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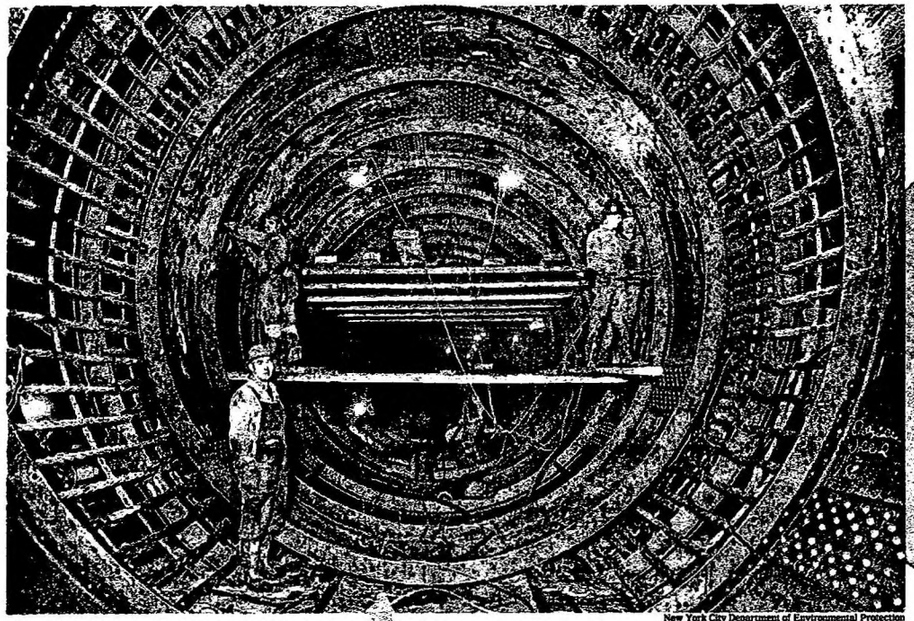
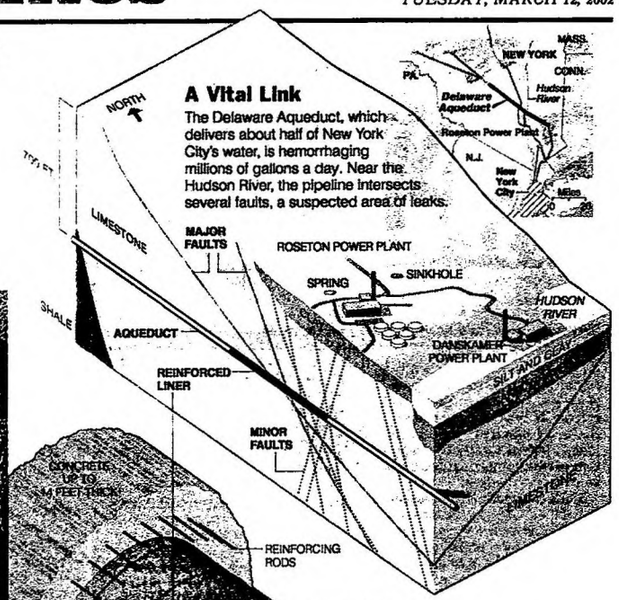
The New York Times

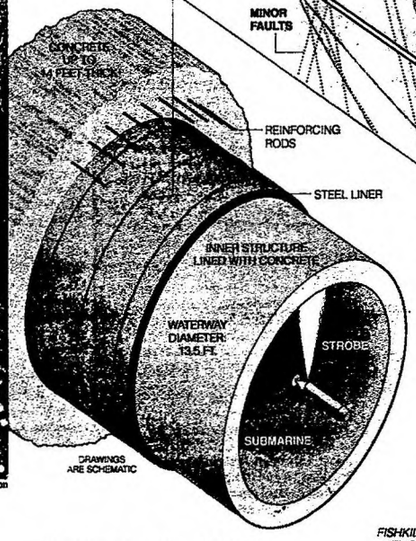
21st-Century Plumbing For a Leaky Old Aqueduct



