l. In addition, the concentration gradient between a production zone and its corresponding monitor well ring is substantial. Because of the substantial gradient, the distribution of radium was evaluated on the basis of concentrations: less than 5 pCi/l; between 5 and 100 pCi/l; and greater than 100 pCi/l. The mine operators generally only analyze ground water samples for dissolved Ra-226 because they believe the Ra-228 concentrations are usually much less than the Ra-226 concentrations. The EPA MCL for dissolved Ra-226+228 is 5 pCi/l, as is the WQD limit for total Ra-226+228 for Domestic and Livestock classifications. The WQD 'treatability limit' for a Domestic classification was 100 pCi/l total until a few years ago when the limit was restricted to 5 pCi/l.

Table I lists the number of wells in both the production zone and monitor well ring with concentrations above and below 500 mg/l. Within the production zones, the vast majority of the radium concentrations exceeded 100 pCi/l. However, in the monitor rings, the radium concentrations in almost 60% of the wells were less than 5 pCi/l, and in almost 80% of the wells were less than 10 pCi/l. Most monitor ring concentrations over 10 pCi/l were from one wellfield (SR-2). The substantially different radium distributions in the production zones and monitor rings are discussed in more detail in the section on statistical analyses.

In the production zones, the highest and lowest radium concentrations seem to be concentrated in separate wellfields. For example, in the H-E and SR-15 production zones, all but one of the radium concentrations exceeded 100 pCi/l (Fig. 2a and 2b). In contrast, none of the radium concentrations in the production zones in CR-4 exceeded 100 pCi/l (Fig. 2c). In the monitor rings, the higher radium concentrations can be associated with the ore trend in a given wellfield, similar to the uranium distribution. For example, in H-E, the elevated radium concentrations were generally to the southwest of the production zone, which follows the southwest-northeast ore trend (Fig. 2a). However, the reason for the radium distribution is not always readily apparent (Fig. 2b and 2c).

Statistical Analyses

Statistical analyses are grouped by the type of analysis. The statistical analyses were selected to provide for additional comparison of the TDS, uranium, and radium concentrations *among* all the production zones and monitor rings and *between* the individual production zones and their associated monitor rings. All the data from the wells, rather than the well averages, were used for the statistical analyses to provide more information on the variability of the data. The statistical analyses were performed using StatGraphics Plus software, Version 5.1. Similar to the water quality distribution maps, box and whisker plots and frequency distribution graphs are presented for some, rather than all, of the wellfields due to space considerations.

