Advancing the Science of Water:
AwwaRF and Water Treatment Residuals

All water treatment processes that remove contaminants produce some kind of waste by-product. These water treatment plant wastes—referred to as residuals—can be solid, liquid, gaseous, or solid–liquid mixtures. Residuals are generally classified according to the type of treatment process that produced them. Principal categories are:

- Sludge—waste produced by the sedimentation basins in conventional coagulation–filtration plants or lime softening plants,
- Spent filter backwash water—water that has been used to clean the filters in conventional or softening plants,
- Membrane concentrate—liquid waste consisting of contaminants rejected by the membrane and any additives applied before membrane treatment,
- Brine residuals—liquid waste similar to the concentrate generated by desalination membrane operations but produced by ion exchange processes,
- Spent carbon—carbon that has exceeded its useful life as an adsorbent, and
- Off gases (primarily volatile organic compounds and radon)—wastes produced by air stripping facilities that release vapor to the atmosphere.

Disposing of these residuals is a primary concern of water suppliers today, but interest in the topic is a relatively recent phenomenon that coincides with AwwaRF's pursuit of research in this area.

"Twenty years ago, essentially nothing was going on in the field of residuals," said Dave Cornwell, president of Environmental Engineering & Technology, Inc. "The only option for disposing of residuals covered in the 1980 edition of *Water Quality and Treatment* was putting them in streams or sewers or maybe a lagoon. That was the state of the art before AwwaRF started moving this field forward. I consider residuals one of the areas in which AwwaRF has really advanced the science. I think this is one of its major achievements."

Brian Dempsey of Pennsylvania State University agrees, claiming "AwwaRF has funded the most critical research that's been done in the area of residuals." When the U.S. Environmental Protection Agency (USEPA) began applying the Clean Water Act's discharge standards to water treatment wastes as well as wastewater plant discharges, "no one knew what to do with water treatment residuals," Dempsey said. "Suddenly water suppliers realized this was a huge problem, and AwwaRF's research was crucial in helping them address it."

Today's water suppliers are not only committed to getting rid of residuals in ways that do not endanger the environment; they are also seeking ways to put residuals to some useful purpose and, in some cases, to offset disposal costs by marketing these waste products to potential users. Water utility professionals are also paying attention to the composition and chemistry of residuals in order to augment their disposal options. Thanks to AwwaRF's research, they are enjoying widespread success.

AwwaRF's fundamental contributions to advancing the science of managing water treatment plant residuals include:

- Synthesizing state-of-the-art knowledge about water treatment residuals,
- Characterizing the content and chemistry of various types of residuals,
- Examining methods to minimize residuals production,
- Assessing a range of disposal methods and their costs, including options for disposing of arsenic-laden solid residuals,
- Identifying beneficial uses for residuals in commercial, industrial, and environmental applications,
- Confirming the merit of reuse as a realistic strategy for residuals disposal,
- Evaluating the effects of residuals disposal on receiving waterways, landfills, and croplands,
- Delineating appropriate conditions for the land application of sludge,
- Advancing an alternative method for disposing of softening plant residuals,
- Optimizing the dewatering processes used to prepare sludge for disposal, and
- Creating a marketing tool to help utilities identify and develop commercial markets for residuals.

Summarizing the State of the Art

AwwaRF's first endeavor to synthesize available information on water treatment residuals began in the mid-1980s and culminated in a basic handbook on handling sludge ("Water Treatment Plant Waste Management," Project 112, funded 1985, published 1987, order number 90527). "As a result of this document, AwwaRF and the drinking water industry were able to see where we were and how to move forward," said Cornwell, the project's principal investigator.

The sludge handbook predicted the type and amount of waste that specific treatment processes would produce under various influent water quality conditions. It outlined a range of disposal methods, including landfill disposal and land application as well as discharges to sewers and receiving streams. It also discussed methods of preparing residuals for disposal, including thickening, pumping, conditioning, and mechanical and nonmechanical dewatering. Information on design considerations drew examples from operating plants and included capital and operating costs, plus performance data, for each of these processes. In addition, the handbook provided a computer program designed to help individual utilities select an optimal sludge treatment system.

"This early study was groundbreaking because it compared a lot of disposal alternatives," said Dempsey. "It was also important because it provided good engineering design criteria for various disposal methods. These criteria have ended up in manuals and state regulations."

A 2006 hardback book, *Water Treatment Residuals Engineering*, updates the 1987 manual and highlights the critical findings of all AwwaRF residuals research projects completed since the original manual was published. The comprehensive 350-page book is the product of another Cornwell project ("Water Treatment Residuals Engineering," Project 2934, funded 2003, published 2006, order number 91093).

