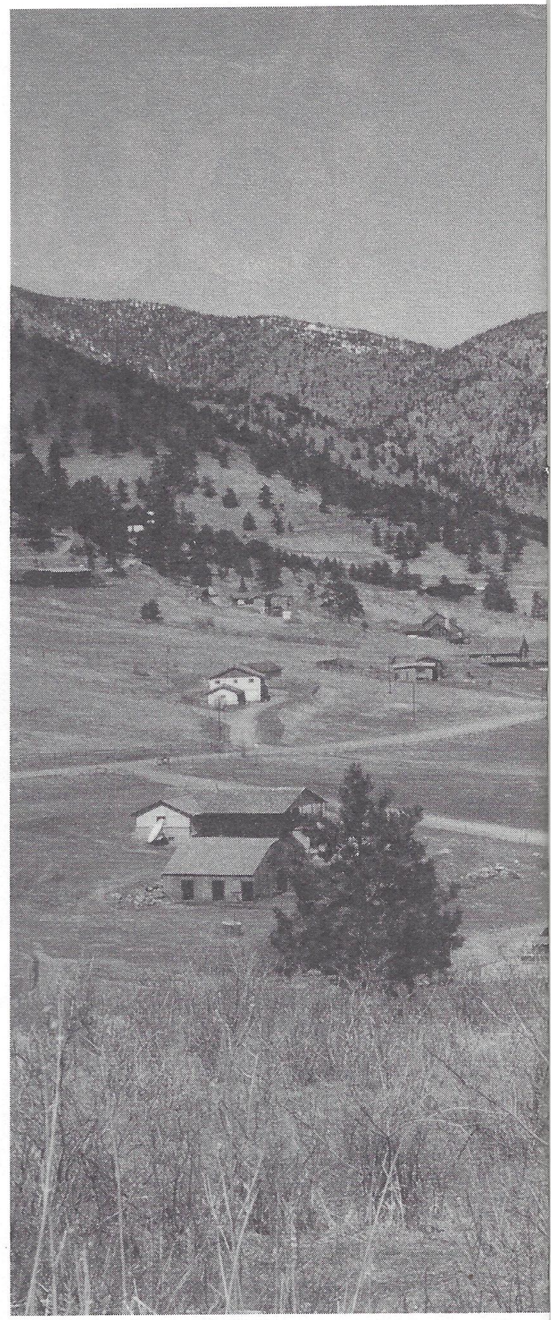
American Water Works Association
journal
MAY 1992

Small Systems

- Viability and Visibility
- Volunteers: A Key to Success
- Treatment Options

also this month

- Defined-Substrate Tests for E. coli



Volunteers Integral to Small System's Success

Joseph U. Tamburini and William L. Habenicht

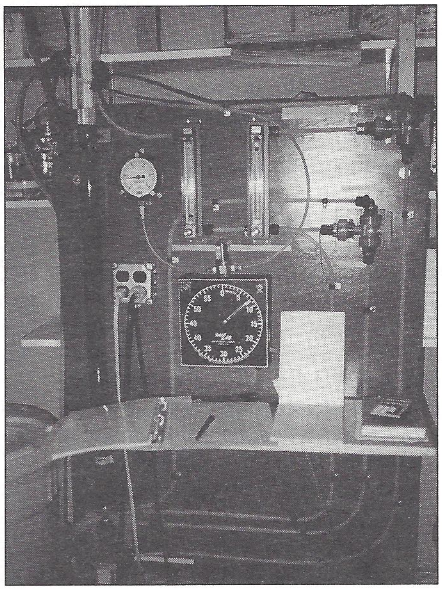
A subdivision in the foothills of Colorado's Rocky Mountains has built a small system whose water meets or exceeds state and federal guidelines. Eighty-four homes are connected to the system, which can potentially accommodate 125 homes. The unique geologic setting introduced water quality problems such as radioactive contaminants as well as more conventional iron and corrosion problems. Communitywide support and involvement assured the success of the project, which was accomplished without outside subsidies. Community residents with expertise in geology, engineering, construction, and financial and business management volunteered their help to design, build, and maintain the system. This donated expertise is estimated to have saved the water district $300,000 to date. In addition to local expertise and volunteerism, the author considers other issues of importance to small systems: responsible interest in health effects, planning on a small system level, and contract management guided by engineering expertise.