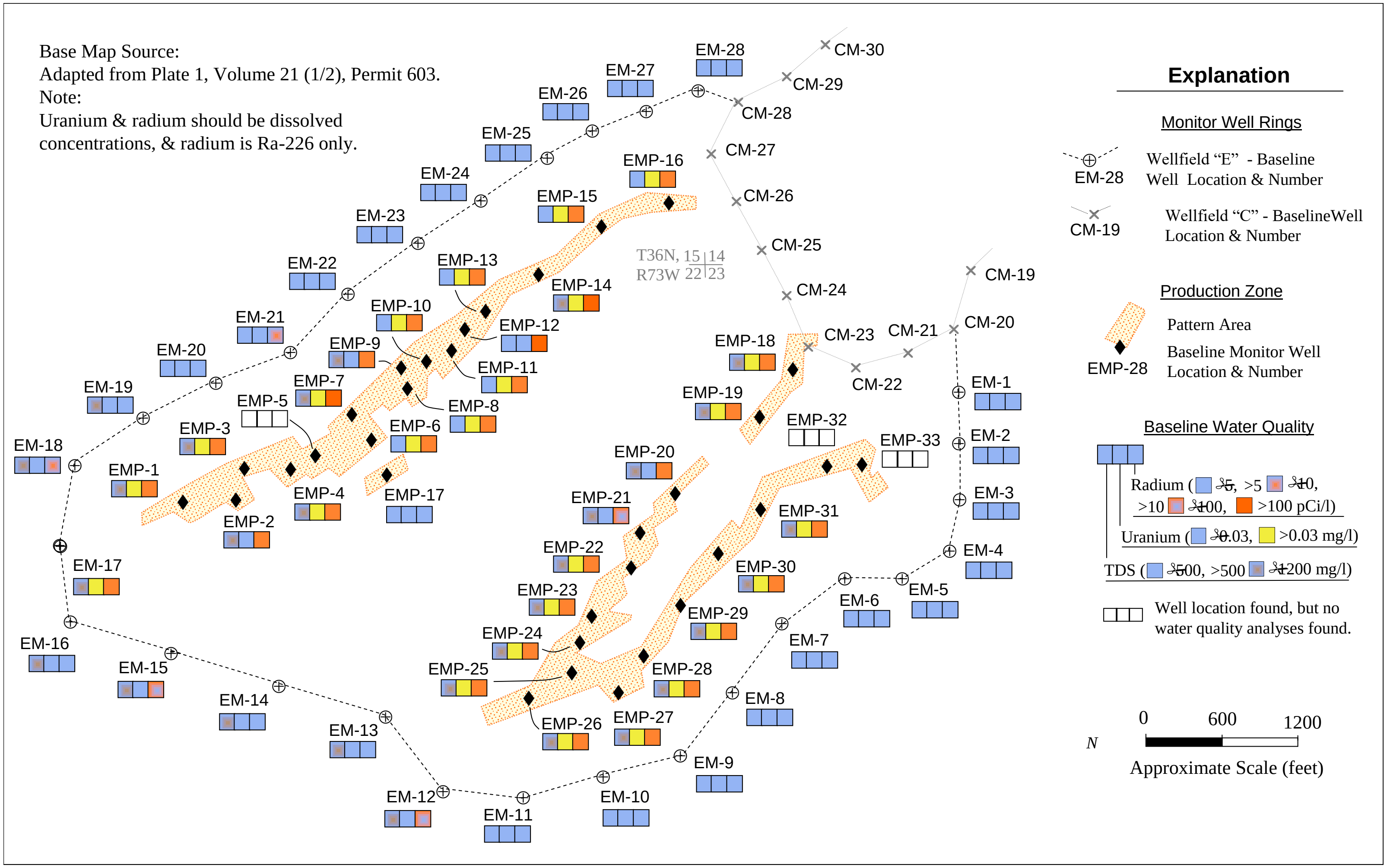


Figure 2a. Well & Production Zone Locations and Baseline Concentrations of TDS, Uranium, & Radium - Wellfield H-E.