Summarizing 20 years of progress in the field of managing residuals, the 2006 book describes the impact of the Filter Backwash Rule promulgated in August 2002, discusses the effects of recently implemented treatment technologies such as enhanced coagulation and desalination, and synthesizes data on the beneficial use of residuals. Its 11 chapters delineate characteristics and disposal options for coagulant and lime softening residuals, spent filter backwash water, membrane concentrate, residuals from ion exchange and adsorption processes, arsenic residuals, spent carbon, and residuals containing radioactivity. In addition, the book offers guidelines for designing and implementing residuals management systems, including marketing residuals for beneficial use. "There's liberal plagiarism from many other projects," said Cornwell, acknowledging the input of multiple contributors.

Exploring Disposal Options

Methods for disposing of water treatment residuals vary according to the type of residual produced. As for traditional sludge residuals, water utilities have largely abandoned the practice of releasing them into waterways in favor of depositing them in landfills. The same is true for spent filter backwash water, which is transformed into sludge once the solids are removed. "Brines and membrane concentrate usually go to sewers, and spent carbon generally goes back to the manufacturer for regeneration and reuse," said Cornwell.

Several early AwwaRF studies investigated the ramifications of both traditional and innovative disposal methods, including direct discharge and landfill disposal.

Direct Discharge to Surface Water. In the late 1980s, Dennis George of Tennessee Technological University studied the effects of alum sludge on a variety of receiving waters through laboratory and field-scale evaluations ("Alum Sludge in the Aquatic Environment," Project 319, funded 1987, published 1991, order number 90582). Testing sludges from four water treatment plants and samples of four corresponding receiving waters, George determined that alum sludge deposits could have detrimental effects on a variety of aquatic organisms.

"We know aluminum can be toxic in aquatic systems," Dempsey said, "but only when the pH of the residual is low enough that the solubility of aluminum hydroxide is high. One of the findings of George's study was that so long as you have a neutral pH, you probably don't have to worry about the impact of aluminum toxicity or iron toxicity when you discharge these residuals to a stream."

AwwaRF's definitive study on the disposal of membrane concentrate was conducted by Mike Mickley of Mickley & Associates ("Membrane Concentrate Disposal," Project 607, funded 1990, published 193, order number 90637). Mickley described the chemical characteristics of membrane concentrate, examined concentrate management and disposal methods and their costs, and conducted a state-by-state review of regulations and permits that applied to various disposal options—including surface water discharge and underground injection. (For more information about Mickley's research, see the section on Membrane Processes.)

Landfill Disposal. Another study more precisely defined the requirements for disposing of coagulant sludges in landfills ("Landfilling of Water Treatment Plant Coagulant Sludges," Project 512, funded 1989, published 1992, order number 90616). In this study, Cornwell collected information on state and federal regulations or guidelines affecting sludge disposal in landfills, determined the type and amount of constituents that leach from coagulant sludges, assessed the physical properties that influence how sludge should be handled in a landfill, and evaluated landfill design considerations.

A six-month pilot evaluation of sludges from alum coagulant processes and an iron coagulant process showed low-level leaching of arsenic, copper, iron, manganese, and zinc, but none of the metal concentrations in the leachate exceeded drinking water maximum contaminant levels. These results indicated that depositing these sludges in landfills would not be expected to adversely affect underlying groundwater supplies.

Beneficial Use of Residuals

Land Application. One of the new frontiers AwwaRF explored was the beneficial use of residuals as a low-cost disposal alternative. Dempsey and Herschel (Chip) Elliott led the first AwwaRF study on the effects of applying water treatment plant sludges to land ("Land Application of Water Treatment Plant Sludges," Project 320, funded 1987, published 1990, order number 90566).

Analyzing some 20 water treatment sludges representing a variety of water sources and coagulant types and dosages, these researchers delineated appropriate conditions for applying sludge to land, taking into account the physical characteristics of amended soils, the availability of phosphorus for plants grown on treated soils, and the toxicity of leachates. The project report included recommendations for measuring and tabulating the chemical characteristics of sludges; selecting application sites and application rates; designing storage, delivery, and application modules; monitoring; and record-keeping.

"We were probably the first to identify the true nature of the material in water treatment residuals," said Dempsey. "I don't think anyone else had looked at the physical and chemical characteristics of sludge before this. We concluded that most water treatment sludges were like the clay fraction of soils, except that the aluminum oxides and ferric oxides in sludge sorb things better. One of the soil constituents they sorb is phosphorus, which is the limiting nutrient for growing many crops. We recommended ways to determine how much phosphorus these sludges removed from soil and ways to overcome this problem by putting more phosphorus back on soil."