New York City Department of Environmental Protection

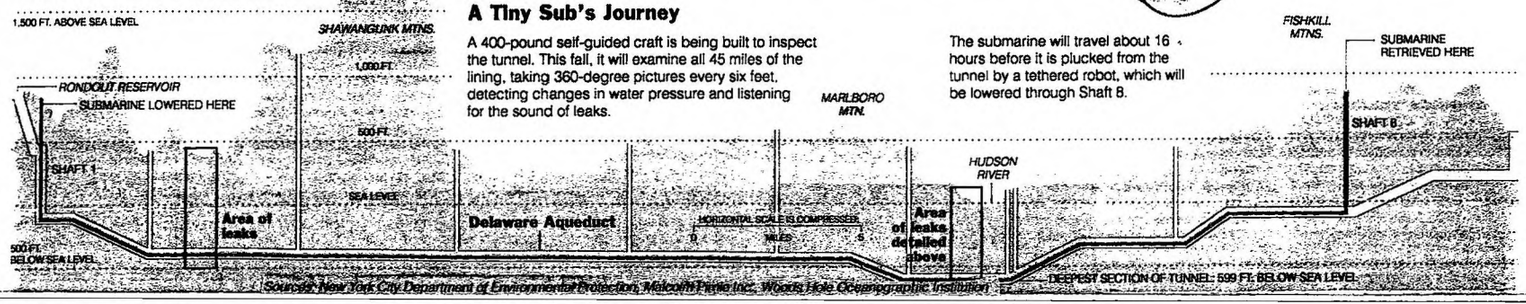
The aqueduct under construction in 1942.





Reinforced, But Perhaps Not Enough

Engineers knew they had to strengthen portions of the tunnel that were punched through weak, fractured limestone. But leaks have sprouted in or near two of these sections. A submarine equipped with cameras will try to find their source.



A Tiny Sub's Journey

A 400-pound self-guided craft is being built to inspect the tunnel. This fall, it will examine all 45 miles of the lining, taking 360-degree pictures every six feet, detecting changes in water pressure and listening for the sound of leaks.

The submarine will travel about 16 hours before it is plucked from the tunnel by a tethered robot, which will be lowered through Shaft 8.

Sources: New York City Department of Environmental Protection, Malcolm Pirnie Inc., Woods Hole Oceanographic Institution

By ANDREW C. REVKIN

NEWBURGH, N.Y. — All along the East Coast, drought has shriveled streams as never before. But tucked in the woods 70 miles north of New York City, a deep pool of clear water spills into a sparkling brook that runs downhill to the Hudson River.

No matter how dry the weather, gauges measure a flow of four million to six million gallons a day.

No one is thrilled, however.

The sinkhole and half a dozen other springs and wet spots nearby are fed by leaks 600 feet underground in one of the most important water tunnels in the world, the 85-mile Delaware Aqueduct.

This 57-year-old tunnel carries, on average, half of New York City's daily supply of a billion-plus gallons of water from reservoirs along the Delaware River where it rises in the Catskill Mountains. It also supplies this town and many others along its route to the city.

At certain times of the year, the tunnel carries 90 percent of the water for the nine million people served by the sprawling 19-reservoir water system, which has long been considered an engineering marvel of the industrial era.

When the tunnel is at full capacity, about 36 million gallons a day escape through uncharted breaks in the concrete and steel lining, engineers for the city say. That might not seem much in a billion-gallon-a-day system, but the leak equals the total daily water usage of Rochester.

And with New York City and surrounding communities preparing to enact drought emergencies in coming weeks requiring strict water conservation, fixing the leak has taken on new urgency, even though city officials say that inspections and repairs could take several years.

"It's particularly true in a drought, but you hate to see that kind of water lost at any time, given what went into building that aqueduct and the reservoirs," said Diane Galusha, who chronicles the deaths of 79 workers during construction of the Delaware tunnel in her book "Liquid Assets: A History of New York City's Water System" (Purple Mountain Press, 1999).

The leaks were first noted by city

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21st-Century Plumbing for New York City's Leaky Old Water Tunnel

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engineers and consultants in 1991. In 1985 and 1996, the leakage rate when the tunnel was running full bore was estimated at 25 million gallons to 34 million gallons a day, engineers reported.

After 10 years of analysis and preparations — a period environmental groups and some city elected officials say was far too long — preparations for the repair effort are under way.

The operation is is risky and elaborate, involving novel applications of technologies from deep-sea explorations and oil prospecting. There are roles for deep-sea divers, robots and pilots flying with heat-sensing cameras that can detect cold tunnel waters as they seep to the surface.

This fall, a pilotless submarine will ply 45 miles of the tunnel looking for cracks. If the submarine works, it may be used by other cities, including Chicago, to inspect aging aqueducts.

The effort to investigate the deeply buried leaks got under way in 1998, but gathered momentum in 2000, when officials agreed there was at least some risk of losing the tunnel entirely. The city began developing a contingency plan "in case of tunnel failure," according to one city memo — on the theory that the leakage might be weakening overlying rock sufficiently to collapse the 13-foot-diameter tunnel.

