DARE BEACHES WATER SUPPLY: FRESH POND TO REVERSE OSMOSIS

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The story of water supply for the Beaches of Dare County can well be a story of political evolution. Efforts to develop a satisfactory water supply began with the formation of the Dare Beaches Sanitary District in the early 1950s. When a suitable water system failed to develop through this avenue, Nags Head and Kill Devil Hills each incorporated and developed separate water supplies. From this beginning, the Dare Beaches Water Authority was created. Difficulty in obtaining financing lead to dissolution of Authority, and the emergence of the County of Dare as the lead governmental unit in development of a water supply for the beaches.

Under the new arrangement, an interlocal agreement was made among Dare County, Nags Head, and Kill Devil Hills to jointly pay for new treatment improvements. This important agreement was later amended to include the construction of a surface water treatment plant at Fresh Pond, and subsequently amended for the regional reverse osmosis plant, which was completed this year.

THE EARLY STAGES: FRESH POND AS WATER SUPPLY

The Dare Beaches Sanitary District was created in the early 1950s as a result of concern by both seasonal and permanent residents of Dare County about development of a public water system for the beach area. It was not until the early 1960s that a public water system was established. Both Nags Head (incorporated in 1961) and Kill Devil Hills (incorporated in 1953) developed their separate water systems at about the same time. The two towns used Fresh Pond - a fresh water lake of about 30 acres - as their water supply. Before deciding to use this fresh water lake (which is more like a mammoth open well) as a water supply, the Towns conducted considerable groundwater investigation to locate suitable groundwater sources. It soon became evident that the surficial aquifer was the only source of fresh water and the decision was made to use the fresh water lake, which straddles the corporate boundary between Nags Head and Kill Devil Hills. The water quality in this lake was almost like rain water - very low in dissolved solids and iron.

Once the decision was made to use the Fresh Pond as a water supply, the two towns began to construct their water plants - one for each town on either side of the corporate boundary between the two communities and about 100 yards apart. Due to the excellent water quality of Fresh Pond, the North Carolina Health Department approved the use of microstrainers, primarily to remove algae and other suspended solids.

The Fresh Pond served adequately as a water supply source until the late 1960s when the towns begin to experience problems with water quality in their distribution systems. The deterioration in quality was due to the failure of the microstrainers to remove the algae. As the pond was drawn down by use, the iron level began to increase, as did the algae bloom. At times, water delivered to homes was the color of tea. Pilot studies indicated that small doses of alum would produce a readily settleable floc. Subsequently, with the approval of the State Health Department, each town constructed a 1,000,000 gallon settling tank, located after the microstrainer, and alum was introduced between the strainers and the tanks. To serve as flocculators, wooden baffles were built into the tanks where the water entered. These worked reasonably well, and with a theoretical settling time of 24 hours or more, a much better quality of water was delivered to the distribution systems.

It was evident by 1969 that the Fresh Pond would not furnish the volume of water needed by the two towns as they continued to grow. The Dare Beaches Water Authority was formed as a vehicle to develop an adequate water supply for the overall beach area. Concerns about financing, and the need for an authority to finance through issuance of revenue bonds, led the North Carolina Local Government Commission to recommend that Dare County be the political entity responsible for development of an adequate water supply for the Dare Beaches. The County became involved in the early 1970s. The County's involvement led to the development of a groundwater supply in the southern end of Roanoke Island, where wells were constructed between the intersection of U.S. 64 and N.C. 345 (Skyco) and the Village of Wanchese. These wells range from 150 to 200 feet deep. The water quality is relatively good, requiring only softening as treatment. Chlorides are less than 100 ppm.

To put water requirements and water supply in proper prospective, the Fresh Pond was determined to have a safe yield of about 1,000,000 gallons per day during the summer months. The source of fresh water on the Outer Banks is precipitation, with only 25 percent of the precipitation available for percolation to the zone of saturation where it becomes a groundwater supply. The Fresh Pond responds hydraulically in the same manner as a large diameter well. Before the Roanoke Island Water Plant came on line in 1979, Nags Head and Kill Devil Hills together used in excess of 1,000,000 gallons per maximum day. By 1980, maximum day use was 2,000,000 gallons. The design capacity of the Roanoke Island Plant is 5,000,000 gallons per day, and in 1983 the peak day was 4,500,000 gallons. It was thus obvious that the water supply for the Dare Beaches was again in jeopardy.