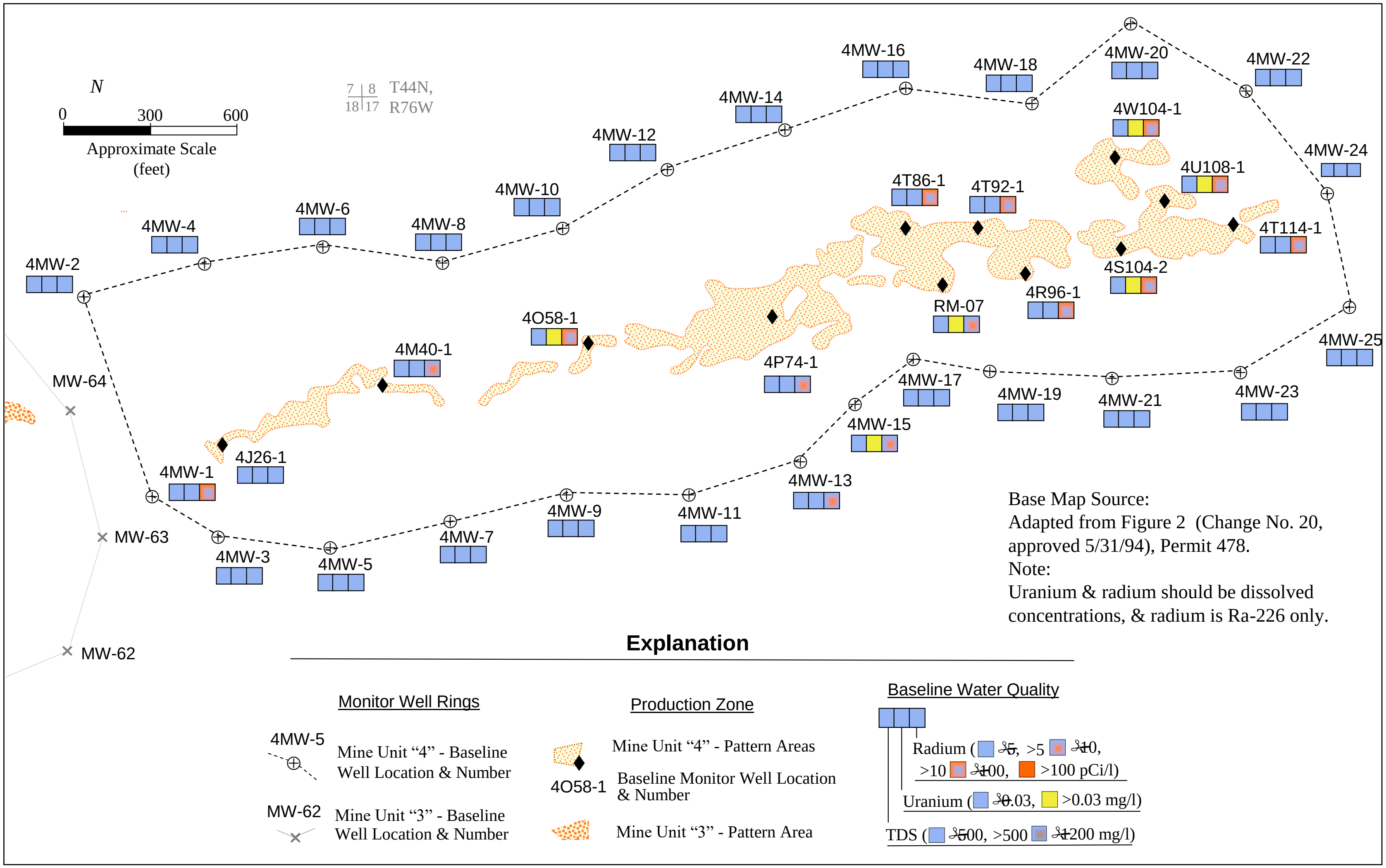


Figure 2b.Well & Production Zone Locations and Baseline Concentrations of TDS, Uranium, & Radium - Wellfield CR-4.

