Critical Water Issues in Tidewater Virginia

Four Papers from Meetings of the American Society of Civil Engineers

Virginia Water Resources Research Center
Virginia Polytechnic Institute and State University
Blacksburg

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This publication was supported in part by funds from the
Virginia Water Resources Research Center and the U.S. Geological Survey,
Department of the Interior, as authorized by the
Water Resources Research Act of 1984.

These papers were originally presented at the 15th Annual National
Speciality Conference, Water Resources Planning and Management Division,
American Society of Civil Engineers, June 1-3, 1988, Norfolk, Virginia.

Additional copies of this publication, while supply lasts,
may be obtained from the Virginia Water Resources Research Center,
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A publication of the Virginia Water Resources Research Center,
Virginia Polytechnic Institute and State University. William R. Walker,
director; Edward Born, assistant director for publications.

Contents

Introduction

The four papers reproduced here were presented at the 15th Annual Specialty Conference of the Water Resources Planning and Management Division, American Society of Civil Engineers, June 1-3, 1988, in Norfolk, Virginia. Each touches on an important water-related problem facing the Tidewater area, which is defined here to include the cities of Norfolk, Suffolk, Portsmouth, Virginia Beach, and Chesapeake and the counties of Surry and Isle of Wight.

The Center is publishing and distributing these papers because we think the information is valuable and deserves to be made available to a larger audience of citizens throughout the Commonwealth. Although the setting is eastern Virginia, the stimuli—stiffer regulatory requirements of the Clean Water and Safe Drinking Water acts, a commitment to improve water quality of the Chesapeake Bay, and a growing environmental awareness among citizens—exist in most localities. Therefore, the discussions in these papers are relevant statewide.

Provocative solutions are offered for the problems. In two of the four papers, regional responses are suggested. This leads to questions on the role of state government: Should it exercise more leadership or will localities remain totally responsible for the resolution of water management problems of the Commonwealth?

Tidewater Virginia is one of the fastest growing areas in the United States. Between 1980 and 2030, its population, according to the Virginia Water Control Board, is expected to grow by 55 percent, from 809,972 to 1,256,740.[1] In addition, there will be a shift in the employment pattern. The number of people employed in agriculture is expected to decrease while the workforce employed in wholesale and retail, services, finance, and real estate is expected to increase by more than 62 percent over the 1980 figures. These changes will not, however, significantly modify the overall water demand for the area which is projected to increase only 3 percent from 1,968 million gallons a day to 2,036 million gallons a day.[2] During the same period the water for cooling in electric power generation, the dominant water use in the area, is projected to remain relatively constant. The big change will be that the amount of water to be supplied by water utilities in the five cities is expected to increase by 70 percent, from 89.6 to 152.5 million gallons a day.[3] Thus, it is the rapid urbanization of this area that is causing the problems examined by the authors of these papers.

Alum has been and will continue to be an important additive to water during the treatment process. The recent amendments to the Safe Drinking Water Act have imposed increased restrictions on the disposal of the alum sludges (a by-product of the treatment process). The amount of these sludges will increase in approximately direct proportion to the amount of water treated. Thus, the safe management of these water treatment sludges pose an ever increasing problem to the purveyors of drinking water. There does not appear, however, to be universal agreement on how best to address this problem.

In "New Solids Handling Technology in an Old Water Treatment Plant," R. Edwin Blair, Jr., director of utilities for the City of Norfolk, discusses the problems the city encountered when it introduced new technologies and treatment processes at an existing facility in response to regulations requiring the safe disposal of solids removed from drinking water. Introducing the new technology proved more difficult and expensive than expected, and Blair hopes that other utilities can profit from Norfolk's experience.

Suffolk, in area one of the ten largest U.S. cities, was until the 1980s dependent on Norfolk for its drinking water. To reduce its dependence and to meet the growth projected for the city, Suffolk began construction of a water treatment plant in 1982 and planned to expand its raw-water supply reservoir. The U.S. Environmental Protection Agency objected to the enlargement of an existing reservoir because of its potential to reduce downstream flows. The city then turned to the development of a deep well to increase its raw-water supply. At that time, brackish groundwater could be mixed with surface water and still meet the water-quality standards established by the Safe Drinking Water Act of 1974. With the passage of the 1986 amendments, however, came more stringent standards that require the treatment of the well water to reduce the amounts of sodium, fluoride, and total dissolved solids in the finished water. What would be the best way to treat the groundwater? How Suffolk decided between two processes is detailed in Mark A. Thompson's "Comparing Reverse Osmosis and Electrodialysis Reversal for Desalting Groundwater in Suffolk, Virginia."

The Elizabeth River in Southside Hampton Roads has been described as one of the two most polluted rivers in the Chesapeake Bay system. Dense population, heavy industry, and geography have conspired against the Elizabeth, a slow-flowing river

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[1] Virginia Water Control Board. 1986. *James Water Supply Plan: Part 2 of 2*, p. II-391.
[2] Ibid., p. II-392.
[3] U.S. Army Corps of Engineers. 1984. *Water Supply Study: Hampton Roads, Virginia: Supporting Documentation to Feasibility Report and Final Environmental Impact Statement*, pp. II-7, 8.

that retains pollutants for long periods of time. Conflicts over land use in the basin grew rapidly during the 1970s and early 1980s. The river is an active commercial and industrial waterway, the home of the world's largest naval base, and the site of nearly 1,300 marina slips for recreational purposes. As the urban riverfront area has become revitalized, the residential use has increased. In 1986 a comprehensive water quality management plan was adopted which will require the active cooperation of state and local agencies to address the river's problems. The development of these institutional arrangements is discussed in "The Elizabeth River: Problems, Conflicts and Solutions" by John M. Carlock, chief physical planner for the Southeastern Virginia Planning District Commission.

The final paper, "Nansemond-Chuckatuck Rural Clean Water Project: A Threatened Success Story" by Paul E. Fisher, director of the Hampton Roads Water Quality Agency, reminds us that obtaining and maintaining clean water is an active and ongoing process. In 1981 the federal government funded the Nansemond River-Chuckatuck Creek Rural Clean Water Project to reduce agricultural nonpoint source pollution from Isle of Wight County and the City of Suffolk through the promotion of best management practices. Considerable progress has been made toward the goals of protecting water quality in shellfish harvesting areas of the two estuaries and in the freshwater reservoirs that provide drinking water to the five cities. However, recent population growth, with the subsequent conversion of land from agricultural to suburban development, threatens the water quality improvements in the recent past. New plans with new goals that better fit the evolving circumstances need to be developed and implemented if water quality in the area is to continue to improve.

We hope that these papers will provide readers with insights into water resource problems of Tidewater Virginia. Their thoughtful approach to the problems of water supply and water quality improvement should be considered by other areas of the Commonwealth which face similar problems resulting from rapid and continuing urbanization.

—William R. Walker
Director

Problems of Installing New Technology in an Old Water Treatment Plant

In response to higher regulatory standards, Norfolk incorporated state-of-the-art technology for waste solids collection and removal. It hopes that other utilities can profit from its experience of moving from pilot study to real-world conditions.

R. Edwin Blair, Jr.

In response to regulatory requirements of the Virginia Water Control Board, the city of Norfolk constructed a solids dewatering facility for its Moores Bridges Water Purification Plant. This facility, constructed on the site of an existing 80 million gallon per day (mgd) facility, was the culmination of over a dozen years of studies, designs, and construction.

Technology utilized in the application represented a specific philosophy of the city to use a process which was state of the art and permanent. As is often the case, the construction process was smooth; however, the start-up procedure identified additional problems and issues which forced the city, the design team, the contractor, and state regulators to revisit a number of institutional as well as physical issues.

This paper summarizes the history of the project and provides recommendations for dealing with the problems of installing innovative technical solutions in existing treatment facilities.

BACKGROUND

The Moores Bridges Water Purification Plant is a conventional water treatment facility with a rated capacity of 80 mgd. The plant was originally constructed around 1900 and has been expanded several times. The latest expansion and modernization occurred in 1976.

The treatment process includes chemical addition, coagulation, sedimentation, filtration, and disinfection. Chemical additions include aluminum sulfate (alum), powdered activated carbon (PAC), lime, chlorine and fluoride.

Heretofore, wastes collected in the facility's sedimentation basins were disposed of by draining to Broad Creek, a tributary of the Eastern Branch of the Elizabeth River.

Regulatory pressures were placed on Norfolk in the mid-1970s to provide a suitable disposal program for the wastewaters. In 1983 a consent requiring construction of waste treatment facilities was executed between the city and the Virginia Water Control Board.