Most small water systems serve low-income communities in the nation's economic backwaters. The people who live there, busy maintaining a grip on the bottom rung of the socioeconomic ladder, may feel discouraged by the problems of creating a quality small system. And the problems are many: limited economies of scale, uncertain system reliability, increasing regulations and testing requirements, and limited funds for professional services, startup, and operations and maintenance.

In Blue Mountain, a small subdivision near Denver, residents also faced those problems when their private wells failed and they realized they needed a community water system. Yet they successfully developed a reliable system whose water meets or exceeds federal and state regulations, and they did it without outside financial help. They succeeded primarily because of community involvement and support—qualities that are available, of course, to all communities. In addition, they capitalized on advantages not often available in small communities.

Proximity to metropolitan area enhances property values

Although it is geographically isolated in the semiarid foothills of the Rocky Mountains, Blue Mountain is just 27 miles from a thriving capital city. Nearly everyone in the subdivision owns his or her property and is concerned about maintaining its value. Most residents have satisfactory incomes; many are professional business people, scientists, or engineers. The professional expertise volunteered by those residents has made a crucial difference to the water system at each stage of its development.



Blue Mountain's water meets the community's self-imposed limit of 10 pCi/L for uranium. The pilot unit above was used to select the best option for uranium removal. The Colorado community is pictured at left.

The Blue Mountain Water District (BMWD) was formed in 1977 to serve the Blue Mountain Subdivision. The subdivision, about a square mile in size and varying in elevation between 6,600 and 7,600 ft mean sea level, is in an area of dramatic vertical rock formations formed when the Rocky Mountains uplifted and broke through the sedimentary rock layers of the plains.

The subdivision has three areas: Eastridge, Westridge, and Valley Floor. Eastridge and Westridge provide spectacular views of Denver on the plains below; the Valley Floor is nestled between the ridges and rock formations. Although the average size of the 125 buildable lots is 5 acres, the amount of natural recharge to the alluvial wells was less than withdrawal. Eventually, as more people moved into the subdivision, a significant number of individual home wells went dry.

Dry wells prompt community effort

Development of the subdivision began in the early 1960s; today there are 300 residents in 89 homes. Since the beginning, the strong sense of community spirit has been the most important factor explaining Blue Mountain's success. Because the subdivision is geographically isolated, residents have traditionally joined forces to get things done, from installing telephone, gas, and power lines to battling destructive pine beetles.

Water shortages were evident as early as 1968. In 1976, when numerous wells began going dry, when cisterns and pumps had to be installed and vehicles had to be purchased or modified to haul water, the community realized another cooperative effort was needed. Residents formed a water district and elected volunteers to a board that has consistently placed the good of the community above power politics and ambition. Board members and others in the community have contributed a high level of business or technical expertise. Equally important, especially in the early years, was the willingness to do manual labor.

Community support for the water board has been strong and is enhanced by excellent communication, both informally and through formal newsletters and presentations at annual homeowners' meetings. The only complaints came from one or two new residents, who hadn't experienced the water problem first hand, when the water district's bond principal—and thus the mill levy—doubled. As one long-time resident put it, "Every morning when I turn on the tap and water comes out, I'm thankful for the water district."

Board members volunteer time

For a small system and community, the proper technical advisors, whether volunteer or hired, are key elements for success. In Blue Mountain, residents selected extremely capable individuals to organize and form a special district as a quasi-municipal subdivision of the state of Colorado. Among the first board members were a metallurgist, a geologist, a plastics manufacturer, and an equipment sales representative–developer. All were volunteers, although state statutes allow payment of up to $35 per meeting per member.

After the legalities of forming the district had been concluded, the first task was to find a water source and fund the required improvements. The engineering report used as a service plan to form the BMWD identified the total system cost (not including easement acquisition or service lines) at about $632,000 and recommended construction in two phases. Phase 1, estimated to cost $432,000, would encompass all of the developed areas except Westridge. Phase 2 would serve the eight homes and sixteen vacant lots in Westridge and would cost $200,000. The total assessed valuation of the BMWD in 1976 was about $796,000. Because BMWD did not qualify for Farmers Home Administration grants or loans or for any other federal or state financial aid programs, the entire system would have to be financed without subsidy.

