Five Billion Gallons Later—Operating Experience at City of Suffolk EDR

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Abstract

An electrodialysis reversal (EDR) plant was installed at the City of Suffolk in 1990 to produce 3.76 million gallons per day (mgd) (142,000 m^3/day) of drinking water. This plant reduces the feed water's fluorides from 4.8 milligrams per liter (mg/l) to 1.3 mg/l and the sodium level to less than 65 mg/l while maintaining a 94% water recovery rate. This plant, which has three separate trains, has produced over five billion gallons of drinking water in its eight years of operation. This paper reviews plant operating data, operating and maintenance costs, and discusses the permitting procedure for concentrate discharge.

Introduction

The City of Suffolk (population approximately 55,000) is located in Southeast Virginia, an area that has experienced rapid growth over the past two decades. In the late 1980's the City evaluated a number of source alternatives for expanding its water supply to meet the increasing demand for water. Alternatives originally considered included expanding an existing reservoir, constructing a major regional surface water supply, or desalinating groundwater. After an environmental impact assessment identified major concerns with raising the existing reservoir dam, groundwater desalination was selected as the most practical alternative. A 916-foot, 4 mgd (279 m, 15,000 m^3) deep well was constructed at the site of an existing 3 mgd surface water treatment plant that used conventional (alum) treatment. The well was initially designed to discharge directly into one of the two raw water supply reservoirs, both operated by the City of Suffolk, that supplied water to the existing conventional plant. Flexibility in the well design also permitted the groundwater to be fed into a membrane desalination process at a later date with minimal modifications once the specific process to be used was determined and construction completed.

Deep Well Construction

The well was constructed of a 24-inch (61 cm) outer casing with a 16-inch (41 cm) stainless steel inner casing that was screened at seven levels ranging from from 445 to 914 feet (136 to 279 m) primarily within the Middle Potomac Aquifer. The pump consisted of seven stages driven by a 300 h.p. constant speed turbine with an intake depth of 300 feet (91 m) and a rated capacity of 2,800 gallons per minute (11 m^3/minute).

Feed Water Quality

The well water has moderate levels (689 mg/l) of total dissolved solids (TDS). However, the fluoride level of 4.6 mg/l is higher than the primary maximum contaminant level of 4.0 mg/l. Also, the sodium concentration of 191 mg/l exceeds Suffolk's water quality guidelines of 50 mg/l for potable water. Hence, a membrane desalination treatment process was required to raise the well water quality to meet drinking water standards. A typical feed water analysis is shown in Table 1.

Table 1: Feed Water Quality

Parameter	Concentration	Units
Bicarbonate	453	mg/l
Calcium	2.27	mg/l
Carbonate	1.2	mg/l
Chloride	21.1	mg/l
Fluoride	4.57	mg/l
Magnesium	0.931	mg/l
pH	8.15	mg/l
Phosphate	2.79	mg/l
Potassium	5.05	mg/l
Sodium	191	mg/l
Sulfate	7.04	mg/l
Total Dissolved Solids (TDS)	689	mg/l

Based on the results of a feasibility study, reverse osmosis (RO) and electrodialysis reversal (EDR) were identified as the most appropriate technologies to reduce the levels of fluoride and sodium, and pilot testing was undertaken in 1987 to evaluate the technologies. EDR was eventually selected for full-scale application in Suffolk because it would result in higher water recovery rates and lower operational costs. Water recovery was important for Suffolk because concentrate disposal is a major issue. Since EDR could produce 94% water recovery compared to 85% water recovery for RO, the volume of concentrate discharge was lower for EDR.

Electrodialysis Reversal

Electrodialysis is an electrochemical separation process in which ions are transferred through ion exchange membranes by means of an electrical driving force. When a DC voltage is applied across a pair of electrodes, positively charged ions such as sodium move towards the cathode. Negatively charged ions such as chloride move towards the anode. Membranes are placed between the electrodes to form several compartments. Flow spacers are placed between the membranes to support the membranes and to create turbulent flow. Water flows along the spacers' flowpaths across the surface of the membranes rather than through the membranes as in RO. Figure 1 shows a typical electrodialysis membrane stack. Electrodialysis reversal is an automatic self-cleaning version of electrodialysis in which the polarity of the DC voltage is reversed two to four times per hour.