Construction began after facility design was completed. The recommended treatment process included waste solids collection and removal from the plant, gravity thickening, and dewatering through use of a diaphragm filter press.

Construction was essentially completed in late 1987; however, equipment and process performance improvements are under way to correct system inefficiencies.

PROCESS SELECTION

The city and its consultant conducted detailed dewatering pilot tests to determine the acceptability of various styles and types of mechanical dewatering devices. It was obvious that due to the limited area available at Moores Bridges site, which is surrounded by a completely developed area, passive systems, such as lagooning or land storage, were not applicable.

It was determined that the dewatered product would be disposed of in local sanitary landfills, thus requiring a finished cake of some 35 percent solids.

It was further decided that wholesale chemical preconditioning of the thickened waste stream was not preferable; addition of chemicals means disposal of larger solid volumes at a correspondingly increased cost.

The selected technology featured a diaphragm filter press with 156 plates. This large unit, custom built, had not been previously used in the water treatment industry for waste stream dewatering, but proved very effective in meeting solids requirements in the pilot program.

PROCESS START-UP

In process start-up it was apparent that in scaling from pilot to plant scale operations some noticeable reductions in efficiency had occurred. Filter cloth

R. Edwin Blair, Jr. is director of utilities for the city of Norfolk.

adjustments, modification of the diaphragm plates, and chemical preconditioning of the thickened solids were evaluated.

In the final analysis, lime addition in connection with filter cloth redesign appears to be necessary to meet full production capacity. This modification, currently under way at a cost of $400,000, will require an additional three months to complete.

LESSONS TO LEARN

Several key points are summarized in initiating new and unfamiliar technologies and treatment processes in existing facilities:

- Insist on a preconstruction pilot testing program;
- Require a guarantee of technology performance from contractor;
- Negotiate, when required, a construction and equipment performance time limit from regulatory agencies that recognizes the risks of incorporating new technologies; and
- Maintain close communications with regulatory agencies throughout design, construction and acceptance process.

SUMMARY

Norfolk embarked on a water treatment plant addition to handle solids generated in a conventional water purification process. Technologies were chosen that provided for a permanent solution to a continuous waste problem. Unfortunately, pilot and plant scale differences have required significant process modifications which in turn have resulted in additional costs and time extensions.

Comparing Reverse Osmosis and Electrodialysis Reversal for Desalting Groundwater in Suffolk

Suffolk developed a deep well to increase its raw-water supply only to be faced with higher regulatory standards for sodium, fluoride, and total dissolved solids. It then had to decide on a method for treating the groundwater.

Mark A. Thompson

BACKGROUND

Suffolk's Situation

Suffolk became Virginia's largest city in land area, and among the ten largest cities, in the nation in 1974 by merger of the urban city of Suffolk and the rural city of Nansemond. Located in Southeast Virginia, Suffolk encompasses a land area of over 430 square miles and a population exceeding 50,000 people. It is one of the fastest growing metropolitan areas along the Atlantic seaboard.

Since 1975 the city's Public Utilities Department staff has been engaged in extensive planning for development of a safe, reliable water supply system to serve existing residents and support the growth anticipated. Until the 1980s Suffolk depended on other municipal jurisdictions for the supply and distribution of drinking water. To reduce its reliance on others and support the predicted growth, the first plan for water supply was in place in 1982 with the construction of the 3-million-gallons-per-day (mgd) G. Robert House Water Treatment Plant.

New Source Development Alternatives

The city's current strategic plan for water supply development was formulated from a 1984 water supply study which considered 12 options. Adoption of this strategic plan by City Council led to further study of the recommended alternative, enlargement of the Crump's Reservoir source to increase raw-water supply to the treatment plant. In 1986 an environmental assessment on the impact of raising the reservoir dam was prepared and submitted for regulatory approval. Environmental impacts and the regulation of minimum flows downstream of the raised impoundment were cited as major concerns by the U.S. Environmental Protection Agency (EPA) in delaying approval of the project. Alternate source development projects, including participating in a major regional surface water supply system and the desalting of brackish groundwaters, were proposed by EPA. The lesser environmental impacts expected from these projects were more acceptable to the regulatory agencies.

In 1986, as an interim water source expansion measure, the city authorized Malcolm Pirnie, Inc. to design and oversee the installation of a new 4-mgd deep well at the water treatment plant site. This well became operational in August 1987. It discharges directly into the Lone Star Lakes system, which also supplies raw water to the water treatment plant. It is also possible to divert a portion of the well discharge directly to the water treatment plant treated reservoir.

Area groundwaters, when blended with raw or treated surface waters, will satisfy current water quality standards established by the Safe Drinking Water Act (SDWA) of 1974. In the future, however, both surface and ground waters will come under stricter water quality standards, as the 1986 amendments to the act and phased implementation of lower contaminant levels are enforced.

Therefore, water from the new well and other deep wells will require treatment to satisfy these new standards. Specifically, the reduction of sodium, fluoride, and total dissolved solids will be necessary.

In response to the opposition of the regulatory agencies to the development of additional surface-water supplies, the city determined that an evaluation of the technology and economics of groundwater desalinization deserved examination.

Water System Demands

Current and projected water system demands were evaluated to determine how much water would be required from a new desalinization facility and the cost of deep well water treatment on a per-thousand-gallon basis.

Mark A. Thompson is director of Suffolk's Department of Public Utilities.

By the year 2000 Suffolk's water demand is expected to reach 10.8 million gallons a day, more than three times its maximum day demand in 1986.

Water treatment plant production has been recorded since operations began in 1982. Beginning in early 1983 at about 1.4 mgd, average daily demand in 1986 increased to about 2.7 mgd on an annual water treatment plant production basis. The highest periods of use occur in the spring and summer of each year. The 1986 maximum day demand was estimated at 3.4 mgd, 125 percent of the average day demand.

The city has conservatively predicted that the 11 percent rate of growth in water demand over the past four years will continue into the future. Without considering the impact of multimillion dollar developments proposed for the northern end of Suffolk as additional demand, a system demand projection of 10.8 mgd has been developed for year 2000.

Without interconnection service from adjoining communities the city's water treatment plant capacity would be exceeded in 1988. A nominal 4-mgd capacity desalinization plant would provide adequate supply for an additional four years.

GROUNDWATER QUALITY

Southeastern Virginia

The city of Suffolk lies within the coastal plain physiographic province of Virginia. This province is characterized by wedge-shaped sedimentary deposits of alternating sands, gravels, silts, and clays. From shallow strata overlying bedrock near Richmond, they deepen to greater than 4,000 feet in the east. There are 1,500 to 2,000 feet of sedimentary deposits overlying bedrock in the Suffolk area.

Groundwater is available from four aquifer systems: the shallow water tables, Yorktown, Upper Cretaceous, and Lower Cretaceous. The Lower Cretaceous aquifer extends from around 380 feet to basement at 1,500 to 2,000 feet. This aquifer has been subdivided into three subzones, or units, based on lithology and water quality. The upper unit, found between 380 to 440 feet, is separated from the other units by up to 40 feet of clay. One distinctive characteristic of this unit is a high fluoride concentration, which currently is being used by the Suffolk as a source of fluoride at its water treatment plant. The middle unit ranges from approximately 480 feet to 900 feet. This portion of the Lower Cretaceous aquifer comprises the main producing zones, with generally high yields and good water quality. Below 900 feet, total dissolved solids increase with depth to greater than 1,000 milligrams per liter (mg/l), most of which is sodium.

The upper and middle units of the Lower Cretaceous aquifer have been used for both industrial and municipal purposes, while lower portions are not used due to poor water quality.

Well Water Quality and Treatability

During 1987 a new 24" x 16", 915-foot deep well and pump assembly was constructed at the water treatment plant. This well, designed to produce 4 mgd, was initially configured to deliver flow to the lake system and to the water treatment plant's treated-water reservoir. The raw well-water quality is characterized by moderate levels of total dissolved solids (563 mg/l), fluoride (4.77 mg/l) and sodium (185 mg/l). Table 1 is a complete listing of the well water quality parameters of interest.