This plan would include requiring upstate communities that tap 125 million gallons a day from the city system to shift to local sources; imposing sharp restrictions in the city; and temporarily using other supplies that are not as clean as the water from the distant Catskills.

But recent engineering studies show no signs that such a calamity looms, said John M. McCarthy, a senior engineer at Malcolm Pirnie Inc., the engineering company hired by the city to conduct the investigation and supervise repairs.

"There is no evidence in all the investigative work we've done that the tunnel is in any imminent danger," Mr. McCarthy said.

The first stages of the project are costing more than $27 million, not including fixing the leaks.

The potential for problems was evident even in the years before World War II, as armies of "sand hogs," the underground workers who specialize in tunnel digging, cut their way deep into the bedrock lying between New York's forested mountains and its concrete canyons.

The Delaware branch of the three-pronged city water supply captures the water from the upper reaches of the Delaware River and stores it in four reservoirs west of the Hudson.

At the Rondout Reservoir, the water plunges 1,000 feet and enters the 45-mile stretch of the tunnel that cuts east beneath scrubby ridges, fast-spreading exurbs and hillside apple orchards before it crosses far below the Hudson.

On the east side of the river, the water rises through shafts and fills another reservoir before it flows south through more tunnels and basins to city taps.

The system is a hydrological triumph, allowing most of the city — even buildings up to 12 stories high — to be supplied by gravity alone.

But right from the start, geologists noted two spots where the landscape dipped along the initial 45-mile route, identifying weakened areas of faults and cracks deep below. One was in Wawarsing, a rural community east of the mountains, and the other on the northern edge of Newburgh, an old industrial town on the west bank of the Hudson.

The most worrisome spot, by far, was the one on the riverbank. Two faults intersect there precisely where the tunnel diggers drove under the river. In the understated argot of engineering, reports cited the area's "unfavorable geology."

As the diggers proceeded, they had to inject cementlike grout into the rock ahead of them, trying to glue the fractured spots together before moving ahead with the excavation.

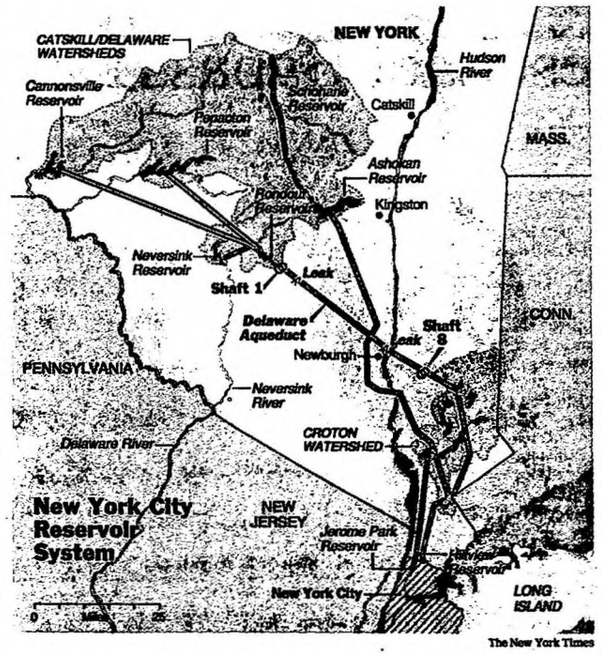
To prevent leaks, engineers added heavy steel liners, nests of reinforcing steel bars and extra layers of concrete.

The Delaware water began to flow in 1945 and all was well. In 1958, the last time the aqueduct was drained, inspectors drove the length of the tunnel in a modified jeep and found small leaks, but nothing significant.

They did, however, notice some problems in the long stretch far beneath the Hudson. "The concrete lining in this area which is directly under the Hudson River has numerous cracks in addition to those that are contributing to the inward leakage," the inspection report noted.

By the 1990's, concerns were growing rapidly, but quietly. The city never publicly discussed the problem until the fall of 2000, when lawyers for Riverkeeper, a private environmental group, released documents obtained under the Freedom of Information Act.

In the file were reports by Victor Feigelman, a longtime engineer for the city and later a consultant, who noted starting in 1991 that significant leakage had developed.



The New York Times

Andrew C. Revkin/The New York Times

A major underground aqueduct carrying much of New York City's drinking water from its source in the Catskills is leaking in several places, including in Roseton, N.Y., about 70 miles north of the city.

The city ran tests introducing harmless dye into the tunnel and timing how long it took to surface in the Newburgh sinkhole. Consistently, it took the dye less than an hour to migrate from the tunnel up through 900 feet of rock to the pool.