The customary maximum bond sale was half the assessed valuation, in this case about $400,000. The board decided to accomplish the entire project in one phase and convinced financial advisers to issue $600,000 of bonds. The board also set up a graduated tap fee schedule with the purpose of encouraging early tap purchases by residents. The fee escalated from $2,400 the first six months to $3,000 when the project was bid. The tap fee rose to $3,500 after construction began and to $5,000 after construction was complete and water was available. Excellent early tap fee sales generated an additional $120,000 in immediate capital. Armed with $700,000, members of the BMWD board went to look for a water source.

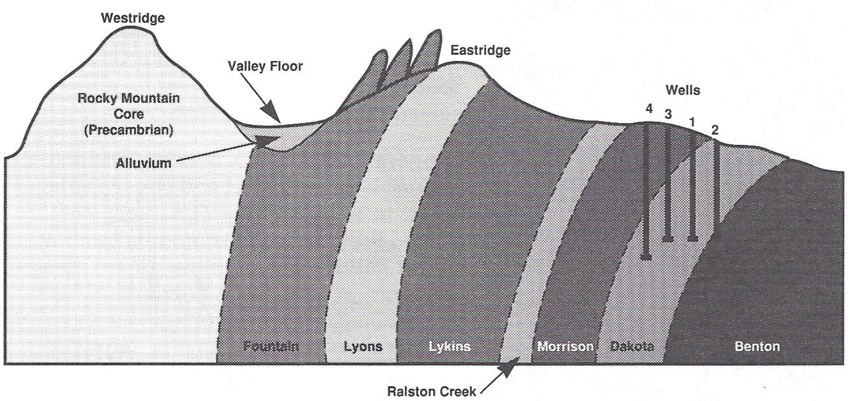


Figure 1. This cross section illustrates geologic formations including the Dakota Sandstone, where BMWD drilled four wells

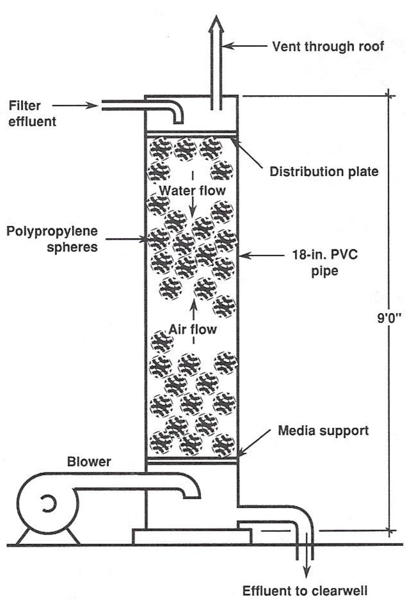


Figure 2. The packed-tower aerator removes 96 to 99 percent of the radon gas that was discovered in all four wells