THE NEED FOR MORE WATER: TESTING THE UNDERGROUND AQUIFIERS

In 1983 the Dare County Board of Commissioners authorized a study of additional water supply sources, which concluded that additional wells could be developed on Roanoke Island. During the peak water use period of 1983 some private wells in the Wanchese Community temporarily experienced lowered water levels because of the proximity of the county wells. Much negative publicity resulted from these problems, and subsequent action by the County included constructing many new private wells to alleviate the problem.

The Village of Wanchese is not served by the County's distribution lines. For political reasons, the County Commissioners decided to develop a brackish water supply source on the beach and to treat the water by reverse osmosis. The County also decided to develop a full treatment plant at the Fresh Pond, using the Nags Head plant facilities for pretreatment and settling and using the available 1,000,000 gallons per day supply in the Fresh Pond. Improvements to the Nags Head Plant consisted of renovation to the existing facilities and addition of filters, a filter control building, and a clearwell. The microstrainer was removed and its chamber was converted to a rapid mix chamber. This plant went into operation in late 1985, and can process 1.5 mgd per day. Combined with the 5.0 mgd of the Roanoke Island

Plant, the County water system has 6.5 mgd of treatment capacity. The maximum day water usage in 1985 was 5,000,000 gallons. Peak day in 1989 was 6.0 mgd.

When operation of the completed Fresh Pond plant began, the County embarked on a test well program to determine whether or not water of a suitable quantity and quality was available in the beach area.

Very little data had been available describing the brackish water aquifers underlying Dare County. Past drilling had been conducted only to locate fresh water, and when brackish water was encountered, no attempt was made to identify it as a potential water resource. Previous deep well drilling in the area included:

- Two permanent monitoring wells on the mainland, which are drilled to depths of approximately 1,000 feet and 1,200 feet and maintained by the State of North Carolina.
- A test hole on the outer banks of Currituck County, which was drilled to a depth of 980 feet and abandoned when no fresh water was found.

These borings gave a general idea of the geological formations, but they provided no information that could be used in the planning or design of a deep brackish groundwater resource.

To develop more adequate data, Dare County undertook a drilling program with the following objectives.

1. Determine the location, thickness, and characteristics of geological strata.
2. Locate usable aquifers.
3. Sample and analyze each aquifer for data relative to desalination plant design.
4. Use test wells to determine aquifer characteristics.
5. Conduct extensive pump testing to determine the potential for hydraulic connections between aquifers and for saltwater intrusion.

Figure 1 shows the two test well locations, which were chosen to make use of available property close to potential treatment plant sites. Well No. 1 in Kill Devil Hills was drilled to a depth of 1,610 feet, and water samples were taken from three aquifers. Well No. 2 in Southern Shores was drilled to a depth of 700 feet without encountering any significant water-bearing strata, and was abandoned following geophysical logging.

An aquifer was located at a depth of between 1,160 feet and 1,400 feet. This is the Claiborne formation, commonly known as the Castle-Hayne aquifer. It consists of highly fractured, confined limestone and extends over much of eastern North Carolina, where, in some locations, it is a fresh water aquifer. Well drillers estimate a potential well yield in excess of 1,000 gpm. Water samples were taken at 1,200 feet, 1,300 feet and, due to an error by the