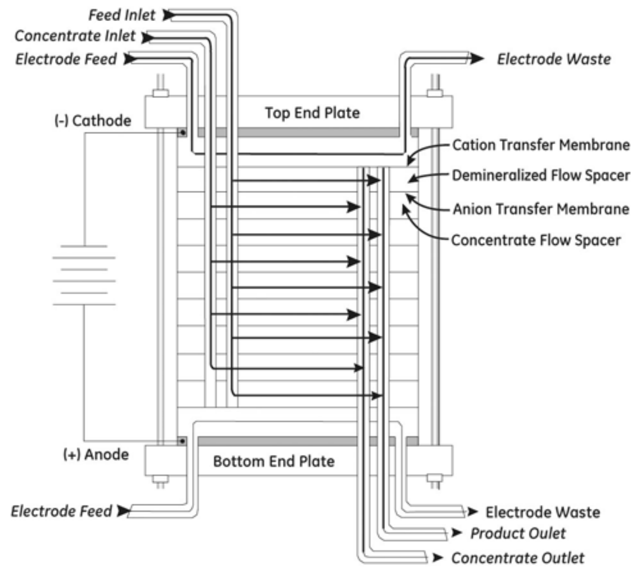

Figure 1: Membrane Stack

EDR at Suffolk

A 3.76 mgd (142,000 m^3/day) EDR facility started operation at Suffolk in August of 1990. Since its commissioning, the plant has produced over five billion gallons of potable water. The plant has three separate units (GE Aquamite 120's), each of which produces 1.25 mgd (4732 m^3/day). Each unit contains 8 parallel lines of membrane stacks, and each line has three stages of stacks in series. Operating lines in parallel increases the production capacity of the unit, and operating stacks in series increases the salt removal capability of the plant. Three stages were required to reduce the fluoride level to 1.4 mg/l.

Suffolk needed a membrane process that could operate at supersaturated levels of calcium fluoride because high recovery was important to minimize concentrate disposal. Even though the concentration of calcium in the feed is low, the fluoride concentration is quite high, and at 94% water recovery the concentrate stream is supersaturated with calcium fluoride. Reversing the DC polarity switches the dilute and concentrate streams every 30 minutes. Any calcium fluoride that has started to precipitate in the concentrate stream is dissolved by the dilute stream. Operation in this unsteady state mode can continue up to levels of calcium fluoride saturation of more than 500 x Ksp.

Performance of EDR

Because Suffolk's EDR plant has been in operation for eight years, considerable data has been collected pertaining to feed, product and concentrate discharge water quality. Other parameters, such as operating and maintenance costs along with power consumption figures, have also been accumulated.

Feed Water Quality

When the EDR plant was first designed, it was anticipated that feed water quality would change over time. It was thought that sodium and chloride levels would increase as a result of increased pumping of the Middle Potomac aquifer, which would in turn cause a westward migration of increasingly higher TDS water. To accommodate this predicted change in feed water quality, the Suffolk EDR system was designed to allow for a 20% increase in TDS levels over initial values with no modifications of the units other than an increase in stack voltage. But the predicted increase in TDS values appears not to be occurring. Over the past eight years no appreciable change in water quality has been observed. The values for feed water quality shown in Table 1 have remained constant throughout the operational history of the system. The reason for this lack of change is not entirely clear. However, one possible explanation currently being explored by the United States Geological Survey (U.S.G.S.) is the recent discovery of a large meteor impact site at the mouth of the Chesapeake Bay. It is believed that the impact occurred approximately 35 million years ago and may have significantly altered the hydraulic properties of the sediments that make up the Middle Potomac aquifer.

Product Water Quality

With no change in feed water quality, EDR product water quality has remained constant. Table 2 shows typical values for several major chemical parameters.

This product water is then blended with the product from the conventional surface water treatment plant prior to its delivery into the City's distribution system. Fluoride, which is purposely kept at a level exceeding the recommended range of 0.8-1.0 mg/l to compensate for the lack of fluoride in surface water supplies, eliminates the need to add more fluoride to the final blended product.

Table 2: EDR Product Water Quality

Parameter	Concentration	Units
Chloride	7.3	mg/l
Conductivity	280	μmhos
Fluoride	1.43	mg/l
pH	7.3	units
Sodium	61	mg/l
Total Dissolved Solids (TDS)	117	mg/l

Concentrate Water Quality

The concentrate from the EDR units is piped from the plant to a nearby brackish water estuary of the Nansemond River. The TDS of the discharge is approximately the same as that of the receiving stream. Table 3 shows typical values for the concentrate discharge water quality.

Table 3: EDR Concentrate Water Quality

Parameter	Concentration	Units
Chloride	308	mg/l
Conductivity	11,070	μmhos
Fluoride	46.5	mg/l
pH	8.51	units
Sodium	2,056	mg/l
Total Dissolved Solids (TDS)	5,210	mg/l

Operation and Maintenance Costs

Significant data has been accumulated over time related to operation and maintenance costs. Table 4 represents recent cost data related to operation of the EDR plant. Values related to operation of the conventional treatment plant are also included for comparison.

