The Restoration & Treatment of Burlington's Groundwater Supply

Meeting and safeguarding a town's water needs posed challenges due to contamination and restrictions on the available land resources.

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The town of Burlington, Massachusetts, restored and treated its contaminated groundwater supply from 1982 to 1997. As a result, 4.5 million gallons per day (mgd) — or 3,125 gallons per minute (gpm) — of groundwater is now being withdrawn and treated from the town's largest aquifer, the Vine Brook aquifer.

This project is an example of innovative planning, design, engineering and construction that provides the town of Burlington with a reliable, safe drinking water supply for the next 30 years. Pumped water from the scattered wells is piped to a single treatment plant. Through legal and technical persistence, the town was able to obtain approximately 40 percent of the cost of this plant from the Potential Responsible Parties (PRPs) whose former industrial activities may have led to the aquifer contamination. The plant is fully automated and includes a state-of-the-art computer system that controls seven wells in the aquifer, and three water storage tanks scattered over 5 miles in the town. The plant can operate unattended.

Background

The town of Burlington draws water from two supplies: the Mill Pond surface supply (with its own treatment plant constructed in 1973) and a series of groundwater supply wells located in the Vine Brook aquifer. The history of the development of the water system, source capacity and status is presented in Table 1.

Before 1949, the town's population of approximately 3,000 relied entirely on private wells. In 1949, the first municipal supply — the Main Station wellfield — was constructed off Meadow Road. This wellfield consisted of thirty-five 2.5-inch tubular wells manifolded

TABLE 1.
Burlington Water System

Component	Year Built	Capacity (gpm)	Status
Main Station (Tubular Wellfield)	1949	500	Abandoned 1975
Well 1	1958	400	Active
Well 2	1959	450	Active
Well 3	1962	250	Inactive 1981-1984*
Well 4	1963	300	Inactive 1981-1984*
Well 5	1965	250	Inactive 1981-1984*
Well 6	1966	250	Abandoned 1975
Well 7	1966	250	Abandoned 1988
Well 8	1968	250	Abandoned 1987
Well 9	1970	250	Abandoned 1975
Well 10	1998	1,100	Active
Well 11	1992	350	Active
Mill Pond	1973	4.0 mgd	Active

Note: *Inactive due to high volatile organic compound concentrations.

together that produced approximately 500 gpm. In 1954, the wellfield was expanded to seventy 2.5-inch wells that produced 700 gpm. However, the wellfield was difficult to operate due to recurring leaks in the manifolds and the absence of well screens and well seals, and it was abandoned in 1975.

As indicated in Table 1, Wells 1 through 9 were constructed to tap the Vine Brook aquifer between 1959 and 1970. These wells served the increasing demands of the rapidly growing town and replaced the failing and eventually abandoned Main Station wellfield.

Throughout the 1960s and 1970s, manufacturing activities in the industrial parks surrounding the westerly and southerly sides of the Vine Brook aquifer led to the contamination of several wells with volatile organic compounds (VOCs). Wells 6, 7, 8 and 9 had to be abandoned in the late 1970s and early 1980s due to declining yields and poor water quality. Wells 6 and 9, located off Sandy Brook Road, were abandoned in 1975 due to excessive iron and manganese concentrations, and the presence of sulfate-reducing bacteria. The cost to treat these wells would have been excessive due to the organically bound nature of the iron and manganese. In the early 1980s, the contamination reached concentrations that forced the town to abandon the then-active Wells 3, 4 and 5, primarily due to elevated levels of trichloroethylene (TCE), a known cancer-causing compound. Well 7 was abandoned in 1987 due to elevated concentrations of VOCs ranging from 12 to 20 parts per billion (ppb) (5 ppb is the maximum allowable contaminant level) and iron and manganese problems. Well 8, located on Wyman Street, was abandoned in 1987 due to similar circumstances.

Therefore, by 1985, Wells 1 and 2 were the only remaining wells capable of being used without treatment. The water quality from these wells was consistently high with acceptably low iron and manganese concentrations.