Dempsey also emphasized the study's implications for water treatment. "AwwaRF studies have helped utilities understand how coagulation processes work," he said. "The total amount of residual produced can be a function of coagulant dose, and many utilities have been able to decrease their coagulant doses as a result of AwwaRF studies. AwwaRF projects have also encouraged utilities to pay attention to the kinds of chemicals used in water treatment so they have more alternatives for residuals disposal. We've learned that if you want to apply residuals to land, you have to be very careful about your treatment processes. You have to have an overview of how each process and each chemical addition is going to affect the quality of the water—and the quality of the residuals—you produce. As a result of our study and Cornwell's work, it became a lot clearer that utilities had to be careful in selecting a coagulant purveyor and in accepting a shipment."

Cropland Application. As the beneficial use of residuals gained appeal among water utilities, AwwaRF funded a follow-up study to examine the effects of applying sludge to cropland ("An Assessment of Cropland Application of Water Treatment Residuals," Project 717, funded 1991, published 1995, order number 90672). For this project, John T. Novak and William R. Knocke of the Virginia Polytechnic Institute and State University conducted field studies to assess the effects of alum and polyaluminum chloride residuals on various considerations such as groundwater quality, soil moisture retention properties, nutrient mobility in soil, metal uptake of crops grown in amended soil, fertilization requirements, crop yields, and crop quality.

The researchers concluded that aluminum-based coagulant residuals could be applied to agricultural or forest lands at loading rates of 1.5 to 2.5 percent by dry weight without negatively affecting plant growth or the environment. The project report included recommendations for sludge application quantities and methods, as well as crop rotation programs.

Describing the Novak project as "the logical next step" after his own research, Dempsey noted that "At this point, land application of water treatment residuals was relatively new, and this study created a lot more confidence that land application would be a reasonable way to go."

Reducing Soil Phosphorus Losses. More than a decade after Dempsey's results were published, AwwaRF funded more research expanding on his work. In a recent project, James R. DeWolfe of McGuire Malcolm Pirnie evaluated the ability of different types of water treatment residuals to reduce phosphorus losses from agricultural land and thus to protect surface water supplies from runoff containing high concentrations of phosphorus ("Water Residuals to Reduce Soil Phosphorus," Project 2845, funded 2002, published 2006, order number 91098).

This research showed that each water treatment residual has unique phosphorus binding abilities depending on the coagulant used, the residual's age, and whether the residual is in liquid form or dewatered. Residuals stored in lagoons and directly applied to land without dewatering exhibited greater ability to bind phosphorus. Results indicated that using residuals to control phosphorus in runoff from agricultural lands and to protect surface water quality has potential as a best management practice.

The project report recommended that water utilities interested in using residuals to control nonpoint-source phosphorus pollution cultivate relationships with appropriate federal agencies to make them aware of the potential role of residuals in managing phosphorus concentrations in agronomic soils.

Flue Gas Desulfurization. Research on other beneficial uses underscored the merit of reusing residuals as a realistic disposal strategy. Water treatment plants that use lime softening generate large quantities of lime residuals. Although the most common methods of discarding lime residuals are direct discharge into a stream and land-based disposal, an AwwaRF project conducted in the mid-1990s examined an alternative method—reusing lime residuals for flue gas desulfurization at coal-fired power plants ("Beneficial Reuse of Lime Softening Residuals for Flue Gas Desulfurization," Project 179, funded 1994, published 1997, order number 90735).

Coal-fired power plants traditionally use finely ground limestone for flue gas desulfurization to lower the sulfur dioxide emissions produced by burning coal. Because lime softening residuals are chemically more reactive than limestone, this research indicated that power plants could reduce their demand for desulfurization reagents and thus save money by switching from limestone to softening plant residuals. Because reagent demand at one power plant is typically greater than the amount of softening residuals produced at a single water treatment plant, an adequate inventory or regional pool of softening residuals might be necessary.

Results of full-scale demonstration testing confirmed the feasibility of reusing lime softening residuals for flue gas desulfurization. The research report recommended that economic analyses of this reuse option be site-specific, evaluating the quantity and quality of the residuals, the proximity of the water plant and the power plant, and the retrofits required for the power plant to use lime softening residuals as a desulfurization reagent.

Marketing Residuals for Reuse. Once water utilities began to view beneficial uses of residuals as viable disposal options, AwwaRF stepped in to help them identify potential markets and educate prospective customers about the advantages of residuals application. For this project, Cornwell summarized federal and state regulations governing residuals disposal, discussed economic and noneconomic considerations of beneficial use programs, and conducted a market search to identify existing or potential beneficial use options ("Commercial Application and Marketing of Water Plant Residuals," Project 470, funded 1997, published 2000, order number 90801).