Figure 1

DARE COUNTY
WATER SUPPLY ALTERNATIVES STUDY - 1985

BLACK & VEATCH
ASHEBORO, NORTH CAROLINA

LOCATION OF TEST WELLS

Approximate Scale 1" = 13,000 feet

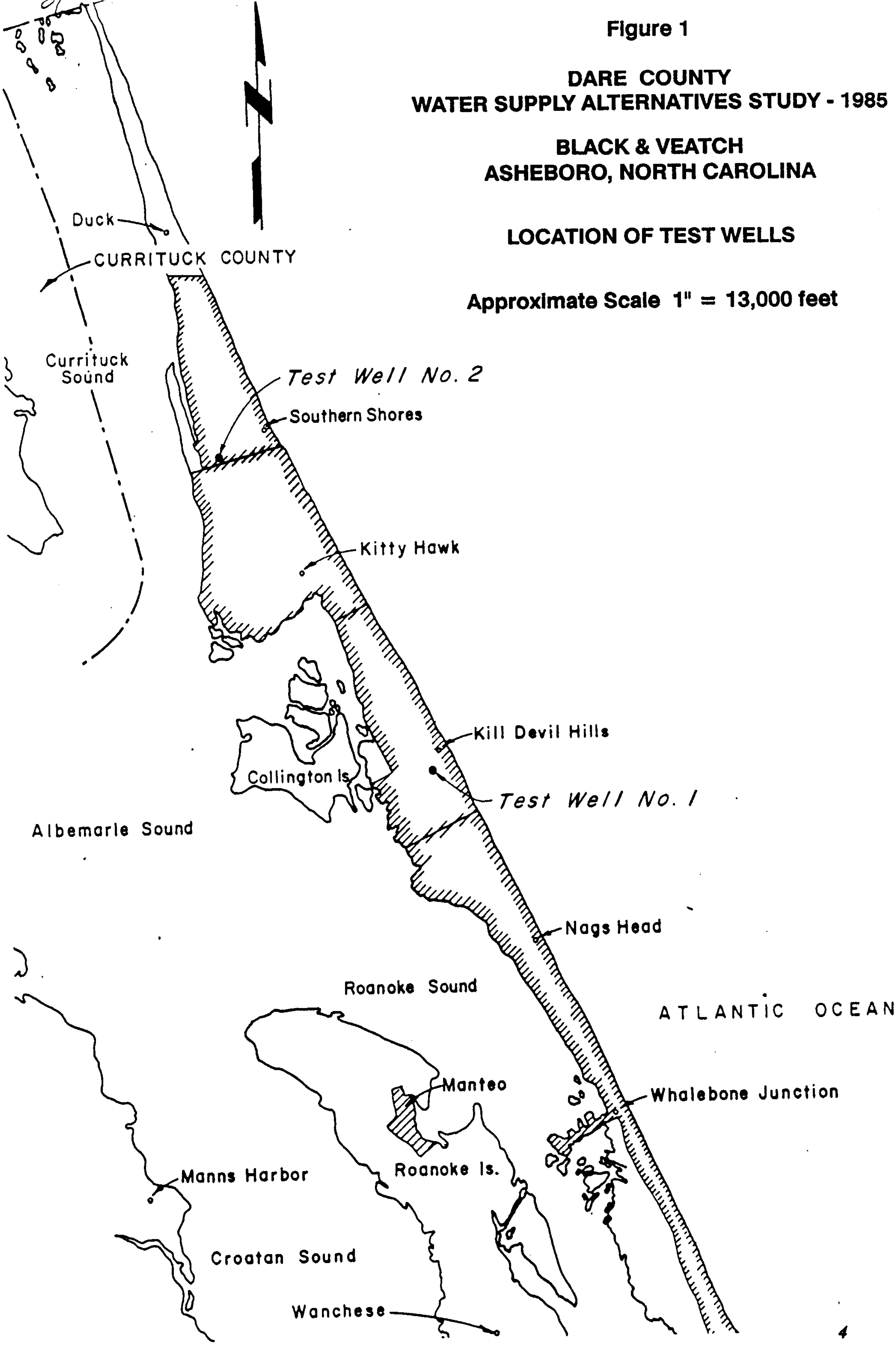

Table 1
CASTLE HAYNE AQUIFER ANALYSIS

PARAMETERS	1,300 FEET DEEP B&V	1,300 FEET DEEP BF GOODRICH	1,200 FEET DEEP B&V	1,157 FEET DEEP B&V
(mg/l unless stated otherwise)				
Alkalinity	446	442	517	498
Aluminum	<1.0	<DL	<1.0	---
Barium	<0.5	0.14	<0.5	---
BOD(5)	<1.5	---	<1.5	---
Boron	---	7.36	---	---
Calcium	505	455	230	---
Carbon Dioxide	---	---	---	---
Chloride	21,950	21,034	20,700	15,200
Chlorine	<0.1	---	<0.1	---
Chromium	0.04	<DL	0.03	---
Color (PCU)	1	---	5	5
Conductivity (umhos/cm^2)	35,500	38,200	42,000	---
Copper	0.053	<DL	0.38	---
Fluoride	1.34	<DL	1.07	---
Hardness	4,660	4,957	4,240	3,340
Iron	1.48	1.1	0.46	16.7
Lead	<0.05	<DL	0.27	---
Magnesium	944	916	511	---
Manganese	0.04	0.11	0.21	---
Mercury	<0.0005	---	<0.005	---
Nitrate	<0.015	<DL	0.315	---
Nitrite	<0.002	---	<0.002	---
pH (units)	7.1	6.69	6.9	6.9
Phosphate	---	---	---	---
Phosphorus	0.031	<DL	0.023	---
Potassium	345	345	0.3	---
Selenium	0.010	---	0.004	---
Silica	3.0	---	29	11.4
*Silicon	---	16.5	---	---
Sodium	12,300	11,203	11,900	9,400
Strontium	34.9	39.9	34.1	---
Sulfate	178	205.7	<2.0	---
TDS	41,786	38,200	39,322	31,561
TOC	124	---	<1.0	---
Turbidity (NTU)	14	---	59	125
Zinc	0.059	---	0.49	---

driller, at 1,157 feet. Table 1 shows the results of these analyses. Although the Castle-Hayne aquifer contains fresh water in some locations in North Carolina, at this test well it is seawater, with TDS and specific ion concentrations similar to ocean water. High yield would reduce the number of wells required and the aquifer confinement will reduce pumping costs; however, development of this aquifer is not now feasible because of the high cost of converting salt water to potable water. This could be a source of water in the future if brackish water resources are unavailable or if technological advancements reduce the cost of seawater desalination.

THE YORKTOWN AQUIFER

The Yorktown aquifer, confined aquifer consisting mainly of sand, was located at a depth between 280 feet and 660 feet. Water samples were taken at 330 feet and 660 feet. Table 2 shows the results of these analyses. The aquifer is stratified, being slightly brackish at the top and somewhat salty at the bottom. This aquifer was further studied as follows.