Fluoride, total dissolved solids, and sodium levels exceed the water-quality goals established by Suffolk for finished water. When used for lake augmentation, well water will cause an undesirable rise in fluoride levels in the lake supply. Thus, without treatment, the use of this well as a direct discharge raw-water source eventually will be limited. Since sodium and fluoride (components of total dissolved solids) are not removed by the conventional treatment methods in use at the water treatment plant,

TABLE 1
WTP Well (Raw) Water Quality

Parameter	Value	
Calcium	2.15	mg/l
Magnesium	0.37	mg/l
Sodium	185	mg/l
Alkalinity	374	mg/l as $CaCO_3$
Chloride	20	mg/l
Iron	0.11	mg/l
Sulfate	6.4	mg/l
Silica	20	mg/l
Conductivity	720	μmhos/cm
Total Dissolved Solids	563	mg/l
Color	5	pcu[1]
Fluoride	4.77	mg/l
pH	8.0	
Total Phosphate	0.60	mg/l as P
Ortho Phosphate	0.59	mg/l as P
Nitrate	0.05	mg/l as N
Ammonia	0.08	mg/l as N
Total Kjeldahl nitrogen	0.20	mg/l as N
Total Organic Carbon	< 1.0	mg/l
Trihalomethane Formation Potential	6	μg/l

[1] Platinum-cobalt units.

desalinization techniques for the removal of dissolved salts are required to reduce these parameters to acceptable levels.

Evaluation of feedwater treatability is of critical importance in determining the feasibility of membrane desalinization. Every feedwater has its own unique water chemistry, which physically and chemically affects membrane fouling and performance. Wellhead testing and laboratory analysis are necessary to characterize feedwaters and to predict treatability. It is not possible to predict the difference in performance of a membrane system on one feedwater from another, even when the waters appear to be similar.

Wellhead tests were conducted in the field and the following feedwater parameters were determined:

Silt Density Index (unfiltered)	< 4
Silt Density Index (filtered, 5 μm)	< 4
Turbidity (unfiltered)	0.8 NTU
Turbidity (filtered)	0.2 NTU
Biological Activity	None
pH	7.9
Temperature	74°F

Water-Quality Objectives

Establishing finished water-quality objectives will have a significant impact on the selection of suitable raw-water resources and treatment facilities for the future. The mix of existing raw waters and the addition of new deep well water characteristics offer a number of possibilities.

While conventional water treatment practices have been acknowledged as a major public health accomplishment in achieving the virtual elimination of widespread water-borne disease that occurred at the beginning of this century, the advent of new technologies for evaluating complex health issues poses a host of new and difficult water-quality problems for the water industry. Concern for these health issues resulted in the passage of the Federal Safe Drinking Water Act (1974) and the 1986 amendments to this act.

Membrane technology is being considered as an economically viable alternative to meet the stricter water-quality standards expected in the future. Trihalomethane reduction (organics removal) and softening are among the new membrane applications now gaining attention. The traditional applications of particular interest in Suffolk include the effectiveness of membranes for the reduction of total dissolved solids.

Naturally occurring levels of fluoride at 4 and 5 mg/l in area groundwaters will no longer be ignored by the regulatory agencies. The new standards for drinking water prohibit levels in excess of 4 mg/l and mandate public notification when in excess of 2 mg/l. While chlorides are permitted to reach 250 mg/l, a better tasting water is produced if held to 50 mg/l. After extensive pumping from deep wells in the area, chlorides may either reach or exceed the 250 mg/l maximum contaminant level in the future.

While maximum contaminant level has not yet been set and has been excluded from contaminants to be regulated under the 1986 amendments, monitoring of sodium levels is required. The standards which have been proposed range from 100 mg/l down to as low as 20 mg/l. A level of 50 mg/l is the figure most often quoted, and is a reasonable treatment goal. The high levels of sodium found in area groundwaters considerably exceed the standards which may be established in the future.

A secondary advisory standard for total dissolved solids has been established by EPA at 500 mg/l. For providing desirable water quality and anticipating future changes to the regulations, a 200 mg/l level of total dissolved solids is suggested. The development of all new water sources, whether surface or ground water, must be considered in light of the objective of holding down the cost of treatment in the future. To this end, the finished-water quality objectives listed in Table 2 have been established by the city staff for the Suffolk system.

DESALTING PROJECT FEASIBILITY

Reverse osmosis and electrodialysis reversal are both membrane processes used primarily for the removal of dissolved solids. In its most simple presentation, reverse osmosis is a membrane process that acts as a molecular filter to remove as much as 95 to 99 percent of most dissolved organics, and more than 98 percent of biological and colloidal material from water.

To understand how reverse osmosis works, con-

TABLE 2
Finished Water Quality Objectives

WQ Parameter	Treatment Goals	
Potassium	< 2	mg/l
Sodium	< 50	mg/l
Nitrate	< 0.05	mg/l
Chloride	< 50	mg/l
Fluoride	0.8-1.9	mg/l
pH	6.8-7.5	units
Total Dissolved Solids	< 200	mg/l
Aluminum	< 0.2	mg/l
Iron	< 0.01	mg/l
Manganese	< 0.01	mg/l
Color	< 2	pcu
Trihalomethanes	< 50	μg/l
Total Hardness	< 100/mg/l	as $CaCO_3$

A 1987 feasibility study revealed that reverse osmosis or electrodialysis reversal would be cheaper than expanding surface-water capacity.

sider natural osmosis. Pure water is separated from a salt solution by a semipermeable membrane, which passes water readily but retards the flow of dissolved solids (salts). Osmosis is the natural process whereby pure water flows through the membrane from a dilute solution into a more concentrated solution, thereby diluting the latter. Water flow continues until the pressure created by the osmotic head equals the osmotic pressure of the salt solution. This is osmotic equilibrium.

If the osmotic pressure is overcome by the application of an external pressure, the flow is reversed and purified water is removed from the concentrated solution.

The electrodialysis reversal process is based on the electrodialysis process in which water flows between alternately placed cation and anion transfer membranes at low hydraulic pressure. A direct current passing through the membrane array transfers ions [dissolved salts in water containing a positive or negative electrical charge, i.e., cation (+) or anion (-)]. This results in alternating water layers between membranes becoming depleted or concentrated in salts or ions.

In the electrodialysis reversal process, the electrical polarity (and the demineralized and concentrate flow passages) are automatically reversed three to four times an hour. This results in a reversal in direction of ion movement and provides "electrical flushing" of scale-forming ions and other charged particles from membrane surfaces.

Feasibility Study Findings

In September 1987, the feasibility study was completed concerning desalinization of the new G. Robert House Water Treatment Plant well and other deep wells in the city. The study determined that reverse osmosis and electrodialysis reversal are technically feasible processes for desalinization of the water treatment plant well. The performance and cost of each process was estimated using actual well water quality analyses and a computer model which simulated membrane performance over a range of operating conditions.

The feasibility study resulted in the following basic findings and conclusions:

- The newly constructed 4-mgd well at the water treatment plant provides only an interim solution, with well water treatment facilities required in the next two years to comply with both current and proposed Safe Drinking Water Act (SDWA) standards.
- Membrane desalinization is favored at the new water treatment plant well site when compared to other well sites, based on the relatively greater raw water volume available, the better quality of the new well, the economy of scale enjoyed by reverse osmosis and electrodialysis reversal processes, and the availability of staff and support facilities at the water treatment plant.
- An 85 percent product water recovery rate for low-pressure reverse osmosis applications, and a 95 percent recovery rate for electrodialysis reversal was determined to be technically feasible. Since the water treatment plant well is permitted by the SWCB to produce no more then 3 mgd on an annual average, average additional treated water production from a reverse osmosis facility would be 2.55 mgd, and 2.85 mgd from an electrodialysis reversal facility. The effective production capacity from an reverse osmosis facility can be increased to 2.63 mgd, since a portion of the raw well water can bypass the reverse osmosis process and be blended with process permeate.
- Estimated total unit capital and operating costs for new desalinization process equipment and control systems evaluated for the new water treatment plant well range from 62 cents to 74 cents per 1,000 gallons, with the lowest cost for the reverse osmosis with raw water blend option. Both these process unit costs and the facility construction and operating costs for desalting City Farm and Virginia Beach well water are higher.
- Current water treatment plant costs are 86 cents per 1,000 gallons. The total treatment cost in 1989 with desalting by reverse osmosis would be $1.53 per 1,000 gallons and $1.62 per 1,000 gallons with electrodialysis reversal. These unit costs include annualized recovery of all capital costs (for the process system, site work, new process building sized for future 6-mgd capacity, new administration building, and new 3.0-MG storage reservoir), all personnel and operating costs associated with the new facility, engineering and contingencies.
- The brine disposal issue is uncertain due to a lack of regulatory precedent. Surface water (brackish) disposal areas are located within reasonable distance. However, the degree of treatment required (if any) will determine the final disposal costs. Such costs could have significant impact on overall unit treatment cost.
- Compared to surface source development projects under consideration by the city, expansion and operation of the Crump's Reservoir supply

system would increase total unit treatment costs to an estimated $2.11 per 1,000 gallons in 1989.