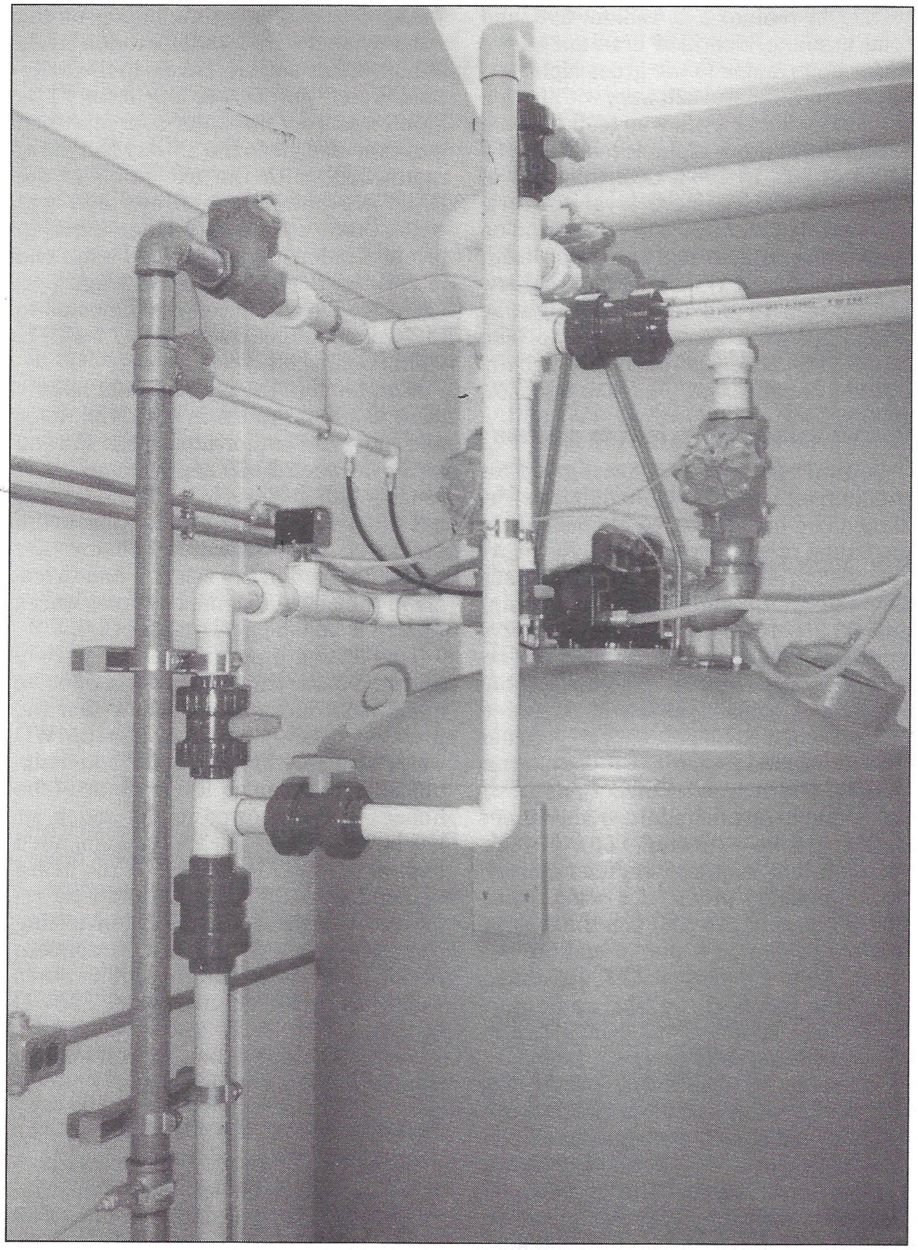
Three geologists who lived in Blue Mountain, one of them a board member, evaluated the recommendations of groundwater geologists involved in the service plan study completed in 1977. The Blue Mountain geologists recommended the Eastridge hogback as the preferred water source. The hogback was formed when the Rocky Mountains uplifted through the sedimentary rock layers and folded the sedimentary rock back on itself (Figure 1). The geologists believed that the highly fractured areas in the fold of the Dakota Sandstone formation would contain significant amounts of water.

According to the state engineer's records, attempts before 1976 to dig wells in the formation had disclosed problems related to both quantity and quality of water. Nonetheless, the alternative—a surface water–alluvial well source from nearby Coal Creek—was judged to be riskier because the creek frequently dries up. Two wells were subsequently drilled in the Eastridge hogback. Tested pumping rates averaged 25 gpm, and water quality tests showed that all parameters were within Colorado Primary Drinking Water Standards. The second hurdle had been cleared. (Interestingly, the alluvial well alternative the board had decided against was attempted without success in 1978 by the rancher who owned the land.)

Construction completed in seven months

With money in the bank and a water source secured, the board devoted its attention to the construction of the system. Landowners donated all easements. The water system was designed and bid early in 1978, and construction began in May. The project was divided into two contracts, one for pipelines and the other for a pumping station and storage tank. Fortunately, the low bidder on the pipeline contract had considerable experience in mountain construction, and construction workers were capable of handling the rock excavation and the steep slopes. The board's less fortunate experience with the other contractor could be the subject of another article but is not described here.

The system was constructed, tested, and operational by the end of 1978. As a matter of fact, the water was turned on to several residences at about 6:00 p.m. Dec. 31, 1978. The fact that the first residence connected to the new system also happened to be the location of the annual valley New Year's Eve party was no coincidence. At the party that night, residents celebrated a central water system and the end to hauling water. This strong appreciation of tap water proved to be a significant contribution to the valley residents' full support of the board through the years.