A screen was set from an elevation of 330 feet to 480 feet, and the well was pumped at 450 gpm, less than one-half of the driller's estimate of well capacity. The pump tests conducted were step drawdown, 24-hour pumping and recovery; and a long-duration pumping test. The latter test was conducted to assess the potential for salt water intrusion and for hydrologic connections between aquifers. The pumping rate and screen setting depth were selected in attempts to draw from the top part of the aquifer only and limit the TDS of the potential supply to 5,000 mg/l or less. The long-duration pump test was conducted for a total of 40 days.

Analysis consisted of tests at the well head for silt density index, temperature, pH, turbidity, and iron concentration. These tests were made each weekday, with the exception of iron measurements, which were made at random. Samples were also sent to laboratories at intervals of approximately one week to be analyzed for a broad range of ions which are factors in desalination process design. The two laboratories used were the Black & Veatch laboratory in Asheboro, North Carolina, and the B.F. Goodrich laboratory in Beltsville, Maryland. The use of two laboratories instead of one was to ensure quality control and to guard against analytical errors of critical water quality parameters. Analyses were conducted on redundant samples sent to each laboratory. Agreement of the results between laboratories was very good, and the redundant sample analysis was not continued during the long-duration pump test.

The water is brackish with average salinity, and with no constituents that would be expected to cause insurmountable problems. The presence of iron in water to be treated by reverse osmosis can cause problems if it is trivalent, or if it is divalent and is present in sufficiently large quantities and could be oxidized to its trivalent state. Iron in concentrations of 0.2 to 0.6 mg/l can be removed by reverse osmosis, but will result in greater membrane maintenance and replacement costs. Pretreatment for iron removal may result in a more economical plant operation. A small pilot plant study was undertaken to determine the potential for iron fouling and to provide additional guidance on the need for pretreatment.