- A reverse osmosis-electrodialysis reversal desalinization project, when compared to the surface water expansion alternative, is less expensive, can be implemented by 1989, will provide the additional water necessary to meet growing demands, and will provide flexibility for future expansion.

Traditional applications of reverse osmosis and electrodialysis reversal have focused on the removal of dissolved salts from seawater and deep well brackish water with total dissolved solids levels in excess of 1,000 mg/l. Product water recovery (percentage of raw water converted to potable water) for these applications have ranged from 25 percent for seawater to 85 percent for brackish water.

Based on the feasibility study and evaluation of the deep well water quality, we determined that a Suffolk reverse osmosis facility could operate at an 85 percent product water recovery rate before either undesirable chemical reactions would occur in the brine to foul (block) the membranes or desired water quality standards were exceeded in the product water. The recovery rate for electrodialysis reversal was estimated at 95 percent. The recovery rate has an indirect impact on production and capital costs in that a high recovery rate will lower pumping costs.

Desalinization Project Concept

Incorporation of electrodialysis reversal or reverse osmosis treatment facilities must be compatible with existing surface water treatment plant operations and satisfying finished water-quality goals when blended with water treatment plant water.

The maximum production rate would be 3.76 mgd for electrodialysis reversal or 3.5 mgd (2.8 product and 0.7 by-pass) for reverse osmosis, with the deep well operating at 4 mgd. On an annual basis, the deep well is permitted to operate only on a 3 mgd average production basis. When the well and electrodialysis reversal or reverse osmosis system is operating, we plan to run it at 100 percent capacity. During low-demand periods of the day, the system would be shut down. On average, this means that the electrodialysis reversal or reverse osmosis system would be operating 18 hours per day and shut down for 6 hours per day. During operation, the electrodialysis reversal or reverse osmosis system would provide the baseload demand to the distribution system, with the water treatment plant making up the balance of demand.

In order to confirm the computer modeling values, develop specific design criteria, and refine the cost data for the purpose of process selection for the full scale project, a pilot plant scale test was required to address the following:

- Verify the cost and performance results estimated in the feasibility analysis. From the pilot data collected, the following information was to be determined:
  - Final process design configuration
  - Scale-up factors
  - Pretreatment and post-treatment requirements
  - Brine treatment requirements
  - Expected capital and operating costs
- Project full-scale performance data at operating conditions, evaluated for the feasibility analysis. Evaluate performance and decide on pilot scale process modifications to optimize membrane system performance.
- Decide between reverse osmosis and electrodialysis reversal on the basis of cost, operability, and flexibility for future expansion.
- Demonstrate the technology to the applicable state regulatory agencies. This effort will facilitate future permit applications and agency acceptance of the proposed process.

PILOT STUDY SETUP

Demonstration of Technology

Although both reverse osmosis and electrodialysis reversal membrane desalinization technologies have been in use for many years and applications are well-documented, the use of these technologies for public water supply in Virginia is largely foreign to both state and local officials. To a great extent, discussions of potential use for Virginia Beach, and EPA's requirement that desalinization be thoroughly investigated when considering raw water source development alternatives in the region, have formed the basis of local knowledge.

Discussions of membrane desalinization, extensively covered by the local media, have focused on seawater and rather limited, unreliable groundwater supplies as feed sources. Consequently, it became necessary to demonstrate the capability of these technologies specifically for the proposed Suffolk application, to satisfy the local officials as to reliability and particularly cost, to provide the state officials with operating and performance data required for permitting, and to provide design data for the full-size system. The Suffolk City Council authorized side-by-side pilot testing of low-pressure reverse osmosis and electrodialysis reversal in October 1987, following the feasibility study described earlier.

Pilot Plant Units

Pilot plant units were leased from Fluid Systems Division, UOP, and Ionics, Inc., and installed in 20-foot shipping containers (previously purchased by the city). The containers were modified by city personnel to provide for electrical service, lighting, ventilation and feedwater service.

The reverse osmosis pilot unit was configured to replicate the proposed scheme recommended in the feasibility study. The estimated feed pressure was 240 psi, recovery at 85 percent and production of 22,500 gpd. Acid and scale inhibitor systems were provided and used.

The electrodialysis reversal unit was designed to produce about 30,000 gpd of product at a recovery of 94 percent. To achieve this recovery with a single stack, the off-spec product resulting from the reversal cycle was reused by placing it in the feedwater tank. No acid or scale inhibitor was used.

Pilot Plant Operation

The reverse osmosis unit started operations with acidification to a pH of 6.6 and injection of 3 ppm of Pfizer "Flocon 100" to control scaling. Feed pressure was 225 psi at a feedwater temperature of 70 degrees F. The unit ran for approximately 1,000 hours, producing an average permeate flow rate of 23,000 gpd, equivalent to a normalized flux of about 21 gfd/psi. After the initial 1,000 hours, the pH was raised to 7.0 and scale inhibitor dose lowered to 1 ppm. The unit ran for an additional 700 hours under these conditions with no noticeable change in flux or salt passage.

The electrodialysis reversal unit was started at its design recovery rate of 94 percent with a stack voltage of 75 volts on each stage. The predicted voltages were 69, 70 and 76 for first, second, and third stages, respectively. The amperages were:

State	Predicted	Actual
1st	6.0	7.4
2nd	3.8	5.0
3rd	2.5	3.1

After about 750 hours of operation, we decided to eliminate the off-spec product recycle. Since the single stack configuration did not provide for staggered stage reversal, it was skewing some of the operating conditions. All off-spec product was being dumped into the feed tank at one time, substantially altering the feedwater characteristics.

Having demonstrated a high-recovery operation, the piping was changed to divert the off-spec product to waste, reducing recovery to 90 percent. The rest of the performance parameters now more closely resembled full-scale operation. The unit was run in this mode for an additional 650 hours.

The actual voltage and reduced amperage requirements for this modified condition were:

State	Voltage	Amperage
1st	75	5.3
2nd	69	3.7
3rd	69	2.3

TABLE 3
RO Pilot Plant Data Summary

Parameter	Value
Feed Water Rate	24 gpm
Total Elapsed Run Time	1684 hours
Product Water Recovery Rate	85%
Feed Pressure	225 psi
Net Driving Pressure	126 psi
Corrected Water Flux	0.17 gfd/psi[1]
Salt Rejection	95%

Water Quality Parameter	Permeate	Blended Product[2]
Calcium	1.71 mg/l	1.80 mg/l
Magnesium	0.10 mg/l	0.15 mg/l
Sodium	10 mg/l	45 mg/l
Alkalinity	13 mg/l as $CaCO_3$	85 mg/l as $CaCO_3$
Chloride	0.6 mg/l	4.5 mg/l
Iron	0.06 mg/l	0.07 mg/l
Sulfate	<1 mg/l	2 mg/l
Silica	<2 mg/l	6 mg/l
Conductivity	29 μmhos/cm	166 μmhos/cm
TDS[3]	23 mg/l	110 mg/l
Color	<5 pcu	4 pcu
Fluoride	0.26 mg/l	1.16 mg/l
pH	6.1	6.5

[1] Gallon per square foot per day per psi of net driving force.
[2] Finished Water Product to the Distribution System based on a 4-part permeate to 1-part raw water blend.
[3] Total Dissolved Solids.

TABLE 4
RO Pilot Plant Data vs. Feasibility Study Estimate (Blended Water)

Parameter	Pilot Plant (PP)	Feasibility Study (FS)	Comments
Calcium, mg/l	1.80	0.16	FS Lower
Magnesium, mg/l	0.15	0.04	FS Lower
Sodium, mg/l	45	49	Similar
Chloride, mg/l	4.5	7.6	PP Lower
Sulfate, mg/l	2	2.0	Similar
Silica, mg/l	6	9	PP Lower
Total Dissolved Solids, mg/l	168	181	PP Lower
Fluoride, mg/l	1.16	1.42	PP Lower
pH, units	6.5	6.1	Similar

COMPARING ELECTRODIALYSIS REVERSAL AND REVERSE OSMOSIS

Water Quality

Both pilot units operated as predicted and with good reliability. Each experienced a slight equipment problem—failure of the oversized acid pump in the case of reverse osmosis and some temporary electrical malfunctions in the case of the electrodialysis reversal. Both systems were repaired, with no reoccurrence of failure. When power was lost to the well source, temporary changes in feedwater quality required a slight increase in feedwater pressure (5-10 psi) until the well was purged and water quality returned to its normal characteristics.