Even as the extent of the leaks became clear, the city identified a new problem. A shaft east of the Hudson, which is used in the rare instances when the tunnel is drained, had a leak somewhere in the bronze valve separating it from the tunnel deep underground.

In December 2000, deep-sea divers began a repair operation that was as dangerous and hair-raising as a spacewalk. Far out of their usual element, they descended 70 stories into the 13-foot-wide shaft in a 12-foot-wide diving bell. Alternating teams spent nearly a week inspecting and finally repairing a half-inch hole where a metal plug had popped out of a fitting.

More analysis led to a plan to use a self-propelled craft to inspect all 45 miles of the tunnel where the leaks are suspected. Oceanographic engineers are building a 400-pound minisubmersible, which they plan this fall to lower 1,000 feet into the vertical shaft leading to the tunnel's upstream end.

The torpedo-shaped device, 9 feet long and 16 inches across, will be programmed to stay dead center in the tunnel and will use five digital cameras to record every foot of the lining as it heads downstream. After traversing the 45 miles, it will be plucked out through another shaft by a tethered submersible robot.

It will also record subtle changes in sounds, in hopes that it may pick up the gushing, gurgling or trickling turbulence of escaping water, said Ben G. Allen, a senior engineer at the Woods Hole Oceanographic Institution in Woods Hole, Mass., which is building the $500,000 device.

While the submersible inspects the tunnel from the inside, the city is preparing to inspect the rock around it from the outside, drilling a series of holes with the same precision equipment being employed in the Arctic to look for oil.

The holes will be drilled to the depth of the tunnel, then turn horizontally in the spots where leaks are thought to occur, Mr. McCarthy said. "They will parallel the tunnel for approximately 1,500 feet," he said, "gathering hydrogeological data on how the water is moving, the rock quality and fractures."

Along with the area near the sinkhole, water engineers are particularly concerned about the tunnel section that lies directly under the Hudson, where the solid rock above thins to about 300 feet and is overlaid by 200 feet of gravel and crumbled rock in the bottom of the culvert-shaped riverbed — material left behind by the last ice age glacier.

In a 1999 report for the city, Mr. Feigelman, the engineering consultant who first identified the Delaware leak a decade ago, wrote, "The most severe scenario, of course, would be a significant leak under the river."

It was statements like this that raised the concerns of Riverkeeper and other private groups.

Marc A. Yaggi, a lawyer for Riverkeeper whose job is to monitor the city water supply for problems, still decries the pace of the repair effort. "It's been 12 years they've been aware of it, and they've done virtually nothing except find out how much it's leaking," he said. "They need to get started fixing it immediately. The downside is just too great to let this go on much longer without taking really aggressive measures."

But city officials say they remain confident that the 8- to 14-foot-thick concrete walls and extra steel reinforcement in the tunnel's weak spots will hold firm until a repair plan can be drawn up.

Joel A. Miele Sr., the commissioner of the city's Department of Environmental Protection, said it was important for New Yorkers to understand that the repairs were never intended as a short-term fix to help relieve current shortages. Given the extraordinary challenges posed by fixing something deep underground in a tube filled with high-pressure water, it pays to proceed cautiously, he said.

When a deep tunnel is emptied of water, Mr. McCarthy noted, the change in pressure can create more risks of collapse than are posed by even a leak as large as that in the Delaware tunnel. Even so, officials are considering slowly emptying the tunnel and sending in work crews.

Another option is building a specialized programmed submersible that could repair cracks autonomously without draining the tunnel,

A risky, elaborate job for deep-sea divers and a pilotless sub.

he said.

Yet another would be to drill down from the surface around the leaking spots, again using the precision equipment, and to inject grout from the outside, Mr. McCarthy said. But this approach raises risks of blowouts similar to those that sometimes cripple oil rigs.

A final possibility, he and city officials said, is that they will conclude that the risks of other repair strategies are too great and that the best choice may be to do nothing at all — except perhaps eventually build a new tunnel to replace the old one.

Mr. Miele, who leaves his position next month after six years, said he was confident that the city would come up with a repair and that the existing Delaware tunnel would last many more decades.

"As an engineer, it never cases to amaze me," he said of the tunnel and the water supply. "It's the best expression of man's capability."

But he did add that fixing the leaks could create new problems and said he had forewarned state environmental officials and Mayor Michael R. Bloomberg about one, concerning the sinkhole in Newburgh.

"When we fix this leak, we're going to shut down that stream," Mr. Miele said. "Those wetlands are going to dry up and that's probably against the law."