In 1984, the town decided to built an interim facility to remove VOCs from Wells 3, 4 and 5. This facility, known as the Phase I Groundwater Treatment Plant, allowed the town to use these wells (which had been inactive since 1981) during summer months when water demands were higher than could be sustained from the Mill Pond and Wells 1 and 2. The

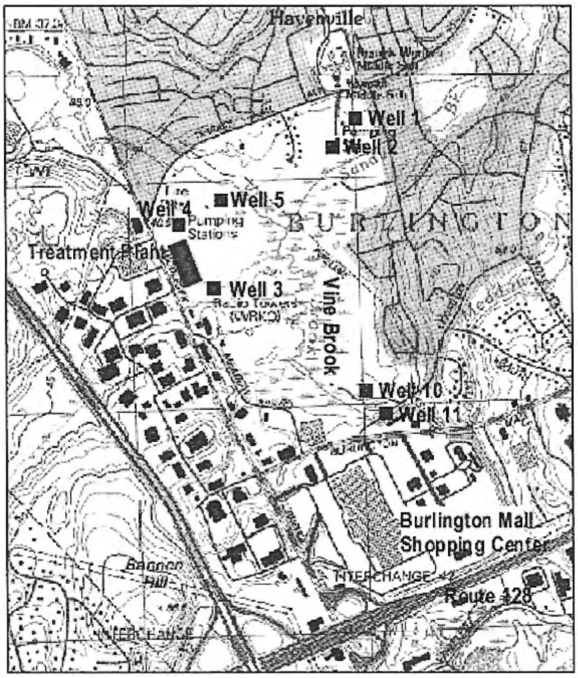

FIGURE 1. Location of Burlington, Massachusetts, water supply system components.

Phase I plant consisted of a pre-engineered metal building that housed electrical panels and controls, a liquid disinfection system, a fluoride system and two blowers for two air stripping towers located outside. The sole purpose of the plant was to provide short relief until a permanent solution could be developed.

From 1979 to 1989, the town engaged in lengthy technical and legal proceedings with the PRPs whose former industrial activities may have led to the contamination. With the support of the Massachusetts Department of Environmental Protection (DEP) and the Attorney General's office, the town reached a settlement of approximately $2,900,000 with the PRPs, enabling the town to proceed with the design and construction of the Vine Brook Groundwater Plant. In addition, the town successfully explored two new well sites, known now as Wells 10 and 11, within the aquifer.

The Vine Brook plant treated water from seven wells at one centralized facility, thereby eliminating the need to construct three separate treatment plants. Wells 1 and 2 were located off Terrace Hall Avenue; Wells 3, 4 and 5 were existing wells located in the vicinity of the existing Phase I emergency plant off the Middlesex Turnpike and were seasonally used by the town in recent years. Wells 10 and 11 were located in the wetlands behind the Knights of Columbus, located off Lexington Street. The locations of the wells and the treatment plant are shown in Figure 1.

New transmission mains were necessary to convey untreated groundwater from Wells 1, 2, 3, 4, 5, 10 and 11 to the new plant. All wells contained high levels of iron and manganese.

New Well Development, Access & Construction

New wells were needed to replace the wells that had been contaminated beyond treatment capabilities. A town-wide groundwater exploration program was developed. Preliminary field work using test wells produced no potential sites outside of the aquifer. It was then decided to focus the search for new sources within the aquifer with the expectation that the sources would likely need treatment for iron, manganese and VOCs. The search was finally narrowed to the westerly corners of the Vine Brook aquifer, in the vicinity of the old Well 7. This well had become unusable due to elevated levels of iron and manganese that had clogged the well's intake screen beyond rehabilitation.

An exploratory test well program was developed in the early 1990s with DEP approval. In 1991, Well 11, located at the edge of the wetlands, was drilled to a depth of approximately 75 feet to serve as a permanent replacement well for the abandoned nearby Well 7. However, an additional well supply with a capacity of at least 900 gpm was needed to compensate for the other wells lost to aquifer contamination. The additional well posed several challenges in terms of hydrogeology, access and construction.

The location of high-yielding well sites was not an easy hydrogeological exercise due to the formation of the overburden aquifer. The water-rich sand and gravel layer narrowed with depth and resembled a cone in shape. After exploration drilling, the final location of Well 10 was determined. This well was located approximately 220 feet in the wetlands.