The quantity of water that can be withdrawn from the Yorktown aquifer for treatment, from either a single well or from a well field, depends upon the geological characteristics of the formation, the amount of water in storage in the aquifer, and preservation of water quality. As mentioned previously, the characteristics of the formation will allow high yielding wells in

Table 2
YORKTOWN AQUIFER WATER ANALYSIS

	Depth of Sample: 609 ft.		330 ft.	
	B&V	BF Goodrich	B&V	BF Goodrich
BOD(5) (mg/l)	<1.5	---	<1.5	---
Alkalinity, as CaCo(3)	372	374	404	174
Chloride (mg/l)	9,374	9,239	418	462
Color (PCU)	10	---	30	---
Conductivity @ 25 C (umhos/cm^2)	22,000	27,350	1,950	2,055
Fluoride (mg/l)	0.83	<DL	0.12	1.4
Total Hardness (mg/l)	2,630	2,736	44.0	40.9
Nitrate-Nitrogen (mg/l)	0.026		0.139	<DL
Nitrite-Nitrogen (mg/l)	<0.002	NA	0.003	---
pH (units)	7.4	7.21	8.2	8.42
Total Phosphorus (mg/l)	0.026	<DL	0.359	
Total Solids (mg/l)	18,175	---	1,250	---
Total Volatile Solids (mg/l)	2,965	---	106	---
Total Suspended Solids (mg/l)	21	7.0	74	68.7
Total Dissolved Solids (mg/l)	18,154	18,990	1,176	1,150
Settleable Solids (mg/l)	<0.1	---	<0.1	---
Sulfate (mg/l)	590	675.9	21	29.7
Turbidity (NTU)	29	7.4	23.5	34.0
TOC (mg/l)	108	---	113	---
Carbon Dioxide (mg/l)	---	43.6	---	1.1
Free Chlorine (mg/l)	<0.1	0.0	<0.1	<DL
Silica (mg/l)	34	32.7	11.5	11.4
Silicon (mg/l)	---	15.28	---	5.32
Strontium (mg/l)	16	18.0	0.16	0.13
Silver (mg/l)	<0.01	---	<0.02	---
Aluminum (mg/l)	<1.0	<DL	0.7	<DL
Arsenic (mg/l)	0.111	---	0.080	---
Barium (mg/l)	<1.0	0.08	<1.0	<DL
Boron (mg/l)	---	2.39	---	1.07
Calcium (mg/l)	310	229	5.02	6.2
Cadmium (mg/l)	0.035	---	<0.01	---
Total Chromium (mg/l)	0.04		<0.02	<DL
Hexavalent Chromium (mg/l)	<0.05	---	<0.02	---
Copper (mg/l)	0.03	<DL	<0.01	<DL
Iron (mg/l)	2.98	<DL	1.44	
Mercury (mg/l)	<0.0005	---	<0.0005	---
Potassium (mg/l)	225	157.5	24.5	20.8
Magnesium (mg/l)	502	520	8.9	6.1
Manganese (mg/l)	0.15	0.05	0.28	
Sodium (mg/l)	5,950	4,626	440	391.9
Lead (mg/l)	0.19	<DL	<0.05	<DL
Selenium (mg/l)	<0.005	---	<0.001	---
Zinc (mg/l)	0.64	<DL	0.23	<DL

excess of 1,000 gpm, which was confirmed by drawdown measurements during pump testing. The apparent specific capacity of the well was 15 gpm/foot. At a well yield of 1,000 gpm, the drawdown was approximately 67 feet, which is within well design parameters.

Well field yield is related to the aquifer's storage capabilities, leakage from adjacent aquifers, well spacing, and formation transmissivity. The conclusion from the hydrologist's report is summarized as follows. The aquifer can safely yield 6.67 mgd, which is the amount of raw water needed for the 5 mgd plant planned for Stage 2 improvements.

- Well spacing should be approximately 1,500 feet, although this could be increased or decreased somewhat as the wells are installed and additional data is obtained.