A 4-ft-diameter ion exchange unit is used to remove uranium. Removals of 90–99 percent of the uranium in the raw water have been consistently achieved.

The project had cost about $600,000, leaving $100,000 in reserve to acquire water rights and for cash flow.

Volunteers responsible for operation and maintenance

The board next turned its attention to operation and management. A billing structure combining users' fees, standby fees, tap fees, and property taxes encouraged water conservation and distributed costs equitably among residents and landowners. Quarterly meter reading and billing were established to ease the administrative burden of the board secretary and treasurer. Board members read the approximately 50 meters. Because of the rugged terrain and inconspicuous hillside locations of meter pits, meter-reading duty involved shoveling snow to uncover the pits and clearing pit lids covered by hillside sloughing, not to mention close encounters with the unique creatures who call the pits home. These weekend meter-reading parties culminated with potluck dinners and, during football season, watching the Denver Broncos on television.

Wells, booster stations, and storage tanks in each of the three pressure zones operated automatically. However, the basic system components—the electrodes, mechanical relays, solid-state timers, chlorination pumps, feed equipment, and control valves—demanded attention. The board was again fortunate when a valley resident with a strong background in industrial and water–wastewater facility construction volunteered for a vacant board position. For five years he provided significant volunteer labor and assistance in keeping the system operational. In 1984, the board contracted with him and his company, Water Utility Services Inc., on a part-time basis. He continued to volunteer, but operation and maintenance demands resulting from water quality problems had become too great to justify a completely volunteer effort.

Water rights present challenge

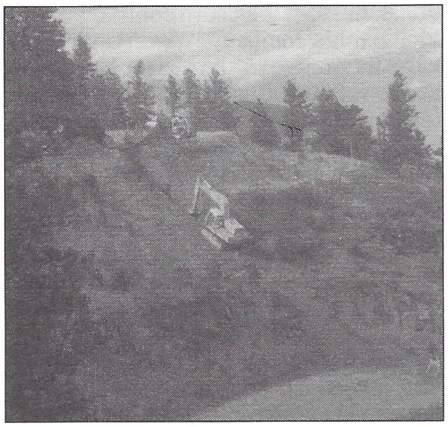
An early challenge was obtaining a legal right to use the water in accordance with Colorado water law. The board first considered trying to establish that the wells were nontributary. Nontributary waters, defined as groundwaters that do not deplete a stream more than 0.1 percent of the wells' pumpage in 100 years, are not subject to Colorado's tributary appropriation law. (The complex concept of "tributariness" in Colorado is beyond the scope of this article.) Because of the unique geologic setting of the wells, the lack of geologic field mapping information, and the suspected presence of faults—and because of the legal complexity of the issue—proving the nontributary case in court would have been an interesting scientific and legal undertaking. From a business standpoint, though, it was an expensive long shot.

Instead, board members chose the more conventional route of water rights acquisition, augmentation plan development, and court approval for tributary water. Because of the overappropriation of Coal Creek Basin and the South Platte River system in general, it was a significant undertaking to acquire and trade water rights, arrange for interbasin transfers, and negotiate with the numerous nearby cities, towns, and other water districts that hired attorneys to protest the augmentation plan. It took 10 years from the date the BMWD had been formed and $100,000 in expenditures before the state engineer issued the well permits. After the water court judge signed the augmentation plan, it took another year and eight months for the state engineer to "process" (sign) the well permits.

Water quality problems arise

The expected problem of quality in water drawn from the Dakota Sandstone formation became evident shortly after well 1 was put into use. Iron levels that exceeded the state-recommended maximum level of 0.3 mg/L were detected. Residents complained about iron staining, and iron bacteria growth in the distribution system began to occur.

The board pilot-tested several methods of iron removal, including chlorination and settling, aeration, and greensand filtration, and chose to implement greensand filtration with permanganate regeneration. The author designed the new system and prepared specifications for equipment purchases and the board bid the equipment. To house the removal unit, board members built a small addi-



The pipeline contractor was experienced in mountain construction. The backhoe on this 65-degree slope is secured by a bulldozer-supported cable.

tion to the pumping station at the well field. Design, construction management, and labor were all donated.