The Burlington Conservation Commission was concerned about wetlands intrusion dur-

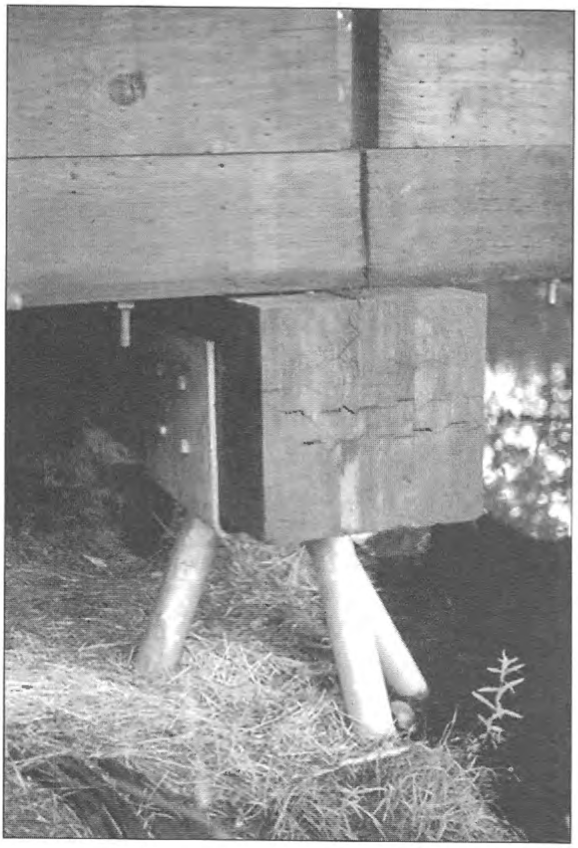

FIGURE 2. Pile cap detail (for accessway).

ing the initial field exploration program and with the long-term impacts associated with a permanent access road built using fill material, wetlands water quality degradation during construction operations and the long-term impacts on the flow path of the Vine Brook that meandered through the site from the southwest to the northeast. In addition, the commission was concerned about aesthetics since this area was a popular vantage point for bird watching. As a response, during the exploration activities a temporary boardwalk system was built to provide access to the test wells and monitoring well network.

To address the Conservation Commission's concerns and to expedite the regulatory review permitting process, it was decided to provide a permanent elevated accessway 24 feet wide and 220 feet long across the wetlands to Well 10. The accessway was designed as a wooden bridge, supported by helical piles supporting wooden beams and the accessway wooden deck was capable of supporting AASHTO H20 loading. The accessway was completed in time to be used for the well-drilling operation that required a 46-ton well drilling rig.

Each deck section was 14 feet long and was supported on a wooden beam within a galvanized beam channel welded to the pile cap of three helical piles (a pile group) on each end (see Figure 2). Pile groups were spaced 12 feet on center laterally and 14 feet on center longitudinally. Each pile was designed for a 13-ton load. Piles were battered at a typical slope of 4:1 (vertical:horizontal). Typical pile installed lengths ranged from 20 to 37 feet. Pile testing was conducted by recording the applied field torque applied per foot of pile, and converting the measured torque to ultimate load. Field torques ranged from 5,500 foot-pounds to 9,600 foot-pounds. At the end of the accessway where the drill rig was situated, an opening approximately 12 by 8 feet was framed into the deck with pile groups at each corner of the framed opening.

This innovative accessway was received favorably by all regulators including the DEP, the U.S. Army Corps of Engineers and local boards, saving valuable permit review time and enabling the construction of the well to proceed. After public bidding , the accessway construction contract was awarded in November 1996 for $420,000.

Construction progressed through the winter and the accessway was completed in March 1997 with no change orders. The contractor used a conventional backhoe with a modified arm to screw the helical piles in place. Pile lengths averaged 32 feet; pile penetration productivity averaged 150 feet per day.

In May 1997, work commenced on Well 10 construction (see Figure 3). The 46-ton drill rig was assembled in pieces on top of a load distribution frame consisting of four I-beams welded in a rectangular frame to spread the load and to avoid overstressing the capacity of the helical piles. With this arrangement, the deflection of the deck never exceeded 0.5 inch.

Well construction for the permanent 18-inch well proceeded as expected until approximately 59 feet below ground surface. A large boulder was encountered that brought drilling progress to a halt. Three options were explored, namely:

FIGURE 3. Well No. 10 construction.

- drilling and blasting the boulder;
- abandoning the partially driven well and starting over approximately 5 feet laterally from the original location; and,
- drilling through the boulder.

After reviewing the risks and costs of each option, the last option was selected. The first option was dismissed due to the risks of uncontrollable uplift of the piles. The second option was dismissed based on cost considerations. Upon authorization from the town, the contractor temporarily dismantled the pull-down rig; mobilized and assembled a dual air-water rig within 5 days and drilled through the boulder using a 12-inch bit.