Table 3 summarizes the reverse osmosis results, while Table 4 compares the actual water-quality data with that predicted in the feasibility study. Note that the actual data is better in almost every case, except for calcium and magnesium. System salt rejection was 95 percent.

Table 5 summarizes the electrodialysis reversal test data, while Table 6 shows the actual product quality vs. predicted. It will be noted that excellent correlation was obtained. Overall salt rejection was 74 percent.

TABLE 5
EDR Pilot Plant Data Summary

PARAMETER	VALUE	
Physical	**Initial[1]**	**Modified[2]**
Feed Water Rate	19 gpm	19 gpm
Total Elapsed Run Time	745 hours	655 hours
Product Water Recovery Rate	94%	90%
Volts/Amps		
Stage 1	75/7.4	75/5.3[3]
Stage 2	75/5.0	69/3.7
Stage 3	75/3.1	69/2.3
Product Water Quality	**12/08/87 Sample**	**01/26/88 Sample**
Calcium	0.81mg/l	1.28mg/l
Magnesium	0.13mg/l	0.16mg/l
Sodium	49 mg/l	40 mg/l
Alkalinity	88 mg/l[4]	103 mg/l[4]
Chloride	2.9 mg/l	2.8 mg/l
Iron	0.06mg/l	0.10mg/l
Sulfate	2.0 mg/l	2.4 mg/l
Silica	20 mg.l	20 mg/l
Conductivity	190	198 μmhos/cm
Total Dissolved Solids	150 mg/l	140 mg/l
Color	<5 pcu	<5 pcu
Fluoride	1.29mg/l	1.16mg/l
pH	6.6	7.2

[1] Off-Spec product recycle.
[2] Without recycle.
[3] Lower voltage and amperage requirements result from the lower TDS feed water by eliminating off-spec recycle.
[4] As $CaCO_3$.

Concentration Considerations

Table 7 shows the concentrate quality for both the electrodialysis reversal and reverse osmosis test units. As with any desalinization application, concentrate disposal was of prime concern during the feasibility analysis. In the Suffolk study, two or three options were available, all of which involved a surface discharge into a brackish water creek or river. As will be seen during the final process selection, the concentrate disposal became a major factor.

Final Cost Evaluation

On the basis of the pilot test results, operating and capital costs developed in the feasibility study were further refined for presentation to the city. Operating costs were reduced from those presented in the feasibility study for both reverse osmosis and electrodialysis reversal. Table 8 shows the comparison for reverse osmosis. It will be noted that by depressing the feedwater pH to 7.0 instead of 6.6, as expected, the acid cost was reduced and the lime requirement for post treatment was eliminated. Also, the absence of fouling indications during the pilot test allowed the elimination of the media filters originally proposed, together with the coagulant polymer feed.

The other significant change was in the high pressure pump power, reduced to $399 a day from $455. However, auxiliary power was added back for degasser blowers and transfer pumps. This cost had not been included in the feasibility study. The overall result of the actual operating data from the pilot study was a reduction in operating cost for the blended product from 33 cents to 30 cents a thousand gallons, or about 10 percent.

TABLE 6
EDR Pilot Plant Data vs. Feasibility Study Estimates

Parameter	Pilot Plant (PP)	Feasibility Study (FS)	Comments
Calcium, mg/l	0.81	0	Insignificant
Magnesium, mg/l	0.13	0	Insignificant
Sodium, mg/l	49	38	FS Lower
Chloride, mg/l	2.9	2	Similar
Sulfate, mg/l	2	1	Similar
Fluoride, mg/l	1.29	1	Similar
Total Dissolved Solids, mg/l	150	140	Similar

The reverse osmosis capital cost was reduced from $2.35 million to $2.075 million. This change was a result of reduced equipment pricing and elimination of the media filter system. The reverse osmosis equipment cost was re-estimated, based on recent bids for similar-sized equipment.

Table 9 compares the operating costs for electrodialysis reversal estimated for the feasibility study with the costs revised as a result of the pilot test program. Note the significant reduction in power. This was achieved by utilizing the head available from the well pump to drive the water through the process, thus eliminating the feed boost pumps. To achieve this, the well pump needed an additional stage, thus increasing the connected load of the motor. This, in turn, added about 2 cents per thousand gallons (at 7 cents/kwhr) to the electrodialysis reversal operating cost. The second significant reduction was for membranes and stack parts. Between the feasibility study and the pilot study, Ionics, Inc. initiated a new membrane manufacturing process which significantly reduced the cost of production. Also, as a result of the pilot test data, stack part costs (primarily electrode costs) were reduced by 50 percent. It is interesting to note that both membrane replacement and stack part unit costs were guaranteed by Ionics for more than 10 years.

CONCLUSIONS

With the completion of the pilot testing program, both the city of Suffolk and the engineers were faced with a dilemma. Both processes had performed as well as, if not better than, predicted in the feasibility study. The original operating and capital costs had been refined in both cases, providing lower estimates than had been previously predicted. Both systems had performed well, and the city's operators felt confident that both processes would provide trouble-free operation. However, with the extremely tight schedule requested by the city for full-scale production, it was not possible to prepare the two sets of bid documents required, competitively bid

TABLE 7
EDR Concentrate Water Quality Summary (mg/l)

Parameter	EDR Value	RO Value
Calcium	8.75	4.16
Magnesium	5.36	1.37
Sodium	860	975
Alkalinity ($CaCO_3$)	4216	2224
Chloride	292	120
Iron	0.16	0.39
Sulfate	84	195
Silica	130	144
Conductivity (μmhos/cm)	8100	4100
Total Dissolved Solids	5057	2853
Color (pcu)	5	30
Fluoride	81	36
pH (units)	8.7	8.0
Ortho Phosphate (P)	6.25	4.06
Total Phosphate (P)	6.25	4.09
Nitrate (N)	<0.05	0.05
Ammonia (N)	0.94	0.53
Total Kjeldahl Nitrogen	1.55	0.72
Total Organic Compounds	5	5

TABLE 8
RO System Operating Costs

Item	FS Prediction ($/Day)	PS Actual ($/Day)
93% Sulfuric Acid		
3425 lbs/day @ $0.05/lb	171	
3302 lbs/day @ $0.05/lb		165
Scale Inhibitor (Flocon 100)		
85 lbs/day @ $1.00/lb	85	
28 lbs/day @ $1.00/lb		28
Lime (post-treatment)		
300 lb/day @ $0.05/lb	15	
0 lb/day @ $0.05/lb		0
Coagulant Polymer		
28 lb/day (1 ppm)@$1.50/lb	42	
0 lb/day (0 ppm)@$1.50/lb		0
Cartridge Filters		
2040 units/year @ $7/unit	40	40
Cleaning Chemicals		
$0 per 1000 gallons	0	
$0.01 per 1000 gallons		28
High Pressure Pump Power		
6500 kwhr @ $0.07/kwhr (121 Hp)	455	
5700 kwhr @ $0.07/kwhr (106 Hp)		399
Auxiliary Power		
0 kwhr @ $0.07/kwhr	0	
630 kwhr @ $0.07/kwhr		44
Total Daily Operating Cost	808	704
Unit Cost (per 1000 gallons)	0.29	0.25
Membrane Replacement Cost (per 1000 gallons)	0.12	0.12
Total RO Operating Cost (per 1000 gallons)	0.41	0.37
Operating Cost: Blended Water (per 1000 gallons)	0.33	0.30

reverse osmosis and electrodialysis reversal, and construct the plant within the time available. Therefore, we decided that one process would be selected for implementation.

Decision Matrix

The methodology for selecting the process caused much soul searching. If reverse osmosis were selected, there would be competitive bidding, with the possibility of reducing the capital cost estimates. If electrodialysis reversal were selected, there would be no bidding. Ionics agreed to negotiate in good faith and guaranteed capital costs until July 1, 1988.

To come to a final decision took several meetings between the engineers and the city, and finally, the development of an evaluation procedure. A total of 100 points was available for each of the evaluation factors. Eight factors and a weighting were developed as follows:

Factors	Weighting Assigned
Capital Cost	7
Process Operating Cost	7
Schedule	12
Operability	18
Maintenance & Serviceability	18
Future Expansion	15
Brine Disposal	18
Product Water Quality	5
Total Points	100

Since the capital and operating costs were almost equivalent, with reverse osmosis having lower capital and electrodialysis reversal lower operation, the intangible noncost factors became the key to the final decision. Electrodialysis reversal became the selected process, in large part because of brine disposal.