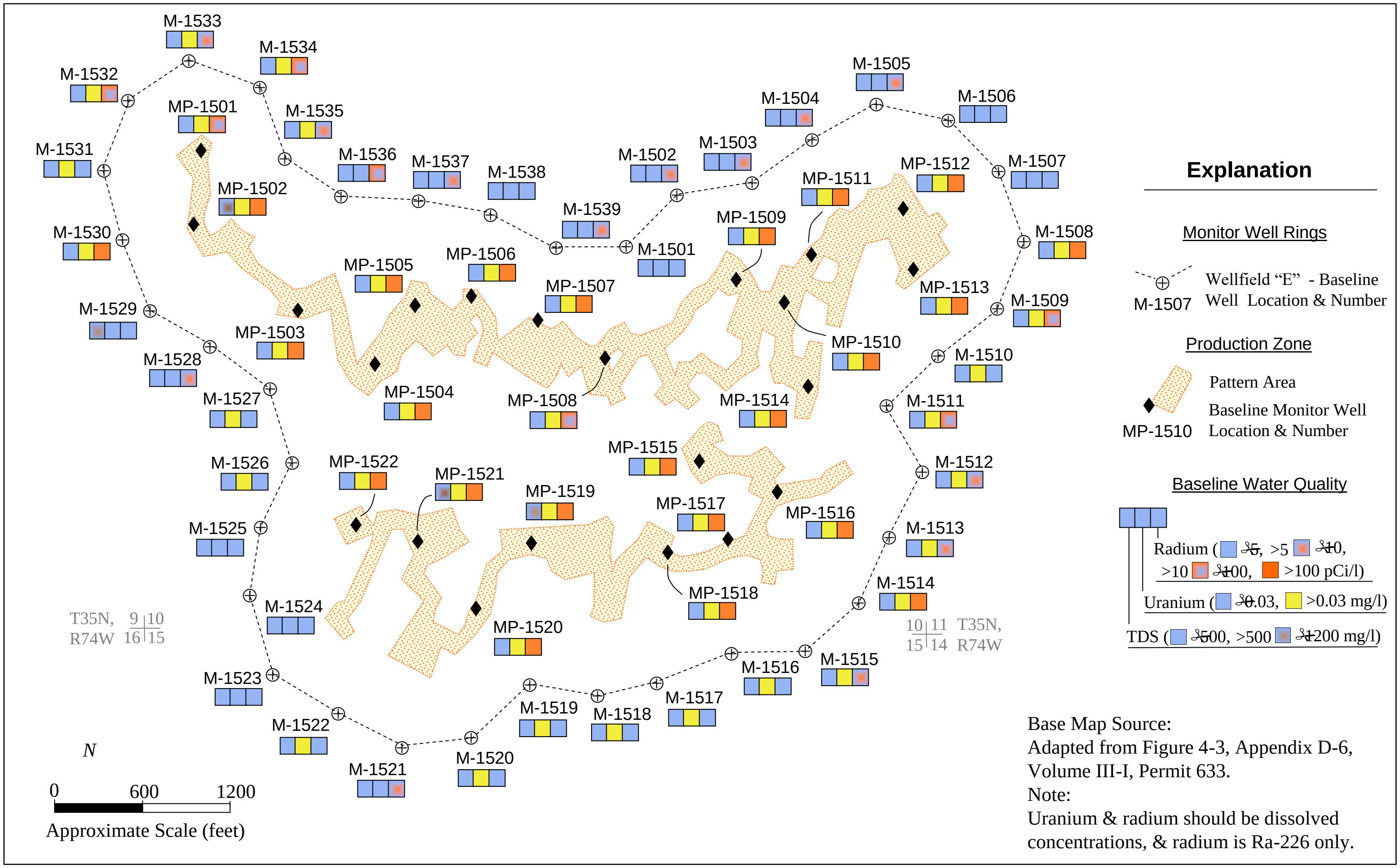


Figure 2c. Well & Production Zone Locations and Baseline Concentrations of TDS, Uranium, & Radium - Wellfield SR-15.

Box and Whisker Plots - TDS and Uranium

Plots of TDS and uranium concentrations for three of the nine wellfields (H-E, CR-4, and SR-15) are shown on Fig. 3. For TDS, the production zone plot and associated monitor ring plot for each wellfield generally appear very *similar*. In contrast, for uranium, the production zone plot and monitor ring plot appear very *different* for all the wellfields but CR-6. Statistical comparison of the production zone and monitor ring medians indicate a significant difference in TDS medians in four of the wellfields (H-B, H-E, CR-2N, and CR-4) and a significant difference in uranium medians in *all* the wellfields. Median concentrations from the production zones and monitor rings were used for the statistical comparisons because the concentrations in many of the production zones and monitor rings are not normally distributed.

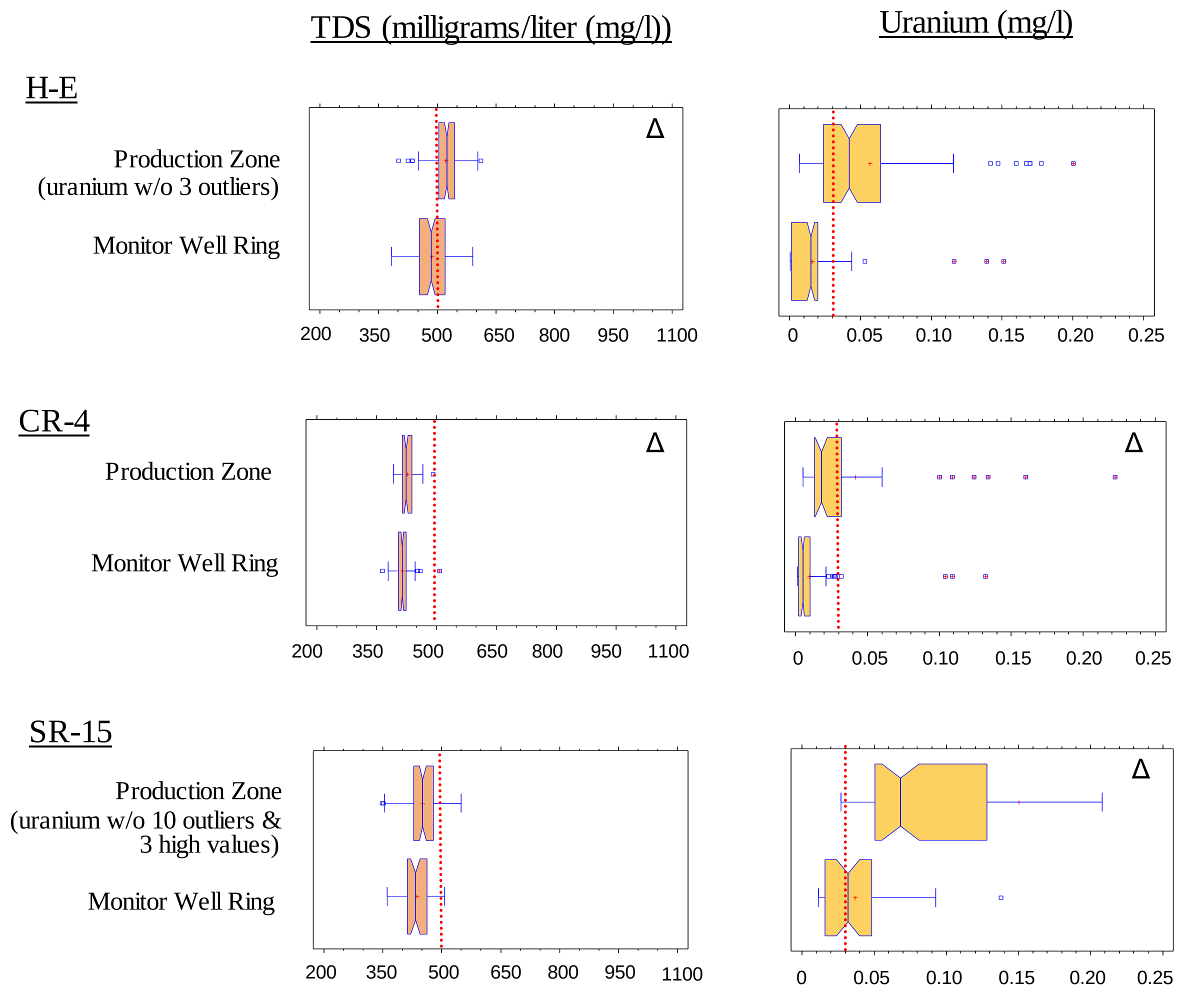
The relatively *narrow* range of TDS concentrations in a given wellfield and the absence of numerous outliers are also apparent on Fig. 3. In contrast, the *wide* range of uranium concentrations is evident, as is the presence of numerous outliners, some of which were omitted from the plots so the scale would be reasonable. All instances in which outliers are not shown are noted on the plots.