The wedge of boulder removed was of a gneiss-granite composition. After its removal, the dual air-rotary rig was withdrawn and disassembled and the pull-down rig reinstalled. This rig continued down to the design depth of 90 feet. After analyzing the sand and gravel sieve characteristics, a 20-foot-long, double wire stainless steel Johnson-type screen was selected, capable of delivering up to 1,100 gpm. Well construction was completed eight days later.

New Well Testing

Wells 10 and 11 were tested together by pumping simultaneously 24 hours per day for 11 days until stabilization was reached. Water levels were monitored in these wells and in up to eight monitoring wells to determine the hydraulic conductivity and safe yield of the aquifer. (Stabilization is defined as no more than 0.1 foot drop in water elevation in a well in a 4-hour period.) At the completion of the 11 days, the water elevation in Wells 10 and 11 had dropped 10 and 17 feet below static groundwater elevations, respectively.

Water samples were collected at the completion of the testing program to determine water quality and to enable the design team to confirm iron, manganese and VOCs concentrations.

Water Mains

Approximately 10,000 feet of new cement-lined, ductile iron water main were installed to convey well water from Wells 1 and 2 (3,500 feet to the plant) and Wells 10 and 11 (6,500 feet to the plant). Four stream crossings were required and were constructed in the wetlands and in accordance with the Conservation Commission's conditions (see Figure 4). Air relief valves were located at selected high points along the pipe route to vent air from the mains during filling operations. The water flow rate from each well was controlled by throttling butterfly valves at each well station. This work was completed in approximately six months.

FIGURE 4. A view of the construction at one of the stream crossings for the new water mains.

Treatment Plant

Design Criteria. Design criteria for the plant focused on reducing concentrations of TCE to less than 5 ppb and reducing iron and manganese concentrations for aesthetic reasons. Table 2 gives the design flow rates and water quality data for the active wells. The filter loading rate was 3.5 gpm per square foot. Air stripper performance was 99.9 percent TCE removal at 48°F at 120:1 (air:water), at a maximum height of 45 feet. The treated effluent concentrations were 5 ppb for TCE, 0.30 ppm for iron and 0.05 ppm for manganese.

Plant Siting. Plant location was a critical consideration. An interim treatment facility (Phase I) with air-stripping towers and chemical feed equipment had been constructed in the mid-1980s to allow the town to use Wells 3, 4 and 5 to meet summer demands. After assessing the feasibility of building three separate plants and comparing the long-term logistics and costs associated with operating and maintaining separate facilities, it was concluded that the new plant would be sited adjacent to the interim Phase I facility near Wells 3, 4 and 5. Approximately 2 miles of new water mains would deliver water from Wells 1 and 2 via Terrace

TABLE 2.
Well Water Design Flow Rates & Water Quality Data for Burlington

Well	Design Flow (gpm)	Iron (ppm)	Manganese (ppm)	TCE (ppb)
1 & 2	850	0.34	0.68	7
3, 4 & 5	800	0.71	0.83	450
10 & 11	1,450	2.30	0.28	1,230