The project culminated in a guidance document designed as a marketing tool for water utilities. "The project report brought all the beneficial use data together in one document," said Cornwell. In addition to providing guidelines for developing and implementing a beneficial use program, the report described more than a dozen specific beneficial use applications, including land application, cement and brick manufacture, turf farming, composting, top soil and potting soil production, road subgrade uses, forest application, citrus grove application, nutrient control, landfill cover, land reclamation, and hydrogen sulfide binding. Case studies summarized utility experience with each option.

"A lot of utilities are using the beneficial use studies," Cornwell said. "Cincinnati has relied heavily on the study on marketing residuals, and Erie County Water Authority near Buffalo, N.Y., moved into some turf farming applications as a result of AwwaRF's work. The city of Newport News, Virginia, expanded on AwwaRF's data and conducted its own research on forest applications."

AwwaRF research has been especially influential at the state level. "Many states didn't allow beneficial use of residuals of any kind," said Cornwell. Some AWWA sections have taken AwwaRF literature on successes to state primacy agencies and have been able to open up beneficial use options within the state." Dempsey concurs. "Consultants have used the results of our work to get permits for land application of water treatment residuals," he said, "and people tell me they've used these studies to identify the best alternatives."

Dewatering

Removing the liquid from water treatment plant sludge facilitates disposal by reducing the volume. In an AwwaRF study designed to optimize mechanical dewatering systems, Steve Dentel of the University of Delaware examined techniques for monitoring and controlling the conditioning procedures applied before dewatering ("Fundamental Methods for Optimizing Residuals Dewatering," Project 555, funded 1997, published 2002, order number 90891).

Focusing on the type and dosage of polymer used to condition residuals prior to dewatering, Dentel developed a protocol for optimizing polymer performance and for choosing between operator-based or automatic methods to control polymer feed rates. The research report predicts expected savings in polymer costs and overall sludge management costs.

In a complementary AwwaRF study on optimizing nonmechanical dewatering systems, Cornwell focused on the freeze–thaw process ("Nonmechanical Dewatering of Water Plant Residuals," Project 905, funded 1993, published 1998, order number 90749). Laboratory and pilot tests showed that coagulant residuals subjected to freeze–thaw cycles had a higher drained solids concentration than residuals conditioned only by polymer. This research provided practical guidance for designing nonmechanical dewatering facilities, taking into account the space required and the maximum quantity of residuals a facility could treat.

Disposing of Arsenic Residuals

In anticipation of a more stringent arsenic standard (eventually promulgated in January 2006), AwwaRF funded a study in 1999 on disposing of residuals from arsenic removal processes, including conventional treatment and lime softening ("Disposal of Waste Resulting From Arsenic Removal Processes," Project 2659, funded 1999, published 2003, order number 90953F).

The study had two principal goals—to elucidate the factors causing arsenic to be released from solid residuals and to identify ways of preventing arsenic mobility into the environment during residuals handling, storage, and disposal. Toward this end, Cornwell and his research team studied eight samples of settled residuals and six spent filter backwash samples. With some 4,000 water utilities expected to be affected by the new regulation, the project report provided utility guidelines for disposing of residuals containing elevated concentrations of arsenic. The researchers also cautioned utilities in the process of selecting an arsenic removal technology to identify the types of residuals that would be generated, the arsenic concentrations that could be expected, and any pretreatment strategies that would be required prior to disposal.

Future Challenges Related to Residuals

Asked about current challenges in the field of managing residuals, Cornwell outlined four. "The major challenge still involves the operations and costs associated with dewatering residuals, although AwwaRF has done a lot to advance dewatering technology and the design of dewatering facilities," he said.

The second challenge relates to regulatory developments. "For the first time, USEPA is developing a National Pollutant Discharge Elimination System regulation, and we've never had a federal regulation on that in the drinking water industry," Cornwell said. "Depending on the limits set in the regulation, this could be a major challenge for utilities that are currently discharging either liquid or mixed liquid–solid residual streams." The regulation is scheduled to be proposed in December 2007 and finalized in September 2009.

"A third major challenge is concentrate disposal," Cornwell continued, noting that this is a prime area for more research. "We need to do more desalination, especially inland. In the Southwest, for example, by the time surface water reaches Arizona, the salt content is pretty high; in other areas of the country, we need to treat brackish groundwater. Concentrate disposal is the limiting factor for membrane desalination. There's no place to discharge it and no economical way to use it beneficially. We're still struggling to find any beneficial use for membrane concentrate."

Issues associated with recycling constitute a fourth challenge in Cornwell's view. "As we rely more heavily on conservation and perhaps become limited by new federal requirements related to discharges, these factors will drive us to use more recycled water. The need to understand and control the effects of recycling at the same time water quality standards are becoming stricter creates another major area for us to move forward in," Cornwell said.

In fact, several current AwwaRF projects are already exploring the effects of residuals on water reclamation as well as potential new avenues for membrane concentrate disposal.