Table 4: Operational and Maintenance Costs

Cost Category	EDR (per 1000 gal.)	Conventional (per 1000 gal.)
Fixed	$0.72	$0.72
Professional Services	$0.06	$0.05
Chemicals	$0.02	$0.13
Utilities ($0.05/kwh)	$0.21	$0.25
Maintenance	$0.17	$0.17
EDR Stack Replacement	$0.23	$0.00
Production (1997)	827,339,440 gal.	390,953,560 gal.
Total Cost/1000 gallons	$1.41	$1.32

Fixed costs are associated with such items as wages and salaries, vehicle costs, telephone and other items that apply equally to both treatment plants. Professional services represent costs associated with services obtained from outside the Department such as sludge removal, laboratory testing and other items that apply to each of the plants on an individual basis. EDR stack replacement figures represent costs associated with replacement of stack membranes, spacers and electrodes. Electrodes are considered a consumable item while the membranes and spacers have a theoretical life expectancy. Costs not represented here are treatment plant replacement costs, and depreciation or debt service on the original plants.

Concentrate Disposal

The concentrate discharge is transmitted via a gravity-fed 12 inch (30 cm) PVC line for a distance of approximately one quarter mile to an outfall located on the banks of Cedar Creek, an estuarine tributary of the Nansemond River.

A National Pollutant Discharge Elimination System (NPDES) permit was originally issued when the plant was first constructed. Upon its renewal in 1993, the plant was unable to pass the newly instituted toxicity testing requirements. Table 5 shows the results from this series of tests.

Table 5: Toxicity Test Results

	9/14/93	12/7/93	3/9/94
Mysidopsis bahia Acute Toxicity	LC50 = 8.2% Fail	LC50 = 10.5% Fail	LC50 = 22.4% Fail
Cyprinodon variegatus Acute Toxicity	LC50 = 100% Pass	LC50 = 100% Pass	LC50 = 100% Pass
Mysidopsis bahia Chronic Toxicity	NOEC = 2% Pass	NOEC = 2% Pass	NOEC = 2% Pass
Cyprinodon variegatus Chronic Toxicity	NOEC = 50% Pass	NOEC = 50% Pass	NOEC = 50% Pass

LC50 = Lethal Concentration 50%, NOEC = No Observable Effect Concentration

Based on these test results, the treatment plant was required to institute a Toxicity Reduction Evaluation (TRE). The purpose of this program was to identify the toxicant to M. bahia and determine a method for its elimination.

Since the vast majority of contaminants to be tested for during the permit renewal process were "no detects," the list of possible toxicants was narrowed to just a few with the fluoride and TDS being the primary ones.

Even though toxicity test data related to M. bahia was extremely limited in the scientific literature, it was found that the organism was extremely sensitive to fluoride. Subsequent testing, using activated alumina, involved the removal of fluoride in the concentrate. The toxicity test results using this sample were then compared with those of the same sample after the fluoride had been reintroduced at the original concentration by means of spiking. The test data seemed to indicate that fluoride was indeed the toxicant. Table 6 summarizes these results.

Table 6: Feed Water Quality

Parameter	8/95	9/95	10/95
LC50% Fluoride Removed	>100	>100	>100
LC50% Fluoride Re-spiked	9.1	14.0	11.6
Fluoride Concentration 100% Effluent	50.8 mg/l	47.4 mg/l	44 mg/l
Fluoride Concentration Effluent After Activated Alumina	0.03 mg/l	0.03 mg/l	0.12 mg/l
Fluoride Concentration In Effluent After After Spike	50.2 mg/l	49.3 mg/l	45.4 mg/l

Once this relationship was determined, it was necessary to find a method for decreasing the impact fluoride was having on this test organism. Several possible treatment/testing alternatives were devised. The first entailed a request to the Virginia Department of Environmental Quality (DEQ) to substitute a different species of Mysidopsis native to the area. (M. bahia is not found in Virginia waters). This was not acceptable to DEQ since they felt that the testing data available for M. bahia was considerable, and they did not want to change to a lesser known organism.

The remaining choices were:

- Modifying Existing EDR Operations
- Alternate Low Fluoride Source
- Ion Exchange Treatment
- Chemical Precipitation
- Wetland Treatment
- Blending with Low Fluoride Water
- Outfall Relocation

Of these options, only relocating the outfall from Cedar Creek to the middle of the Nansemond River, a distance of approximately 2 miles (3 km), was deemed acceptable. Calculations determined that to replace the existing outfall with one that terminated in a multiport diffuser would result in a mixing zone of sufficient size to reduce concentrate fluoride values to non-toxic levels. Engineering and design of this outfall extension is currently underway with a construction schedule that anticipates completion by June of 1999.

Summary

EDR has fulfilled all expectations for the City of Suffolk in helping it meet its current and future water demands. Its ruggedness and ease of operation have proven to work very well over the years. Plans are currently underway to double the size of the EDR plant with the addition of several more units. (The building housing the original units was constructed to allow for expansion at a later date.) Another deep well owned by the City is available to use as a feed water source, and a draft water withdrawal permit from DEQ has already been obtained. EDR is here to stay in Suffolk.

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