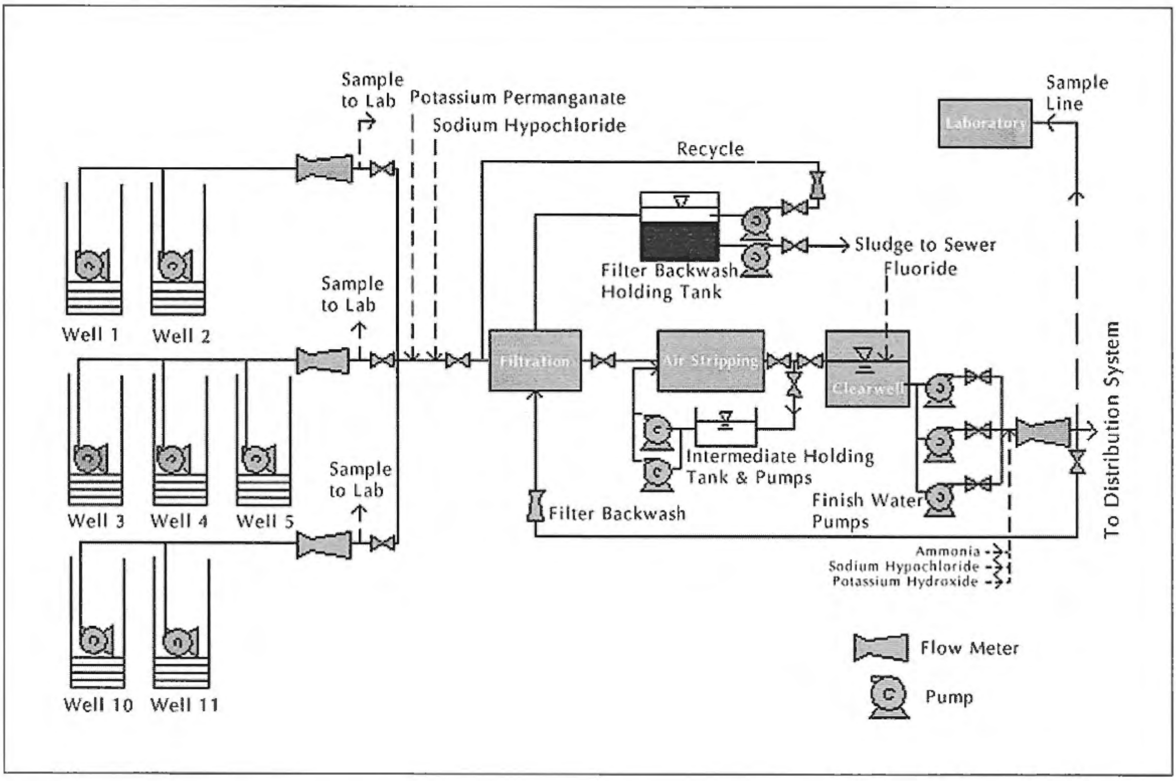

FIGURE 5. Process schematic for the Vine Brook Groundwater Treatment Plant.

Hall Avenue, and from Wells 10 and 11 via Lexington Street and Meadow Road to the plant. A new 16-inch water main running the length of the Middlesex Turnpike would be necessary to convey up to 4.5 mgd of treated water into the distribution system.

Locating the plant adjacent to the existing Phase I facility presented several design challenges. The site was bounded by wetlands on all four sides and the groundwater and soils at the site were contaminated. These issues needed close attention during the final design.

The preliminary design was reviewed by a design-review board assembled by the town, including representatives from the Town of Burlington's Department of Public Works, Conservation Commission, Building Department, Fire Department, Engineering Department and Water Department. Specific design requests included full automation, a state-of-the-art fire alarm system with separate fire, chemical leak and gas leak identification features, a full-service laboratory and provisions for plant expansion.

Treatment Plant Specifics. The new treatment facility consisted of a pre-engineered metal building with a floor plan approximately 140 by 70 feet, attached to the existing Phase I facility on town property. The interior of the Phase I plant was gutted in its entirety in order to provide room for new air blowers and motors and in order to provide space for a workshop. Since this building had never been winterized, the walls and roof were insulated and a heating system added. New louvers and doors entering into the new plant were also constructed.

The treatment process removes iron, manganese and VOCs from the groundwater (see Figure 5). Stormwater from the site is carefully directed through collection piping to a series of infiltrating pipes into the ground and the adjacent wetlands (see Figure 6).

The treatment plant has a capacity of 3,200 gpm, or approximately 4.5 mgd. Well water is pumped to the plant and is treated as follows:

- Filtration of the well water through eight vertical pressure filters to remove iron

FIGURE 6. Storm water infiltration piping outside the treatment plant.

and manganese. Each filter is 12 feet in diameter, and 12.5 feet tall. The filter media consists of 24 inches of green sand (zeolite) and 21 inches of anthracite (see Figure 7). The filters are routinely backwashed using a vigorous air/water mix.

- Air stripping to remove VOCs. Two new towers approximately 11.5 feet in diameter and 41 feet tall are used in conjunction with the two existing towers to provide a two-step air stripping process (see Figure 8).
- Chemical treatment to enhance the filtration process, using potassium as an oxidant and sodium hypochlorite as an oxidant/disinfectant.
- Further treatment for disinfection with sodium hypochlorite and ammonia, corrosion control with potassium hydroxide and fluoridation before pumping into the distribution system.
- Reserve exterior space of approximately 800 square feet and provisions for adding granular activated carbon filters if required in the future to polish the plant effluent.

The plant is fully automated and includes a sophisticated computerized control system. The supervisory control and data acquisition (SCADA) computer system allows the operating staff to control all pumps, valves, filters and air stripping flow rates, and to adjust chemical feed rates and flow rates, as well as to monitor water quality parameters of incoming and treated water quality throughout the treatment plant. The control system records and analyzes water quality data for the plant operators and for mandated reports to the DEP.