During the study, the Commonwealth of Virginia initiated proposed limitations on total phosphorus discharge. Since completion of the pilot work, these proposed limits have been approved and established as policy. This policy limits phosphorus discharges to 2 mg/l for all discharges greater than 50,000 gallons per day, unless an NPDES permit is issued before July 1, 1988. If the permit is issued before that date, only discharges greater than 1 mgd would be regulated. On a pounds-per-day basis, the electrodialysis reversal plant could be installed and expanded to double the capacity without exceeding the state discharge requirements. Thus, the 94 percent recovery of the electrodialysis reversal, plus its ability to reject phosphates, became the deciding factors.

More stringent regulations limiting phosphorus discharges and a 94 percent product recovery rate were the factors that helped tip the scale in favor of electrodialysis reversal.

TABLE 9
EDR System Operating Cost Comparison

Item	FS Prediction ($/Day)	PS Actual ($/Day)
Acid	0	0
Scale Inhibitor	0	0
Lime	0	0
Stack & Pump Power		
2.6 kwhr/1000 gallons @ $0.07/kwhr	684	
1.5 kwhr/1000 gallons @ $0.07/kwhr		395
Cartridge Filters		
2040 units/year @ $7/unit	40	
1440 units/year @ $7/unit		28
Cleaning Chemicals		
$0.01/1000 gallons	38	38
Stack Parts		
$0.06/1000 gallons	226	
@ $0.03/1000 gallons		113
Nonstack Parts		
$0/1000 gallons	0	
$0.015/1000 gallons		57
Total Daily Operating Cost	988	631
Unit Cost (per 1000 gallons)	0.26	0.17
Membrane Replacement Cost (per 1000 gallons)	0.10	0.06
Total Operating Cost (per 1000 gallons)	0.36	0.23

Project Capital Cost

The total present-day cost for a nominal 3.8-mgd capacity electrodialysis reversal facility at the selected site, was estimated as follows:

EDR Process Package	$ 2,350,000
Storage Reservoir Package	700,000
Site Facilities Package	1,755,000
New WTP Control/Lab Package	400,000
Subtotal	$ 5,205,000

Suffolk's water rates have gone up to cover the cost of the EDR plant, but in return the city gets excellent water from a source not affected by droughts or future higher water quality standards.

Engineering	550,000
Contingencies (5%+)	295,000
Total Project Budget	$ 6,050,000

The cost of the electrodialysis reversal process package includes switchgear. The site facilities package cost is based on a building sized for capacity only. It also includes well pump modifications and generator set with enclosure.

The total budget estimate is equal to $1.61 per installed 1,000 gpd.

Impact on Water Rates

The final evaluation of the study was to determine the impact of the construction and operation of the electrodialysis reversal project on the current city water rate structure. This is presented in Table 10. It will be noted that in 1989, the total water treatment production cost is estimated at 61 cents more than in 1988.

From this, the observation can be made that although the city of Suffolk must increase its water rates to cover the cost of the newly constructed electrodialysis reversal plant, this additional cost will approximately double the city's current supply.

This capacity will not be affected by drought, will be relatively impervious to the standards-setting role of EPA, and will produce an excellent quality drinking water for many years to come.

TABLE 10
Water Treatment Costs with Desalinization

	WATER TREATMENT PLANT			DESALINIZATION PLANT			TOTAL		
	Q (mgd) (ADP)	Annual$ (x 1000)	Unit $ ($/Kgal)	Q (mgd) (ADP)	Annual$ (x 1000)	Unit $ ($/Kgal)	Q (mgd) (ADP)	Annual$ (x 1000)	Unit $ ($/Kgal)
WTP Only Current:	2.70			.00			2.70		
Capital		.00	.00		.00	.00		.00	.00
Process Cost (var)		246.38	.25		.00	.00		246.38	.25
Operating Cost (fixed)		502.61	.51		.00	.00		502.61	.51
New Well Power		99.00	.10		.00	.00		99.00	.10
Totals		847.99	.86		.00	.00		847.99	.86
Electrodialysis Reversal 1989 (1st Year):	0.51			2.82			3.33		
Capital		.00	.00		616.19	.60		616.19	.51
Process Cost (var)		53.98	.29		319.08	.31		373.06	.31
Operating Cost (fixed)		100.52	.54		555.82	.54		656.34	.54
New Well Power		.00	.00		133.81	.13		133.81	.11
Totals		154.50	.83		1624.90	1.58		1779.40	1.47

NOTES:

Total water treatment costs for the first year of operation (1989) are based on full capacity utilization of the EDR process and deep well, with the surface WTP operating at approximately 0.5 mgd (1/6 capacity). This is a conservative basis for determining real costs, since in practice the surface plant must normally operate up to at least 1.0 mgd. Consequently, actual first year treatment costs should be slightly less than presented in this table.

If financing cannot be secured at 8%, a higher rate of, say, 10% would result in 1989 annual costs approximately $0.05 per 1000 gallons higher than reported in this table.

The Elizabeth River: Problems, Conflicts, and Solutions

Described as one of the two most polluted rivers flowing into the Chesapeake Bay, the Elizabeth is used by shipbuilders, transporters, and recreationists. Lining its banks are the world's largest naval base and coal exporting facility, seafood processors, and, increasingly, upscale residential housing. This multiplicity of use may be the river's salvation, for it is uniting citizens in the basin to save it.

John M. Carlock

INTRODUCTION

Southeastern Virginia is a region of 2,000 square miles, bounded by the Atlantic Ocean on the east, the James River on the north, North Carolina on the south, and extending nearly to Interstate 95 on the west. It contains the cities of Chesapeake, Franklin, Norfolk, Portsmouth, Suffolk, and Virginia Beach, and the counties of Isle of Wight and Southampton. This diverse region, also known as Southside Hampton Roads, is home to nearly one million people. The Elizabeth River is one of the 25 major water bodies in the region.

The Elizabeth River is the dominant physical feature in the metropolitan heart of Southside Hampton Roads. The river physically divides the region. Environmental psychologists and designers tell us that the Elizabeth River is a "hard edge," an impenetrable barrier. Historically, this has been the case as toll ferries and tunnels have been necessary to move from one community to another. The river unites the region culturally and socioeconomically. It is Norfolk Harbor—the home of the world's largest naval base, the world's largest coal exporting facilities, numerous shipping terminals, and Mile Marker Zero on the Atlantic Intracoastal Waterway. It is festivals like Harborfest and the Seawall Festival that draw millions to the waterfront annually. It is often-maligned. Through concern for cleaning the river, it can unite the people of the region. All share in the benefits derived from the river, and all contribute to its problems.

The Elizabeth River is a tidal estuary with four major segments and numerous tributaries. The longest segment of the river stretches upstream 17 miles from its mouth at Hampton Roads. Under natural conditions, the Elizabeth River was fairly broad and shallow with a deep channel. Extensive wetland areas along the river and its tributaries have been bulkheaded and filled for dredge disposal and urban development. Major dredging projects have resulted in a channel varying from 35 to 45 feet in the main stem and southern branch, and channels between 10 and 25 feet in the eastern and western branches. Active projects will deepen the main stem to 55 feet, much of the southern branch to 45 feet and the lower eastern branch to 35 feet.

Typical of Virginia's coastal plain, the Elizabeth River Basin is flat. This nearly 225-square-mile basin has a maximum natural elevation of approximately 20 feet. That elevation is exceeded only by highway overpasses and municipal landfills. The basin constitutes 10 percent of the land area of metropolitan Southside Hampton Roads, but contains nearly 50 percent of its population. The basin's population is projected to grow nearly 20 percent by the year 2005, while employment in the basin is forecast to grow nearly 80 percent in the same time period. Much of this employment growth is expected to occur along the main stem and southern branch. Population growth is anticipated primarily in the upper ends of the three primary branches.

This growth will result in the development of extensive acreage. In 2005, about 25 percent of the basin will be used for residential purposes, 10 percent for commercial and institutional activities, and 17 percent for industrial. It should be noted that this allocation reflects actual use, rather than ownership, of government land. Nearly 40 percent of the basin will remain undeveloped as vacant land and in agricultural use. Thus, there is a considerable reserve of land for additional development in the next century. This undeveloped land also serves in part to buffer the river from the adverse impacts of urbanization.