- There is sufficient space on the Baum Tract for installing the 6.67 mgd well field.

The quality of the water withdrawn by the wells is another factor that affects well yield. Water quality varies with depth as TDS concentration increases towards the bottom of the aquifer. As pumping begins, the higher salinity waters could migrate towards the well both vertically and horizontally. Figure 2 is a schematic presentation of what can happen if the aquifer is overstressed. The figure shows a theoretical salinity interface between water acceptable for treatment and unacceptable water which migrates toward the well field. The potential for saltwater intrusion can be minimized by limiting well yield and well field pumping, by adequately spacing wells, and by properly locating wells within the aquifer.

REVERSE OSMOSIS DESIGN FOR DARE COUNTY WATER

Typical measures of performance of the reverse osmosis process are salt rejection, membrane flux (flow through the membrane per unit time), percent recovery, and time between membrane cleanings. Factors which affect performance are operating pressure, feedwater temperature and concentration, recovery control, product pressure, and ionic constituents in the water. Several of these characteristics and factors are discussed below. Cost comparisons were made between electrodialysis (ED) and reverse osmosis (RO) treatment processes (see Table 3) .The costs were generally the same by either approach.

The concentration of dissolved solids in the feedwater is of prime importance in planning RO systems. The higher the concentration, the higher the feed pressure must be to overcome the osmotic pressure of the feedwater. At constant pressure, percent recovery decreases as TDS concentration increases. (Recovery is the percentage of feedwater which passes through the membranes to become product water.) This is a critical parameter in determining RO feasibility, because higher recoveries reduce raw water requirements and the amount of RO membranes to be used. Higher recoveries also minimize pretreatment costs and the amount of brine to be handled. Standard RO design uses as high a recovery as possible without causing damaging scale formation.

A change in feedwater concentration may adversely affect RO performance. In the Yorktown aquifer in Dare County, there is potential for both upward and horizontal movement of higher TDS concentration water into the well field. Such movement would gradually increase feedwater TDS, resulting in higher osmotic pressures and lower recovery. In time, the