Energy efficiency is a key feature of the treatment facility. Premium efficiency motors and variable speed drives are utilized on all large pumps to maximize operating flexibility and to minimize power consumption. Moreover, the use of variable speed drives allows pumping rates and air blower flow rates to be modified while maintaining high efficiencies.

Another noteworthy design feature is the filter backwash water recycle system. Due to the elevated levels of iron and manganese, the filters require backwashing approximately once every two days. Backwashing is conducted in two steps and two different rates. Backwash rates are typically 10 to 15 gpm per square foot (gpm/sf) of filter area during the high rate step and 5 to 7 gpm/sf during the low rate step. Upon completion of a filter backwash, this wa-

FIGURE 7. Greensand filters and piping.

ter is returned to a holding-settling tank with a capacity of approximately 300,000 gallons. The top of the backwash tank is equipped with a floating intake device that allows the cleaner component of the backwash water to be reused. The settled component of the backwash water is collected at the bottom of the holding tank and pumped to the municipal sewer. With this arrangement, over 80 percent of the backwash water is recycled.

A fully equipped laboratory provides analytical instruments to measure iron, manga-

FIGURE 8. Aeration towers.

TABLE 3.
Breakdown of Lowest Bid for Treatment Plant Construction

Contract	Cost ($1,000)
Site Work	755
Dewatering	200
Concrete Work	1,200
Pre-engineered Building	625
Masonry	65
Miscellaneous Metals	44.08
Waterproofing & Sealants	41
Painting	129
Fire Protection	35
Plumbing	55
HVAC	188
Electrical	647
Instrumentation & Control	300
Filters	570
Chemical Feed Systems	375
Process Piping, Pumps & Valves	500
Laboratory	125
Landscaping	45
Hazardous Soil Disposal	20
Non-hazardous Soil Disposal	13.5
Total Bid	5,995
Engineers' Estimate	6,100

nese, color, turbidity and chlorine residual concentrations. The laboratory is also used to perform other routine analyses required for compliance with DEP regulations.

Bidding for the treatment plant work was completed in accordance with Massachusetts General Laws Chapter 30 and 149 for vertical (building) projects. Six general bids were received ranging from $5.99 to $6.6 million. The breakdown of the lowest responsive bid is listed in Table 3.

Construction Sequencing. Construction commenced in May 1997 and was completed in April 1999. Initial construction activities focused on excavation, dewatering and below-ground concrete work. The base slab of the plant measured approximately 140 by 70 feet and required 1320 cubic yards of 4,000 pounds per square inch (psi) concrete in a 3-foot thick mat (see Figure 9). The contractor requested a monolithic pour that was approved after a thorough review of the concrete subcontractors plans for concrete delivery, pumping, quality control and field operations for placement, vibration and curing. On August 28, 1997, concrete placement commenced at 6:00 in the morning and was completed at 2:00 in the afternoon. After finishing, the entire top of the mat was covered in wet burlap that was kept saturated for three days to prevent premature curing and cracking.

Construction Challenges. Dewatering contaminated groundwater was a critical issue that required the construction of a temporary on-site aeration system (see Figure 10). The groundwater table was extremely high (3 to 5 feet below grade), necessitating the installation of eight dewatering wells, each 35 feet deep, feeding a common 12-inch pumped header that was aerated before discharging to an on-site lagoon with a spillway into the wetlands. Each dewatering well pumped typically 100 gpm. The water was sampled weekly.

Geotechnical borings and test pits excavated during the design phase indicated the presence of contaminated soils on a portion of the site. To determine the extent of contamination before foundation excavation began, soil samples were obtained at various depths in a series of test pits and analyzed. With the knowledge gained, excavated soil was segregated into clean and dirty stockpiles and the contaminated soil (approximately 100 tons) was disposed off-site at a licensed facility.