WATER QUALITY SITUATION

The Elizabeth River has been characterized by the Chesapeake Bay Program as one of the two most polluted rivers in the bay system. Some of this is to

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Without additional controls, nonpoint source loadings in 2005 will be significantly higher than today.

be expected, given the river's natural characteristics of minimal freshwater inflow and long residence times. Historically, it has been a problem river. In 1914 the Public Health Service concluded that the taking of shellfish from the Elizabeth should be prohibited due to bacterial pollution. In the late 1930s this situation continued and led the Virginia General Assembly to establish the Hampton Roads Sanitation District to provide improved treatment of municipal sewage discharges to the river. In the 1970s algae blooms were observed in the upper reaches of many of the tributaries. Throughout this period, many people suspected problems with toxic substances due to the basin's industrial character.

Today, the water quality of the Elizabeth River presents a mixed picture (see Table 1). Water quality is marginal-to-good for conventional indicators and pollutants such as dissolved oxygen, biochemical oxygen demand and nutrients. Largely because of nonpoint source pollution, the river continues to exhibit poor quality with respect to bacterial contamination. Levels of metals and organics in the water column and sediments are elevated, particularly in the lower southern branch and main stem. Water quality attributable to these parameters can be characterized as marginal-to-poor in these areas.

TABLE 1
Water Quality Condition by River Branch

Segment Parameter	Main Stem	Western Branch	Eastern Branch	Southern Branch
DO[1]	Marginal	Marginal	Marginal	Marginal
BOD[2]	Marginal	Marginal	Marginal	Marginal
Chlorophyll A	Good	Good	Good	Marginal
Fecal Coliform	Good	Good	Good	Marginal
Total Nitrogen	Good	Good	Good	Good
TP[3]	Good	Good	Good	Good
Arsenic	Good	Good	Good	Good
Cadmium	Marginal	Marginal	Marginal	Marginal
Chromium	Good	Good	Good	Good
Copper	Poor	Poor	Poor	Poor
Lead	Poor	Poor	Poor	Poor
Mercury	Poor	Marginal	Marginal	Marginal
Nickel	Poor	Poor	Poor	Poor
Zinc	Marginal	Marginal	Marginal	Marginal
PNAH[4]	Good	No Data	No Data	Poor
TBT[5]	LD[6]	LD	LD	LD

[1] Dissolved Oxygen
[2] Biological Oxygen Demand
[3] Total Phosphorus
[4] Polynuclear Aromatic Hydrocarbons
[5] Tributlyltin
[6] Limited Data

Source: Hampton Roads Water Quality Agency with Southeastern Virginia Planning District Commission. 1986. *Comprehensive Elizabeth River Water Quality Management Plan: Preliminary Management Recommendations.*

There are currently 53 point source discharges to the Elizabeth River. Of these, only eight are characterized through the National Pollution Discharge Elimination System as major sources. Insofar as conventional pollutants are concerned, most of the point source dischargers are doing a good job of meeting water quality requirements. Problems arise with the discharge of toxic organics and metals. Many of the identified problems are associated with past disposal practices and difficult-to-control dischargers such as vessel traffic and ship building and repair. In a 1986 study, *Hazardous Waste in Southeastern Virginia,* the Southeastern Virginia Planning District Commission (SVPDC) found that of 80 facilities in the region that were licensed as hazardous waste generators, transporters, or disposers, 54 were in the Elizabeth River Basin. Most were located close to the river or one of its tributaries. A recent U.S. Environmental Protection Agency study identified nearly 700 sites in the metropolitan area that potentially could be considered for inclusion in the Superfund program. Although this list has been subsequently reduced to less than 200, it is still indicative of the potential problems in the basin.

The first significant consideration of nonpoint source pollution in the Elizabeth River Basin came in the 1978 Hampton Roads Water Quality Management Plan. Field sampling and water quality modeling analysis revealed that nonpoint source contributions of conventional pollutants overwhelmed point source contributions. This analysis was based on a design storm with a two-year frequency, one which has been exceeded with regularity. There has been no recent quantified forecast of nonpoint source loadings to the river. However, using the aforementioned population and employment forecasts, it can be concluded that without additional controls, nonpoint source pollutant loadings in 2005 will be significantly higher than at present.

WATERWAY USE CONFLICTS

Conflict is inherent in the use of both the waterway and the surrounding basin. The Elizabeth River is an active commercial and industrial waterway. Ten shipyards, which undertake major commercial and military ship repairs, are located along the river. Concurrently, the river is home to nearly 1,300 marina slips for recreational vessels. There are 20 boat ramps and another 20 sites, primarily along the tributaries, with potential as canoe put-in/take-out points. Recreational use of the river has increased rapidly in the past 10 years due in large part to the revitalization of the Norfolk and Portsmouth water-

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TP[3]	Good	Good	Good	Good
Arsenic	Good	Good	Good	Good
Cadmium	Marginal	Marginal	Marginal	Marginal
Chromium	Good	Good	Good	Good
Copper	Poor	Poor	Poor	Poor
Lead	Poor	Poor	Poor	Poor
Mercury	Poor	Marginal	Marginal	Marginal
Nickel	Poor	Poor	Poor	Poor
Zinc	Marginal	Marginal	Marginal	Marginal
PNAH[4]	Good	No Data	No Data	Poor
TBT[5]	LD[6]	LD	LD	LD

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Along the shoreline, conflict is also apparent. Residential land uses can be found adjacent to and across the river from heavy industrial activities, such as shipyards. Heavy industrial activities are located adjacent to recreational uses. Seafood processing and rail facilities are surrounded by commercial and residential areas. With the continuing popular desire for waterfront residential property and urban recreation areas, such conflicts are likely to increase. Seemingly, increased public access to and awareness of the river have led to stronger citizen support for strict controls on waste dischargers and other water quality improvement efforts.

The potential for conflict also exists in our goals for the future use of the river and its basin. During 1986, the SVPDC, in cooperation with the Hampton Roads Water Quality Agency (HRWQA), completed *Comprehensive Elizabeth River Water Quality Management Plan: Preliminary Management Recommendations.*

With the help of user groups involving industry, local government, and environmental representatives, river use goals were defined to include:

- To maintain the usage of the river system as an "industrial and commercial highway";
- To maintain the aesthetic quality of the river system for noncontact enjoyment of viewers;
- To improve and maintain water quality at a level which does not threaten the health of living resources (human and nonhuman) using the river system;
- To prevent river system use activities from adversely impacting the environment in adjacent waterways and areas;
- To encourage waterfront land use activities and decisions compatible with other goals.

These goals must be viewed within the framework of existing river uses and the Clean Water Act goal to make the waters of the United States, "fishable and swimmable." Obviously, achievement of these goals in a manner which produces compatibility will not be easy. Tough decisions will be required and many of them will require considerable expense on the part of individual citizens, local government, industry, and the military.

SOLUTIONS

The Comprehensive Elizabeth River Water Quality Management Plan: Preliminary Management Recommendations contained three principal recommendations for improving water quality in the river, while achieving economic goals. The SVPDC and HRWQA are now working to refine those recommendations insofar as they relate to land use and waterfront development.

Local governments are proceeding with land development activities to improve the basin's environmental quality.

The Virginia Water Control Board has embarked on a number of initiatives as the result of the Chesapeake Bay Agreement and the various Elizabeth River studies. A toxics management strategy and water quality standards for nutrients and tributyltin paints have been adopted. (Tributyltin paints, which are considered to be very effective antifouling paints for vessels, have been found to be extremely toxic to marine organisms. The Virginia standard is presently the most stringent in the United States.) A Comprehensive Elizabeth River Restoration Strategy is being developed. Finally, the Lower James River Water Quality Management Plan is being developed and will include the Elizabeth River.

The Hampton Roads Sanitation District (HRSD) and Portsmouth have entered an agreement to eliminate discharges from the Portsmouth Pinners Point Sewage Treatment Plant. Sewage from Portsmouth will be piped under the Elizabeth River for treatment and discharge at the HRSD Virginia Initiative Plant. That plant is being substantially expanded and upgraded to provide nutrient removal. HRSD is also working with the Norfolk to evaluate treatment options for wastewater from its Moores Bridges Water Treatment Plant, which discharges to a tributary of the Elizabeth River.

The Southeastern Public Service Authority (SPSA) of Virginia has implemented a regional solid waste disposal and resource recovery system. This system has resulted in the closing of municipal incinerators, four major municipal landfills, and an obsolete Navy power plant in the Elizabeth River Basin. SPSA also is implementing a hazardous waste management program, which will eliminate the potential disposal of hazardous waste in the municipal solid waste disposal system. That program includes household hazardous waste collection days, a waste disposal certification program, education and training activities, and planning for a regional hazardous waste transfer station.