The WQD limit of 500 mg/l TDS for Class I - Domestic ground water classification is shown as a dotted line on each TDS plot. The general distribution of TDS values either above or below this limit in a given wellfield is readily apparent, although the values in H-E straddle the limit, and this confirms the evaluation of the TDS distribution maps. The EPA MCL of 0.03 mg/l uranium for drinking water is shown as a dotted line on each uranium plot. On all the monitor ring plots, except the plot for SR-15, the majority of the uranium values are less than 0.03 mg/l, which confirms the evaluation of the uranium distribution maps.

Also, even though the wellfields at Christensen Ranch are generally somewhat smaller than the wellfields at Highland and Smith Ranches, there is no corresponding decrease in the range of either TDS or uranium concentrations. In addition, the three wellfields with the higher TDS concentrations are not from the same mine (H-E, SR-2, and CR-6), and the three wellfields with the higher uranium concentrations are not from the same mine (H-E, SR-2, and SR-15). No statistically significant correlations were found among the median TDS and uranium concentrations in the production zones and monitor rings.

Frequency Distributions - Radium

Figure 4 provides an example of the radium distributions in the production zone and associated monitor ring in H-E. The radium distribution in the production zones is quite scattered, and most of the concentrations exceed 100 pCi/l, as illustrated in the upper graph on Fig. 4. In contrast, the vast majority of the radium concentrations in the monitor ring are less than 100 pCi/l. In those instances where radium concentrations do exceed 100 pCi/l in the monitor ring, the high concentrations are from only one well or a few wells. When the values from that well (or wells) are removed, the majority of the concentrations are less than 5 pCi/l. For example, in lower left graph in Figure 4, the radium values from only one well (Well EM-17) exceed 100 pCi/l. Once the values from that well are removed from the distribution, all the remaining radium values are less than 25 pCi/l as shown on the lower right graph in Fig. 4. H-E is typical of all nine wellfields, with the exception of SR-15 in which the radium concentrations in the monitor ring are scattered between about 5 and 50 pCi/l.



For TDS, the dotted line at 500 mg/l represents the WQD classification limit for Class I -Domestic ground water. For uranium the dotted line at 0.03 mg/l represents the EPA drinking water standard.

Δ in the upper right corner of a plot indicates the production zone and monitor ring medians are significantly different.