Figure 2

POTENTIAL EFFECT OF PUMPING YORKTOWN AQUIFER

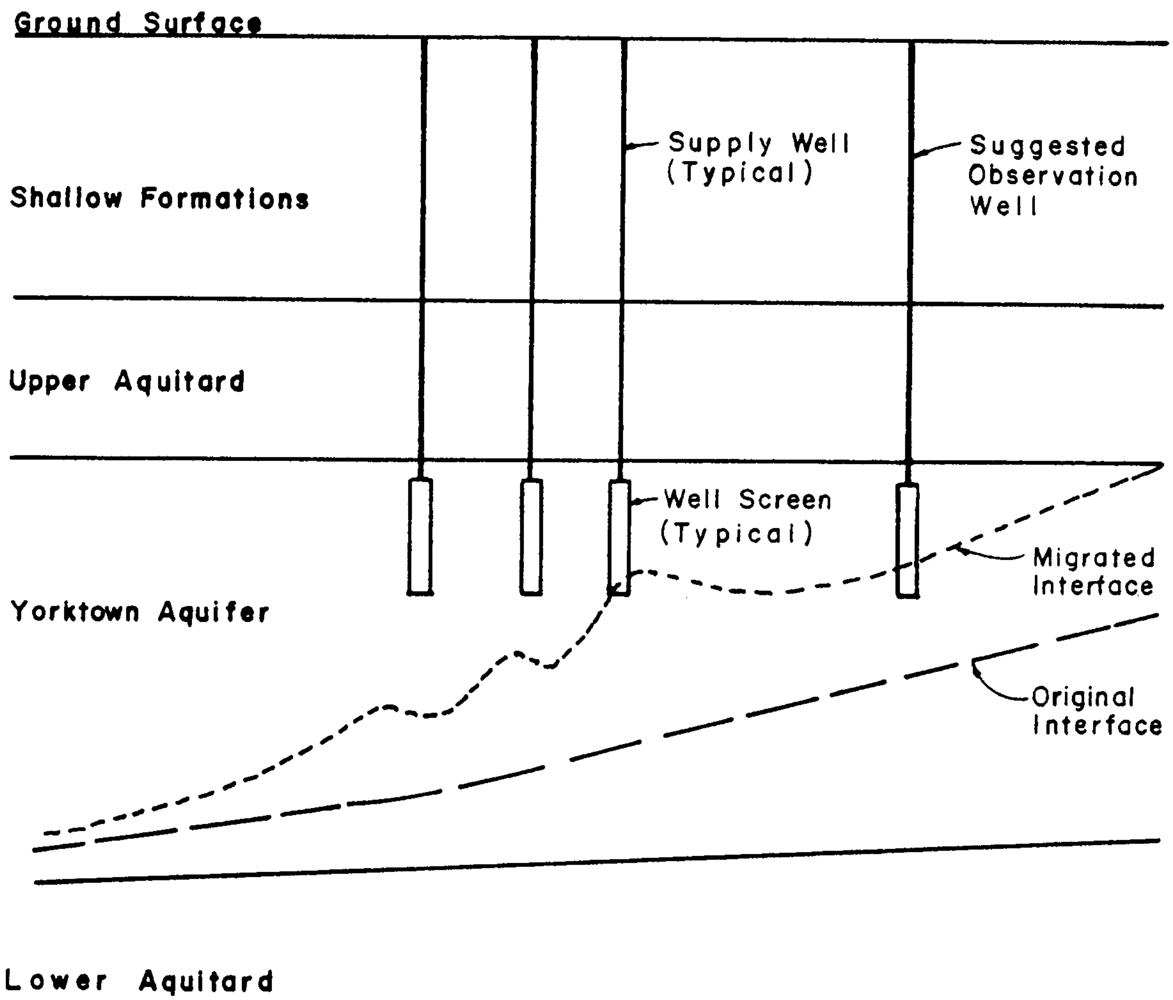

Table 3
PROBABLE FEED WATER ANALYSIS FOR COST COMPARISON BETWEEN RO & ED

Parameters	Pretreated Water
Alkalinity (mg/l)	30.00
Chloride (mg/l)	3380.00
Fluoride (mg/l)	1.64
Hardness, Calcium (mg/l)	206.00
Hardness, Total (mg/l)	820.00
pH (units)	6.60
Total Dissolved Solids (mg/l)	6995.00
Sulfate (mg/l)	520.00
Sulfide (mg/l)	<0.10
Turbidity (NTU)	0.43
Calcium (mg/l)	80.90
Iron (mg/l)	0.037
Potassium (mg/l)	68.10
Magnesium (mg/l)	203.00
Manganese (mg/l)	0.011
Sodium (mg/l)	1628.00
Silicon (mg/l)	0.35

plant capacity would be reduced. Proper well field design and operation can minimize salt water migration in the aquifer, but some increase in feedwater salinity can be anticipated over time. This increase was considered in the plant design.

Salt rejection is a percentage measure of how much salt is removed from the feedwater (i.e., TDS retained by the membrane). Each ion is rejected to a different extent, and overall rejection is a weighted average of the rejection of each constituent. Salt rejection is relatively constant with the age of the membrane, but is reduced if the net operating pressure across the membranes is reduced.

Most RO membranes available today have excellent rejection characteristics for the ionic constituents typically found in brackish water. Rejections greater than 90 percent are easily achieved, and 95 percent is possible, depending upon the feed pressure and ionic constituents. Greater salt rejection results in a purer product water. If the feedwater TDS is not too high, the product water will have TDS well below statutory limits, and blending of some feedwater with product water may be possible. This will reduce both the amount of raw water and the number of RO membranes required.

For Yorktown aquifer water having a nominal TDS of 4,000 mg/l, the product water could be expected to have a concentration of 200 mg/l with 95 percent salt rejection. Bypassing and blending of only 5 to 7 percent of the raw water flow would be possible, but would not be economical.

