Anticipating Growth

A recently completed water supply connection project enables the Tarrant Regional Water District, in Fort Worth, Texas, to pump water from its eastern reservoirs to a lake that will serve fast-growing populations on the north and west sides of the city. The project lowers the probability of drought in the service area from once in 10 years to once in 50 and obviates the need for a longer and more expensive additional pipeline. By David H. Marshall, P.E., M.ASCE, Russell L. Gibson, P.E., M.ASCE, Alan C. Hutson, P.E., M.ASCE, and Elizabeth R. Blackwelder, M.ASCE

The Benbrook booster pump station receives flows from the Rolling Hills station and pumps water through both 96 in. (2,438 mm) and 84 in. (2,134 mm) pipeline to Eagle Mountain Lake. Three large pumps and one small pump are required to meet the facility’s initial 230 mgd (870,55 m³/d) capacity.

The 20 mi (32 km) pipeline has two outlet structures, one to the Clear Fork of the Trinity River, serving a water treatment plant in Fort Worth, the other a flow control structure and subaqueous outlet at Eagle Mountain Lake. A balancing reservoir is planned for the halfway point.

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Completed in 2002, the system reliability and enhance-
ment study assessed potential improvements to the seven
reservoirs of the Tarrant Regional Water District’s system and included evaluations of the pipeline and pump station hydraulics, operating costs, and reservoir hydrology. It eval-
uated five different configurations of possible transmission system improvements in the light of capital costs, water treat-
ment costs, and long-term operating costs. The study recom-
mended the development of the Eagle Mountain connection to provide additional water deliveries to the northern part of
the system, and it revealed that this solution would reduce the number of times that the West Fork reservoirs would be too low. The solution would also delay the need for a third
eastern Texas pipeline and offer lower operating costs than other solutions.

After the study, the district initiated pipeline route screening and selec-
tion assessments, which were conducted on the basis of each alternative’s environmental ramifica-
tions, the ease with which land could be acquired and the cost of the land, the degree to which right-of-
way could be preserved, and overall costs. The route selected, running north to south through an
area west of Fort Worth, allowed for a wide enough right-of-way to accom-
modate a future, parallel pipeline.

The Eagle Mountain connection carries water that has been pumped from the eastern reservoirs, and it has a maximum capacity of 350
mgd (1.3 million m³/d). The pipeline is steel with a mor-
tar lining. To increase the line’s service life, the steel pipe
is protected from corrosion by a coating and by a cathodic system. Steel pipelines in these diameters are flexible, requir-
ing a flexible coating. The coating systems considered for this project included the two most common—tape wrap and polyurethane—and a relatively new flexible coating called side-
extruded polyethylene.

The two local pipeline suppliers that were likely to bid on the project were both capable of applying polyurethane, but additional facilities would have been required for the side-
extruded polyethylene, so polyurethane was chosen by the pipe companies that won the bids.

Imported angular pea gravel was used for pipe bedding and embedment. This material flows well under the haunches
of the pipe and is easily compacted. One pipeline contrac-
tor used vibrating plates mounted to a backhoe to vibrate both
sides of the pipe at once. The other pipeline contractor used a large compaction wheel to compact the embedment material.

All of the joints of the steel pipeline were welded after the backfilling was completed, and the joints were protected with
heat-shrink sleeves. The welding process made it possible for the contractor to backfill the pipe trench almost immediately after
laying the pipe, which shortened the schedule, made the site safer,
and saved an estimated $2 million to $3 million on the project.

The pumps, motors, and variable-frequency drives that were necessary for the pumping stations were preplanned
using a negotiated bid process authorized by special legisla-
tion enacted for the benefit of the Tarrant Regional
Water District. The legis-
lation allows the district to
use the negotiated bid process when the conven-
tional bidding process is
not practical in order to
achieve competitive bidder-
ning of specialized equip-
ment. The owner and the
engineer determined to pur-
chase the pumps, motors,
and variable-frequency drives directly from the manufacturers and to
provide the equipment to
the installation contractor.

The negotiated bid pro-
cess includes the following
steps:

- The engineer prepares
  bidding documents, including descriptions of the bid negotia-
  tion process and of the selection criteria.

- The owner receives sealed price proposals from the bidders. Bidders are allowed to write any exceptions to the technical specifications and to the commercial terms and con-
ditions.

- The owner and the engineer review and rank the propos-
als according to the criteria.

- The owner and the engineer meet with the short-listed suppliers and negotiate technical and commercial terms and prices with each supplier.

- The owner makes a final selection based upon the selec-
tion criteria.

For this project the selection criteria and the weight given
to each were as follows:

- Evaluated bid price (capital and life-cycle cost): 25 percent;
- Equipment performance: 25 percent;
- Manufacturer quality control and experience: 25 percent;
- Compatibility with commercial terms: 25 percent.