Figure 3. Box-and-Whisker Plots of Baseline TDS & Uranium Concentrations in Ground Water at Three In Situ Uranium Wellfield in Wyoming.

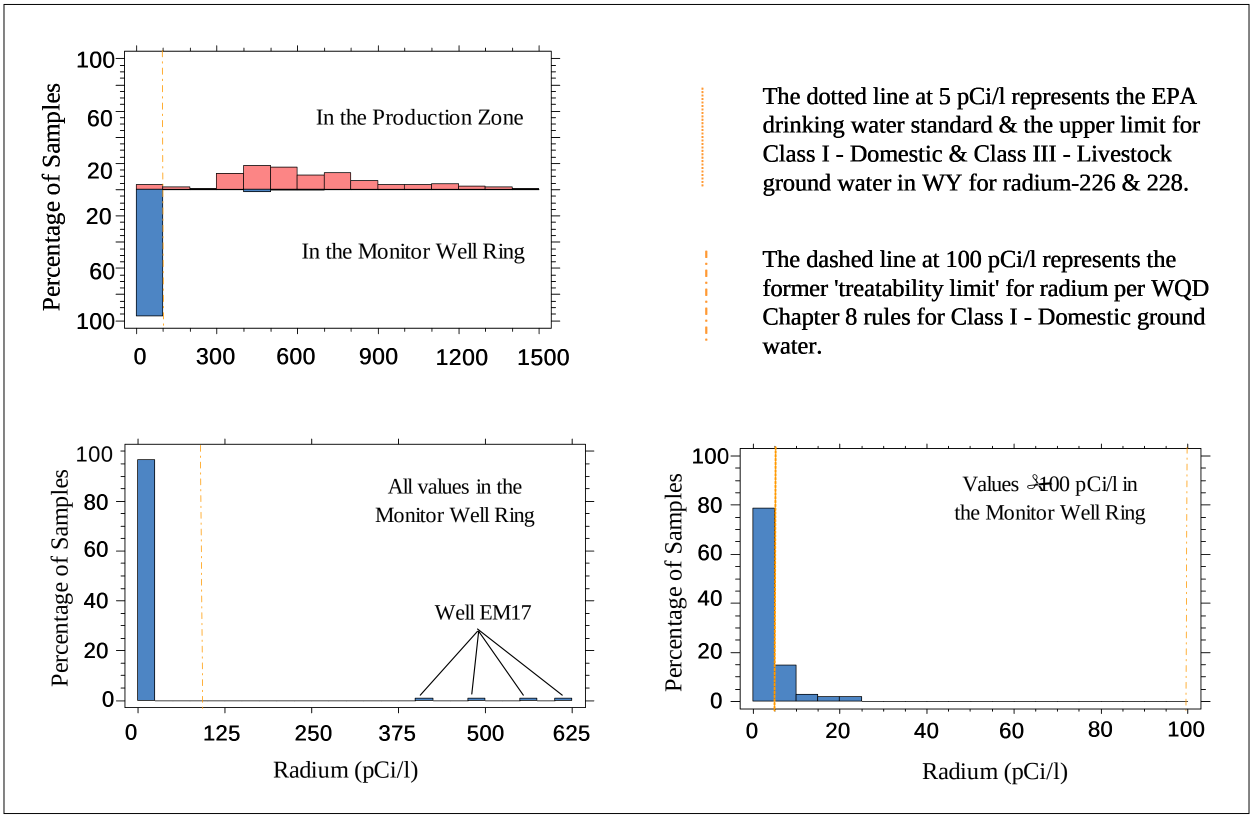


Figure 4. Graphs of Baseline Radium Frequency Distribution the Production Zone and Associated Monitor Ring at an In Situ Uranium Wellfield in Wyoming.

Recommendations

The baseline water quality conditions in the State of Wyoming create some unique concerns for uranium mine operators, regulators, and ground water users. There are significant water quality differences inside and outside most uranium production zones, but these differences are generally limited to a very specific set of parameters, specifically radionuclides. These parameters often not part of >routine= water quality analyses that might be done by rural water users. In addition, the regulatory approaches of those federal and state agencies involved in the regulation of in situ uranium mining (EPA, Nuclear Regulatory Commission (NRC), and WDEQ) have developed along different paths. The following are just a few recommendations intended to highlight possible actions that could improve the understanding of the water quality distribution near uranium deposits and harmonize the regulatory requirements.