Certain ions which are commonly dissolved in water are either difficult to remove or potentially harmful to RO membranes. There is a saturation point for ions in solution after which precipitation of the ion occurs. If this occurs in an RO vessel, the precipitate will scale on the membrane, reducing the water flux across the membrane. The most common scalants are calcium carbonate ($CaCO_3$) and calcium sulfate ($CaSO_4$). Other possible scalants are barium sulfate ($BaSO_4$), strontium sulfate ($SrSO_4$), calcium fluoride (CaF_2), and silica (SiO_2). The critical location of scaling is on the brine side of the membrane, where concentrations are greatest. Dissolved iron and aluminum compounds can also be a source of scaling.

Scaling can be controlled by:

(1) Reducing recovery to avoid exceeding solubility limits.

(2) Removing the calcium ion (or other scaling ion) through pretreatment.

(3) Removing the carbonate/bicarbonate ion by adding acid.

(4) Adding a scale-inhibiting chemical.

Analysis of Yorktown aquifer water found in Dare County indicates no unusual scaling problem. Plant design included pH adjustment and chemical addition for scaling control, as is practiced at most RO plants. Because some iron was present in the test well, a pilot plant was operated to determine the effect of iron from this well on RO membranes. No negative problems were experienced from the small amount of iron present.

An RO plant designed to produce potable water would consist of many RO membranes assembled in vessels (and groups of vessels) and staged. Reverse osmosis process options are as follows.

- Spiral wound permeators, consisting of sheets of membranes and spacers wound around a collection tube. Usually, several permeators are placed in series in a single pressure tube.

- Hollow fiber permeators, consisting of many hair like fibers in a bundle, located inside a pressure tube.

- Parallel single-staged systems, consisting of many permeators connected in parallel.

- Brine-staged systems, wherein the brine from the first stage becomes the feedwater for the second stage. This approach both maximizes recovery and minimizes brine volumes.

- Product-staged systems, where products from the first stage are passed through a second stage to provide higher quality product water.

All of these options have much in common. Permeators are mounted on racks and connected by manifolds. Recovery is controlled by a valve on the brine manifold. Provisions must be made to sample and replace permeators individually and to clean permeator racks. RO systems usually have parallel racks of permeators that can be operated independently to increase or decrease plant flow. Several on-line instruments are necessary to provide performance data for operating decisions.

Construction materials must be carefully chosen for all parts of the RO system due to corrosion potential. Wherever practical and economical, non-metallic materials should be used for all wetted parts. High operating pressures also must be considered when selecting materials.

Pretreatment and other appurtenant systems are also required:

- Cartridge filtering system to remove suspended particles down to 5 microns. Chemical feed systems as required by detailed process design.

- Chemicals most likely needed are acid for pH control and a scale inhibitor.

Recent developments in the design of membranes allow plants to operate in the range of 250 to 275 pounds per square inch. This is about one half the operating pressures experienced as recent as four years ago, and results in considerably less energy use - as much as 40 percent less. As improvements continue to be made in membranes, operating pressures will drop even further, with a resulting reduction in energy requirement.

The day will come (in the not too distance future) when operation and maintenance costs for RO-treated water will compare very favorably with treatment costs of surface water. The Safe Drinking Water Act (SDWA) will hasten this day, and we may well see increased use of groundwater where available, even though it is brackish or very hard. RO plants are being used in Florida for softening, more economically than lime softening plants. Some of these RO plants operate at pressures ranging from 125 to 150 pounds per square inch.

CONCLUSION

One final impressive aspect of the Dare County reverse osmosis water treatment plant is that no funds had to be borrowed. The $10.5 million facility was paid for through impact fees collected by Nags Head, Kill Devil Hills, and Dare County over the past four years. Also, the plant was designed to adequately handle an increased level of dissolved solids over time.

The plant that went on line has a current capacity of 3 mgd, with piping and provisions to add another 5 mgd in the existing building. Facility costs included the 5 MG ground stoarge tank, light wells, plant, ocean discharge, and computer systems.

The political strides in Dare County over the past 25 years have equaled those in the technical area of water treatment. Facilities have progressed from the two plants at Fresh Pond and a plant at Manteo to a truly regional system, in which one entity furnishes water to all of the incorporated communities.