Five bids were received for the Rolling Hills vertical pump package and four for the Benbrook horizontal pump package.
The negotiated bid process offers many advantages to the owner. It allows the owner to consider criteria other
than price for selections, making it possible to place more emphasis on quality than on price. It also gives the owner
more control in selecting the equipment and a greater ability to limit the risks.

From the east and west balancing reservoirs located at
Kenedale, which work together and are referred to collect-
ively as the Kenedale balancing reservoir, the water
can serve Fort Worth’s Rolling Hills Water Treatment Plant by gravity through parallel 108 in. (2,743 mm) and 84 in.
(2.134 mm) pipelines. The existing 90 in. (2.286 mm) Ben-
brook connection pipeline continues from the water treatment
plant to Benbrook Lake, where water can be stored in winter to meet peak demands in summer.

The Rolling Hills booster pump station is located just south of the Rolling Hills Water Treatment Plant and is connected
to the 90 in. pipeline. The original concept for the pump sta-
tion was to boost water from the Kenedale balancing reser-
voir over a high point on the Benbrook pipeline to feed the
Eagle Mountain connection. In analyzing the gravity system
that conveys water to the water treatment plant, the engi-
neree determined that the existing 108 in. (2,743 mm) and
84 in. (2.134 mm) pipeline could not meet the system demands by gravity. Several options were studied, including building a third gravity pipeline and raising the balancing reservoir.
Although these upgrades will be required at a later time,
it was determined that low-head pumps could be added to the Rolling Hills booster station to postpone these upgrades for
20 years. The low-head pump station added approximately $6
million to the cost of the booster station; a new gravity line
would have added $3 million.

Using the booster station to pump water only during peak demand makes it possible to lower the hydraulic grade line
approximately 44 ft (13.4 m), which significantly increases the hydraulic capacity of the existing pipelines between the Ken-
nedale balancing reservoir and Rolling Hills. During times when demand is not at its peak, gravity flows will still be used, lowering costs even more.

Vortex turbine pumps inside suction cans are required at the Rolling Hills booster station owing to potential variations in the suction head. The Rolling Hills booster station pumps
into the Rolling Hills Water Treatment Plant using low-head pumps when flows are lower, high-head pumps, and it pumps
over the hill at Longhorn Park with high-head pumps. Vari-
able-frequency drives reduce the speed of the high-head pumps
so that they can run in parallel with the low-head pumps. This
innovation reduced the number of pumps required, thereby
reducing costs while also maintaining pumping efficiency and
operational flexibility. The pump station was initially con-
structed with four high-head and two low-head pumps, with
provision for expansion to four high-head and five low-head pumps. One additional slot for another pump will be added
when the station is expanded.

The Benbrook booster station is located below Benbrook
Dam in southwest Tarrant County. It receives flow from the
Rolling Hills station and pumps water through the 96 in.
(2,438 mm) and 84 in. (2,134 mm) pipeline to Eagle Moun-
tain Lake. The layout of the pump station accommodates
three large pumps and one small pump. The small pump is required when flows are lower and to supplement the larger pumps when flows are higher. All four pumps are needed to
meet the facility’s initial 230 mgd (870,550 m³/d) capacity. A
total of six pumps will be required to meet the anticipated future capacity of 350 mgd (1.3 million m³/d). The pump sta-

The Commission on Special Cases, et al.
A total of six pumps will be required to meet the anticipated future capacity of 350 mgd (1.3 million m³/d) at the Benbrook booster station. The pump station therefore includes six pump slots, two of which will be used in the future.

Side-suction horizontal split case pumps were installed at the Benbrook booster station. Bottom-suction horizontal split case pumps also were considered but were determined to be less cost effective because of the additional construction costs that would have been incurred to accommodate the basement pipe gallery that such pumps require. Moreover, the side-suction pumps facilitate a floor plan that provides easier access to the suction piping. The suction tank at this station is sized for 14 million gal (52,990 m³/d).

The tank at Rolling Hills is 65 ft high, and the one at Holly Water Treatment Plant, in downtown Fort Worth. This outlet adds flexibility and redundancy to the Tarrant Regional Water District’s delivery system.

The Clear Fork outlet structure consists of a flow control valve vault, a stilling basin, and a baffle chute spillway. It was designed to meet flows ranging from 30 to 120 mgd (113,550 to 454,200 m³/d) with the head in the pipeline 70 to 140 ft (21 to 43 m) above the discharge point. To control the discharge, several types of valves were studied that would lower the high pressure in the pipeline to the atmospheric pressure conditions required for discharge. These included butterfly valves with orifice plates, in-line and submerged discharge sleeve valves, and multiple orifice valves. The studies showed that too many butterfly valves with orifice plates would be required to meet a wide range of flows. Thus, the design criteria should be specified in the contract documents.