A unit rated to remove iron at 50 gpm was installed, with an automatic backwash system, additional piping for flexibility, a backwash pond, and a building addition, for about $20,000. The iron concentration in raw water had ranged from 0.5 to 3.5 mg/L, and the system consistently removed iron to < 0.05 mg/L. After numerous hydrant and line flushings, the iron was removed from the system.

In 1982, after the iron removal unit was operating, routine tests showed the water was slightly corrosive. The Langlier index was about –0.94 to –0.5. Dissolved-calcium tests were conducted in both raw and treated water and at the ends of the distribution system. Dissolved calcium at the end of the distribution system was 56 percent higher than that in the treated water, indicating that the cement–mortar lining in the ductile iron piping was very likely corroding. A lime feeder, eductor, and in-line static mixer ended the corrosion problems. By 1983, residents believed (mistakenly, as it turned out) that all water quality problems had been solved.

Radioactivity discovered

Water drawdown in the wells steadily increased during pumping as development continued. Connections had been made to 73 homes, and a need for additional wells was apparent. Well 3 was drilled in 1982. Tests indicated it would produce more than 30 gpm, so the immediate water quantity needs appeared to be met. All quality parameters were within state Primary Drinking Water Standards except radioactivity as measured by gross alpha.

The gross alpha was measured at 140 pCi/L. The state limit is 15 pCi/L for gross alpha excluding radon and uranium. Gross alpha was utilized as an indicator of radium 226 and radium 228, which was limited to 5 pCi/L. Further testing of radium 226, radium 228, and total uranium identified uranium as the major contributor to the gross alpha levels. Radium 226 and 228 were within state regulatory limits. Followup tests showed variations in gross alpha levels from 160 to 46 pCi/L. In 1983, determination of maximum contaminant levels on uranium was still several years away, and no state limits existed. The Colorado Health Department and USEPA stated that levels between 10 and 100 pCi/L might be acceptable. The board decided to take the conservative approach and self-imposed a limit of 10 pCi/L for uranium.

Options considered to remove uranium

Several options were investigated for uranium removal. A pilot unit was designed and built and several donated ion exchange resins* were tested. Resin A† removed 97.4 percent of the uranium at a flow rate of 1.5 gpm/sq ft (70 ml/min) and 92.2 percent at a flow rate of 6.4 gpm/sq ft (300 ml/min). Resin B‡ removed 97.4 percent at 1.5 gpm/sq ft but 79 percent at 6.4 gpm/sq ft. Activated carbon removed 56 percent and softener media removed 25 percent; those alternatives were discarded. Further pilot tests using resin A estimated the bed volumes that could be expected before breakthrough and required regeneration. It was difficult to predict full-scale operation because in the pilot test the column was only 1.5 in. in diameter and the bed volumes were very small. However, based on this trial run, the criterion of 35,000 bed volumes was established as the basis for system design.

In September 1985, during pilot testing and design of the uranium removal system for well 3, well 4 was being drilled. Like well 3, it tested at an acceptable rate greater than 30 gpm. The gross alpha, however, was about 20 pCi/L, higher than the level that had been decided on. Radium 226 and 228 had been analyzed all along and found to be low enough to meet current state standards. The uranium levels in wells 1 and 2 also fluctuated but were low; when water from those wells was blended with water from well 4, it met the self-imposed uranium limit. Well 3 remained high in uranium and was not used.

Board conducts home radon tests

The radioactivity and uranium removal investigations prompted the BMWD to test for radon 222, disclosing levels ranging from 4,600 to 10,000 pCi/L in all four wells. The board immediately began a testing program of homes in the service area to learn whether these radon levels in the water had affected customers. The tests included homes that had never been connected to the water system and had continued to use individual wells. Individual wells were also tested for radon 222.

About 10 percent of the homes on the water system were tested for radon levels of both water and air. Levels in the delivered water were lower the farther the home was from the water source, which was expected given the 3.7-day half-life of radon 222. With the exception of the BMWD's pumping stations and wet wells, there was no correlation between levels of radon in the delivered water and in the air of the respective dwellings. Levels in the air of the homes connected to the system ranged from 0.3 to 1.5 pCi/L, within published typical values.

About half of the unconnected houses were tested for radon in both well water and air. Water in individual wells showed levels between 2,000 and 6,000 pCi/L—roughly half the level in the BMWD wells but two to three times greater than in the delivered BMWD water because the radon decayed in the system. Radon levels in the air at unconnected residences ranged from 0.8 pCi/L to 2.3 pCi/L.