Well Rehabilitation & Renovations

Sequencing of rehabilitation at well pumping stations 1, 2, 3, 4 and 5 required careful consideration. Existing Wells 3, 4 and 5 were rehabilitated first using conventional well cleaning and surging techniques to redevelop well capacity. A staggered approach was adopted to minimize the complexity of the startup process (Wells 3, 4 and 5 first; then Wells 10 and 11, and finally Wells 1 and 2). Renovations consisted of removing the existing pump, piping and valves within the station; cleaning and

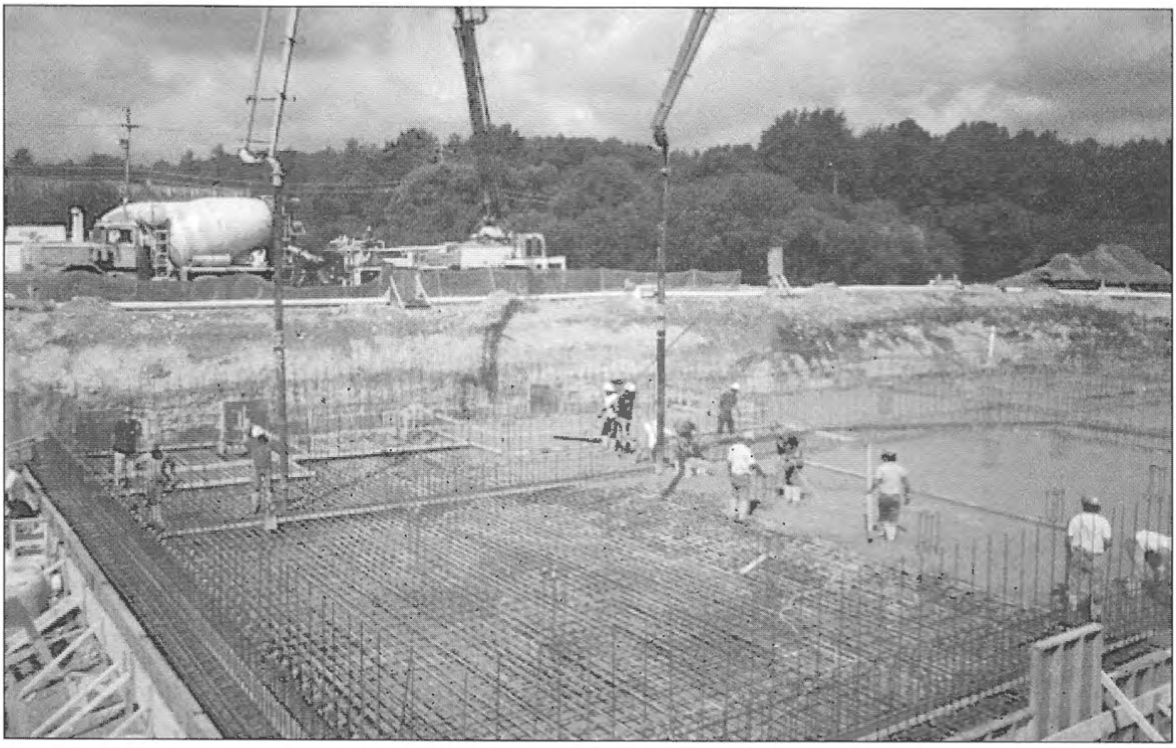

FIGURE 9. Base mat concrete placement for the treatment plant.

surging the existing well to remove particulate accumulation on the submerged well screen using chemical and mechanically operated surging techniques; and installation of a new pump, piping, valves and instrumentation consisting of a remote control panel to