Local governments in the basin are also proceeding with many land development activities which will enhance environmental quality in the basin. The four cities are at various stages in updating their comprehensive plans and related regulatory measures. This effort is expected to assume increasing importance due to passage by the Virginia

General Assembly of the Chesapeake Bay Preservation Act. Portsmouth has completed a coastal zone land use plan, outlining steps that can be taken to improve management of its shoreline. Virginia Beach has adopted a stormwater management ordinance, requiring the implementation of best management practices for the control of nonpoint source pollution. The cities of Chesapeake and Virginia Beach have both enacted tree protection requirements.

The SVPDC, the HRWQA, and the four localities are participating in Virginia's coastal resources management program in order to enhance their ability to manage their coastal environment. The SVPDC has recently published *The Waters of Southeastern Virginia,* an analysis of water-oriented recreation needs and opportunities in the region, including the Elizabeth River. Recommendations in this study augment local efforts to provide increased public access to the river. Data collection and analysis efforts are underway to improve the basis for land-use and water quality management decisions. Public education and training programs are also designed to fulfill the need for improved decision making.

CONCLUSION

An institutional framework to address the problems and opportunities associated with land development in the Elizabeth River Basin and the use of its waters has been established through the efforts of local and state officials. It builds on growing citizen interest in improving the river's quality. The river has problems which will require attention. Many of these problems have been corrected, and environmental improvements are becoming apparent. For many others, the road to solution remains long and arduous. The land- and water-use conflicts, described above, are not likely to be eliminated entirely. However, with good faith efforts by citizens, government at all levels, and private industry, many can and will be ameliorated.

Cleaning Up Nansemond-Chuckatuck: A Threatened Success Story

The progress made since 1981 in reducing water pollution by agriculture is being threatened by development in this rural area, but two regional agencies are fighting back.

Paul E. Fisher

INTRODUCTION AND SUMMARY

The Nansemond River-Chuckatuck Creek Rural Clean Water Project (RCWP) is a federally funded agricultural pollution control program located in Isle of Wight County and the city of Suffolk. During the 10-year project life, which began in 1981, almost $2 million in federal cost-share funds will be spent on agricultural nonpoint source pollution control best management practices (BMPs). Project goals include the protection of water quality in the shellfish harvesting areas of the two estuaries as well as in the freshwater reservoirs which are the primary potable water supply source for Suffolk, Norfolk, Virginia Beach, Chesapeake, and Portsmouth.

While the cost-share installation of BMPs is federally funded, various local, regional, and state agencies have been involved in the planning, procurement, and management of the project. Cooperation has been superb and is a model for programs of this type. Midway through the project, all funds have been contracted and extensive installation of BMPs has occurred. A significant reduction in agriculturally generated pollutants from field crops and livestock has followed.

Threatening the water quality success of the project is the recent trend of land-use conversion from agricultural uses to suburban development patterns. While a nonpoint source pollution control plan is in place for such activities, it is not mandatory. Also, because centralized public sewage treatment is not available in much of the area, proposals for private package sewage treatment plants are accompanying rezoning requests and other development activities. Such discharges pose a direct threat to shellfish harvest areas and have other problems related to maintenance and ultimate cost to the public. In response to the trend, the Southeastern Virginia Planning District Commission and the Hampton Roads Water Quality Agency have prepared a regional policy recommending against private sewage treatment plants. Also, the Hampton Roads Water Quality Agency is providing information to the localities in the area of nonpoint source management.

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PROJECT LOCATION AND DESCRIPTION

The Nansemond-Chuckatuck RCWP project lies at the geographic center of the Greater Hampton Roads Area in the coastal plains physiographic province of Virginia. It includes approximately 161,365 acres. Roughly 30 percent of the project area is in Isle of Wight County with the remaining 70 percent in the City of Suffolk. In 1984 the population of the area was approximately 38,000 people; however, the last three years have seen rapid growth.

Agriculture and agribusiness are the major forms of industry in the project area with 825 farms having an average size of 177 acres. Farming in the area consists of swine, dairy, poultry, and beef enterprises as well as intensive production of such row crops as corn, soybeans, peanuts, and small grains. The two major estuaries draining the area are the Nansemond River and Chuckatuck Creek. The Nansemond River discharges into the James River at its confluence with Hampton Roads and the Chuckatuck Creek discharges into the James River approximately two miles further upstream. Approximately 30.3 miles of the project area are influenced by tidal action. Water quality of both estuaries has been studied extensively by the Hampton Roads Water Quality Agency and its contractor, the Virginia Institute of Marine Science.

The Nansemond River and Chuckatuck Creek once supported extensive commercial and sports fishing. However, in more recent times municipal, industrial, and nonpoint source discharges have resulted in extensive areas of the shellfishing grounds being condemned for direct market harvesting. Through pollution control activities in the 1970s and early 1980s, the point source discharges of significance to the estuaries were removed. The Hampton Roads Water Quality Agency planning indicated, however, that water-quality problems would persist due to agricultural runoff and, ultimately, urban runoff. In addition to the estuaries, the project area contains seven water-supply reservoirs owned by Norfolk and Portsmouth. These supply the majority of potable water to the southside Hampton Roads metropolitan area. Additionally, Suffolk's water supply lakes are in the project area as are numerous deep wells used to supplement the surface water sources. Based on past field studies, water quality in the public water supply reservoirs is considered to be degraded due to excessive nutrient, phytoplankton, and fecal coliform bacteria levels. Although not a threat to the public health due to water treatment processes, the degraded raw water may increase treatment costs. Stormwater runoff is considered the primary source of pollutants to the water supplies.

In response to the water-quality analyses, the Hampton Roads Water Quality Management Plan recommended that the Nansemond River area be the target of agricultural nonpoint source pollution control. The reasons for conducting a Rural Clean Water Project in the Nansemond-Chuckatuck area were clear:

- To protect the critical water supply sources and
- To protect and revitalize the commercial and recreational shellfisheries.

To implement the Hampton Roads Water Quality Agency recommendation and effect a cleanup of agricultural pollution sources, the U.S. Department of Agriculture has awarded matching grant funds approximating $2 million. Depending on the pollution control practice, farmers must provide a percentage of the cost of the BMP. Twelve BMPs are receiving extensive implementation in the area:

- Permanent Vegetative Cover
- Animal Waste Control System
- Diversion System
- Grazing Land Protection System
- Waterway System
- Cropland Protective System
- Conservation Tillage System
- Stream Protection System
- Permanent Vegetative Cover on Critical Areas
- Sediment Retention, Erosion, or Water Control Structures
- Fertilizer Management
- Pesticide Management

Participation by farmers has been extensive and all project funds have been contracted. In terms of agricultural pollutant reduction, the project is very successful.

In support of the project, the Hampton Roads Water Quality Agency, Virginia Water Control Board, Virginia Health Department, and the cities of Norfolk, Portsmouth, and Suffolk are cooperating in a monitoring program to study the water-quality effects of the project. While it is known that a significant reduction of pollutants coming from treated areas has occurred, it is too early to quantitatively link those reductions with water quality trends in the receiving waters.

CONCLUSION: THE NEXT DECADE

Compounding the difficulty in linking agricultural pollutant reduction to an improvement in water quality in the area is the rapid increase in suburban types of development (bedroom communities and supporting commercial services). Ultimately, nonpoint source loadings from developing areas may mask any water quality improvements resulting from the RCWP.

In relation to the Greater Hampton Roads area, the Nansemond-Chuckatuck RCWP area is geographically central. That fact, in conjunction with major transportation improvements, property costs, and other factors, is elevating the desirability of the area as a location for growth. In Suffolk alone, building permits for residential units issued in the last two years exceed by more than 350 the number issued in the previous five (1,478 vs. 1,116).

Through qualitative observation of another estuary, a parallel may be drawn as a forecast of what could happen in the Nansemond-Chuckatuck area. At one time the Lynnhaven estuary in Virginia Beach was a noted commercial shellfishery. As suburbanization of that basin occurred, stormwater runoff precipitated the condemnation of the entire estuary for direct shellfish marketing (although after prolonged dry periods in an area adjacent to Seashore State Park, it is occasionally opened). It is clear to the author that a similar fate awaits the Nansemond-Chuckatuck estuaries unless steps are immediately taken to control the stormwater runoff coming from new development activities.

The opportunity to avoid a similar fate in the Nansemond-Chuckatuck area exists through the implementation of a comprehensive stormwater management program. With the recent strengthening of the Virginia Erosion and Sediment Control Law and program, and with a provision in the Chesapeake Bay Preservation Act which allows local government to use its development control ordinances for water-quality management purposes, the tools to maintain the estuaries and reservoirs in a viable condition are in place. A commitment to use those tools, and the results of their implementation, will be decided in the coming decade.

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