This testing program was not a scientific study, nor can many conclusions be made from it, but it did show that the presence of radon 222 in the BMWD water probably had not contributed significantly to radon air levels. None of the houses tested showed indoor radon air levels above the USEPA-recommended limit of 4 pCi/L. Nonetheless, the board decided that the radon should be removed. (Incidentally, the radon testing was done early in the "radon concern period" before testing equipment was widely available or affordable. BMWD worked with a local testing laboratory and assisted it by testing several ways to sample water for radon.)

Packed-tower aerator installed

Research determined that either activated carbon or air stripping would remove radon gas. The carbon removed 80 to 85 percent of the gas. However, radon's radioactive daughter products, as well as uranium and radium, remained, all of which had associated gamma radioactivity. Although the gamma energies were relatively low and could be handled, the removal efficiencies for air stripping appeared more promising. A counterflow packed-tower aerator (PTA) was designed and built and installed between the iron filter and lime feeder. A schematic of this system is shown in Figure 2. Removal efficiencies of 96 to 98 percent were consistently achieved for a 9-ft-high PTA at 20 gpm/sq ft with a counterflow of 100 cfm/sq ft using polypropylene spheres§ as the PTA fill. When the feed rate was increased to 30 gpm/sq ft, the air flow dropped to 30 cfm/sq ft and the removal

*Sybron A-641, C-249, AC-100 activated carbon, and conventional water softener media, Sybron Inc., Birmingham, N.J.
†A-641, Sybron Inc., Birmingham, N.J.
‡C-249, Sybron Inc., Birmingham, N.J.
§Jaeger Tri-Packs Inc., Fountain Valley, Calif.

efficiency dropped below 90 percent. The PTA unit, including blower, venting, electrical work, and controls, was constructed by Water Utility Service Inc. for $2,000 (excluding volunteer labor). Since its installation, the PTA unit has consistently removed 96–99 percent of the radon.

A major side benefit of air stripping was that CO_2 in the well water was removed along with the radon. Thus the water chemistry was adjusted so that the water remained stable, eliminating the need for lime stabilization. The decrease in maintenance associated with the lime system removal was a welcome relief.

Having solved the radon problem, the board again turned its attention to uranium removal. Drawdown levels of well 2, which had the best water quality, had increased dramatically, and the well could not meet demand. In well 1 iron continued to be a problem, and levels of uranium began to approach the board's self-imposed limit as pumping drawdown levels increased. The pilot testing was completed and an ion exchange resin was selected.* Specifications were prepared for a 4-ft-diameter pressure tank; the resin was specified separately for a savings of $20,000.

Installation of parallel spare water lines helpful

Volunteers built an addition to the pumping station at the well field. The greensand iron filter was converted to a dual-media prefilter by removing the greensand and installing sand–anthracite media. This was necessary to protect the costly ion exchange resin, because although the iron level was lower, iron was still present. The permanganate feed system was relocated and fed at the wellheads in each well supply line. This was easily accomplished because the BMWD had planned and installed a system of parallel water lines with spares and access vaults, similar to a duct bank, when wells 3 and 4 were drilled. The permanganate feed is continuous and adjusted to form an oxide coating on the dual media and remove the iron before raw water reaches the ion exchange resin. The permanganate feed rate is critical, because breakthrough to the ion exchange resin is undesirable.

The ion exchange unit—complete with a new automatic backwash control panel, regeneration system, automatic valves, relocated and upgraded radon PTA, piping changes, and building additions—was constructed by Water Utility Service Inc. and limited volunteer labor for about $30,000. The regeneration of the ion exchange is a concentrated salt brine, which is hand-batched when needed. A copy of the complete treatment process isometric schematic is available from the authors.

*A-642 (potable water equivalent of A-641), Sybron Inc., Birmingham, N.J.