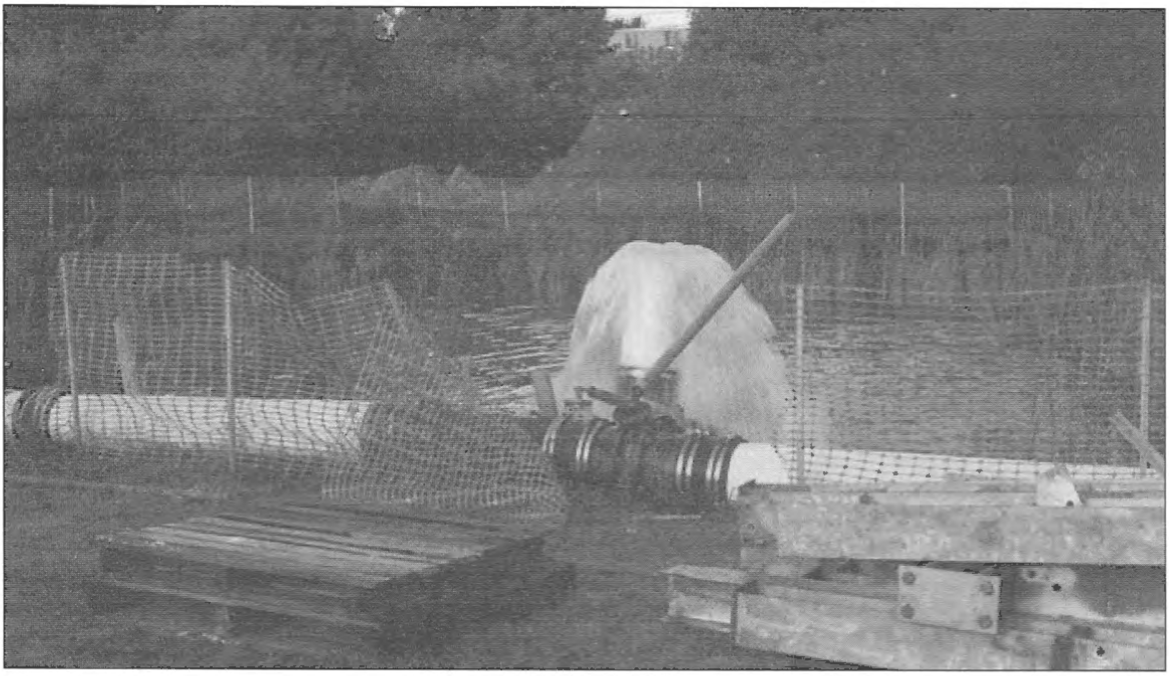

FIGURE 10. On-site dewatering effluent aeration system.

TABLE 4.
Summary of Construction Contracts

Contract	Bid ($)	Change Orders ($)	Subtotal ($)
Treatment Plant	5,995,000	126,000	6,121,000
Well 10	92,000	34,000	126,000
Well 10 Accessway	420,000		420,000
Well 11	75,000		75,000
Water Mains	728,000	28,000	756,000
Total	7,310,000	188,000	7,498,000
PRP Contribution			2,900,000
Net Town Cost			4,598,000

monitor and control well flow, level and pressure.

Testing

Startup and testing consisted of a series of dry runs of the plant processes and pumping the water to waste until the plant as a whole was operating satisfactorily and effluent water quality met the Massachusetts DEP water quality standards. Startup was an iterative process whereby individual process components, such as raw and intermediate pumping equipment, and each chemical feed system were tested separately and then in concert with other combinations of equipment until the entire plant was tested and debugged. As the plant became operational and its output capacity increased, the town's reliance on the Mill Pond Plant lessened, allowing that plant to be taken out of service for maintenance and repairs.

Automation

The treatment plant's control is accomplished by a state-of-the-art system equipped with a backup computer if the primary computer fails for any reason. With this design, the plant operator can, from any personal computer workstation in the plant, monitor the status of the wells, treatment systems and chemical feed systems, and immediately identify any audible alarms.

The plant is attended 16 hours per day. During unattended hours of operation, the plant can transmit any alarm conditions to the town's fire and police departments via a dedicated fiber-optic connection to the town's municipal network. This setup is particularly important for the fire department since it can readily distinguish a fire alarm from a chemical spill or gas leak and respond accordingly.

Training

The operating staff from the town's water department were trained for approximately four weeks in each aspect of the plant's operation. Training was specified as part of the contract specifications. In addition, a comprehensive operation and maintenance manual was prepared by the project's consulting engineer to assist the plant operators and establish a maintenance schedule for all major equipment items. In this way, equipment will be routinely inspected and maintained to prolong the life of the plant.

Costs

The treatment plant, wells and connecting water mains were constructed over a 24-month period. The costs for the complete project are listed in Table 4.

Long-Term Monitoring

Due to the importance of the Vine Brook aquifer in the town's water supply system and its sensitive location adjacent to several developed industrial and commercial office parks, the aquifer is being carefully monitored. On a quarterly basis, samples are collected from all production wells and a series of monitoring wells around the aquifer. Data generated from this sampling regime enables the town to track trends and changes in water quality and adjust plant operations, if needed.

NOTES & ACKNOWLEDGMENTS — *This paper was the winner of BSCES's seventh annual (1999) Earnest A. Herzog technical paper competition. SEA Consultants performed the groundwater exploration program and design, and served as administrator of all construction contracts. Fiore Construction, Inc., of Leominster, Massachusetts, constructed the Well 10 accessway. Layne Christensen Co., of Dracut, Massachusetts, installedWell 10. Water main work was completed by Tom Gioioso Construction, Inc., of Rockland, Massachusetts. Charwill Construction, Inc., of Meredith, New Hampshire, constructed the treatment plant. Griffin Dewatering, Inc., of Danbury, Connecticut, performed the treatment plant dewatering work.*

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