Technical Topics

Considerable data is available on water quality in the vicinity of uranium deposits, although due to the limited interest in uranium in recent years, much of the data has been relegated to archives.

Additional Data Interpretation. There are four suggestions for additional data interpretation. First, there are several more in situ wellfields in Wyoming from which baseline data is available. The analyses in this study should be expanded to include this data. Second, data from aquifers overlying and underlying the existing wellfields should be incorporated into the analysis. Third, data from areas where it may be possible to distinguish uranium ore zones, other than those in delineated wellfields, should also be incorporated. This data could include data from the vicinity of open pit uranium mines and from areas of exploration, although the latter may be proprietary. Fourth, the distribution of parameters other than TDS, uranium, and radium may provide more insight on the water quality distribution in the vicinity of uranium ore zones.

Continued Data Collection. There are four suggestions for continued data collection. The first is to update the analyses in this report as data from new wellfields becomes available. The second is to compare data on ore distribution in the aquifer matrix with the water quality data to determine how closely the water quality 'mirrors' the ore distribution. However, the ore distribution data may be considered proprietary unless the ore has been mined. The third is to develop a better understanding of the distribution of oxidation/reduction conditions in the vicinity of the uranium ore zones. This understanding is considered essential for improved discussions of mining efficiency and restoration effectiveness after mining. Therefore, improved and/or additional collection of data such as oxidation/reduction potential (eH) and iron species, is necessary. The fourth recommendation is to evaluate the distribution of radon near wellfields; however, collection of radon data is not currently required.

Geographic Information Systems (GIS). Most of the wellfields were developed before the advent of Geographic Information Systems, and many of the available maps and drawings are not georeferenced. The information on the maps and drawings would be easier to incorporate into the data analysis if it were in a GIS-compatible format.

Regulatory Topics

To date, the water quality protection requirements for an in situ mine have generally been based on operators' delineations of the production zones and monitor rings rather than the baseline water quality distribution. For the production zones, the delineations are generally based on ore grade and economic recoverability rather than on water quality and related subsurface conditions such as the reduction/oxidation (redox) potential in the aquifer. In addition, not all operators necessarily use the same criteria to delineate production zones. For the monitor rings, the locations are dependent on aquifer transmissivities to ensure any excursions can be detected quickly. In Wyoming wellfields, the distances from the production zones to the monitor rings are generally similar, on the order of 400 to 600 feet.

Despite the limited attention to baseline water quality in delineating production zones and selecting monitoring locations inside and outside the production zone, the existing system has generally proven protective of waters outside the production zones. However, as uranium mining expands, as mining of more complex uranium deposits is attempted, and as additional pressures on limited ground water resources are encountered, a better understanding of the relationship between the ore distribution and water quality conditions is necessary as is education of the various water users.

Water Quality Distribution. The ore trends and the statistical distribution of the water quality data need to be kept in mind in any discussions of water quality protection requirements. With respect to the ore trends, the often abrupt differences in water quality perpendicular to the ore trend and the generally more gradual differences along the ore trend may be overlooked in efforts to simplify the characterization of subsurface conditions at uranium mines In addition, ground water restoration after mining may be complicated by the fact that the trend may be perpendicular to the overall direction of ground water movement. With respect to the statistical distribution of the water quality data, WQD currently allows averaging of the data from the baseline wells in a production zone to establish the ground water classification of that zone. The averaging is allowed in recognition of the mixing that will occur in that zone during mining. In contrast, WQD classifies each well in the monitor ring on an individual basis. However, several aspects of the 'averaging' approach need clarification, such as use of averaging after ground water restoration and whether the median would be more appropriate than the average based on the data distributions.

Education. There are an increasing number of ground water users in Wyoming and, as a result, an increasing pressure on limited water resources. Neither the federal or state regulatory agencies have water quality requirements for individual drinking water wells or for livestock wells, in part due to the difficulties of trying to monitor and enforce any such requirements. Although there may be water well sampling requirements established by local governments or by lending institutions, and federal agencies have water quality guidelines, these requirements and guidelines often do not recognize the potential impact of mineral deposits, such as uranium, on water quality. As a result, parameters such as uranium and radium are often not included in the analyses. The public has become increasingly aware of water quality issues, including the health risks associated with inorganic parameters such as arsenic, and an effort to increase awareness of concerns related to naturally-occurring uranium ores may also be beneficial and avoid potential water use conflicts in the future.