The ion exchange unit has consistently removed 90 to 99 percent of the uranium in the raw water. Although uranium levels in raw water from well 3 (which is now in use) have occasionally been as high as 135 pCi/L (0.20 mg/L), the treated uranium levels have typically ranged from <1 to 1.5 pCi/L (<0.001 to 0.002 mg/L). The resin was initially regenerated after 35,000 bed volumes (the design estimate), even though no breakthrough occurred. The regeneration was made to ensure the design procedure was workable. The second run is now at 85,000 bed volumes with effluent uranium levels of <1.5 pCi/L (0.002 mg/L). The treatment processes of the plant have exceeded expectations and continue to perform well. All tests were performed by a commercial testing laboratory.

Efficient business practices established

This review has been limited to design, construction, and treatment techniques. BMWD has achieved other equally important accomplishments, including computerized billing developed in house, computerized records on water use, newsletters, budgeting, annual reports, 20-year cash flow projections, and monthly statements. A coming challenge is management of the wastes associated with the treatment unit. Because a thorough regeneration has not been accomplished, waste has not been a problem. However, the board has sampled and is analyzing backwash waste sludge.

Residents willing to shoulder expense

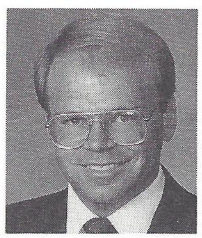
The BMWD has successfully developed a sophisticated, well-maintained, reliable water system that has consistently delivered high-quality water that meets or exceeds federal and state regulations. This has been accomplished not with outside financial subsidies, but instead with a great deal of neighborly spirit and volunteer support. Volunteered services by board members and others, including operation, maintenance, design, and construction, are conservatively estimated to have saved the BMWD more than $300,000 in its 15-year existence.

Even with this significant volunteer subsidy, the cost of water to the residents is relatively high. The total average monthly costs of water, including property taxes, is approximately $100.00 per household. The current tap fee is $11,500. About half of this cost is debt service on the bonds issued in 1977, which are scheduled to be retired by 1998. The BMWD has never missed or been late on interest or principal payments. Although a few special districts have recently defaulted on their bond obligations, the special district vehicle has created a win–win situation for Blue Mountain residents and its bondholders, and BMWD will fully meet its financial obligations.

High cost of water is a fact of life for Blue Mountain and other small districts and systems because of increased regulations, decreased subsidies, and consumer demand for high-quality, safe water. The BMWD board encourages its fellow water purveyors to enlist citizens with a can-do attitude and a strong sense of community spirit and public welfare; enlist the best technical assistance available, whether it is volunteer or contract; and do it right the first time. The majority of small systems may not appear to have these resources, but an inward inspection may help identify easily overlooked self-help mechanisms. Water may be expensive, but as Blue Mountain residents have learned, "Try living without it!"

Acknowledgment

Among those who have contributed their technical and managerial skills to the BMWD are Howard Lacy, King Robertson, Ramon Bisque, Ken Hotchkiss, Bonnie Papke, Bill Habenicht, Kelly Kellogg, Joe Tamburini, John Hilf, Donna Barrow, Ken Hoyer, Doris Robertson, Ed Ford, Fred Tschiffely, Al Wedell, Douglas Stevens, George Rouse, Jerry Papke, and Chuck Brescia.



About the authors: *Joseph U. Tamburini, who is vice-president of Rothberg, Tamburini & Winsor Inc., 1100 Stout St., Suite 750, Denver, CO 80204, has been a consulting water and wastewater engineer for 19 years. His involvement with the BMWD began when it was formed in 1977; he managed design of the original water system and administered the construction contract. He moved to Blue Mountain in 1979 and has since volunteered treatment and system design and general consulting assistance. He has been president of the BMWD since 1984. Tamburini holds a BSCE from Bucknell University in Lewisburg, Pa., and an MSCE from the University of Colorado in Boulder. He is a licensed professional engineer in Colorado, New Mexico, New Jersey, and Ohio, a licensed class A water operator in Colorado, and a certified hazardous materials manager. Tamburini is a member of AWWA and its Fluoride Standards Committee and of Water Environment Federation (formerly WPCF). He is a past-president of the Rocky Mountain Water Pollution Control Association, which gave him the Arthur Sidney Bedell Award in 1991 for service to the organization. Tamburini is a contributing author of* Public Handbook of Water Systems *(Van Nostrand Reinhold, 1986) and has published several articles on water quality issues. William L. Habenicht is president of Water Utility Services Inc., 9375 Blue Mountain Drive, Golden, CO 80403.*