Steel tanks were selected over steel tanks because of their lower expected life-cycle costs and to eliminate the downtime for painting. What is more, the brittle membrane is susceptible to local discontinuities caused by variations in the subgrade. So the team recommended that the design criteria specified in the contract mandate that, if the slab cracked, it should have sufficient depth and reinforcement to be capable of resisting the computed stresses according to the guidelines promulgated by Committee 350—Environmental Engineering Concrete Structures—of the American Concrete Institute with an additional environmental load factor and that the slab have a minimum capacity to account for any actual discontinuities that might be expected in the subgrade.

The American Water Works Association’s standard D110 (Wire- and Strand-Wound, Circular, Prestressed Concrete Water Tanks) calls for the foundation to use either a structural floor or membrane slab. Under many conditions the membrane slab will be less costly; however, the nature of the subgrade and the size of the tank (as well as economic considerations) should be used to determine the type of foundation. The standard specifies the assumptions that underlie the successful performance of the membrane slab. It is critical that the designer understand these assumptions and be confident that they can be met. Nevertheless, the standard leaves many decisions to the tank designer and to the owner’s engineer, and careful examinations are necessary to assure the engineer and the designer that certain fundamental assumptions regarding the membrane floor have been met by the design and construction team.

Since the Rolling Hills tank was to be constructed on poor soil conditions, possessed large inlets and outlets, and was very tall, the design required a 3 ft (0.9 m) thick reinforced concrete slab supported by 175 drilled shafts. The Benbrook tank, having a competent limestone foundation, could be designed with a 12 in. (305 mm) doubly reinforced slab supported by highly consolidated crushed stone as a flexible base material. The flexible slab sits on the limestone, and a drainage system beneath the slab was provided.

Typical industry practice leaves the design of the foundation to the tank manufacturer with few detailed design considerations. The desire for lower stresses, coupled with the lower material costs of thin membranes, encourages a competitive tank manufacturer to make the floor as thin as possible. This leads to slabs so thin that shrinkage cracks may result along the slab reinforcement, requiring repair and maintenance and reducing the reliability of the tank. What is more, the brittle membrane is susceptible to local discontinuities caused by variations in the subgrade. So the team recommended that the design criteria specified in the contract mandate that, if the slab cracked, it should have sufficient depth and reinforcement to be capable of resisting the computed stresses according to the guidelines promulgated by Committee 350—Environmental Engineering Concrete Structures—of the American Concrete Institute with an additional environmental load factor and that the slab have a minimum capacity to account for any actual discontinuities that might be expected in the subgrade.

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A 120 mgd (454,200 m³/d) river outlet allows delivery of the eastern Texas water to Trinity River’s Clear Fork. The division between Clear Fork and Trinity River is used by the Holly Water Treatment Plant, in downtown Fort Worth. This outlet adds flexibility and redundancy to the Tarrant Regional Water District’s delivery system.

The Clear Fork outlet structure consists of a flow control valve vault, a stilling basin, and a baffle chute spillway. It was designed to meet flows ranging from 30 to 120 mgd (113,550 to 454,200 m³/d) with the head in the pipeline 70 to 140 ft (21 to 43 m) above the discharge point. To control the discharge, several types of valves were studied that would lower the high pressure in the pipeline to the atmospheric pressure conditions required for discharge. These included butterfly valves with orifice plates, in-line and submerged discharge sleeve valves, and multiple orifice valves. The studies showed that too many butterfly valves with orifice plates would be required to meet a wide range of flows. Thus, the design criteria should be specified in the contract documents.

A 48 in. (1,219 mm) multiple orifice valve proved to be the best selection for this application owing to its low cost, small footprint, and ability to operate under the full range of flow conditions. This valve uses two steel plates with orifices drilled in both plates. One plate is stationary, while the other slides up and down as required to modulate the flow. The valve opens when the plates are slid so that the holes align. The multiple orifice valve breaks the head—that is, produces the required pressure drop—by directing flow through multiple small orifices.

An impact-type stilling basin was constructed downstream of the flow control valve. This was done to dissipate the velocity of the water as it enters the river. Water velocity is dissipated when the jet of water exiting the flow control valve hits a vertical hanging baffle. The water changes direction, and the turbulence effectively dissipates the energy. The water then flows under the baffle and over a weir. The location of the stilling basin was considered carefully because placing the basin at the top of the riverbank would have required the construction of a baffled chute spillway to slow the water as it traveled toward the riverbed. On the other hand, placing the basin at the riverbed would have created construction and maintenance difficulties in addition to permanently exposing the basin to flooding. The higher baffled chute spillway was selected to carry the water down to the river bottom because it required less excavation and would be easier to maintain.

The spillway lowers water 10 ft (3 m) from the impact-type stilling basin to the riverbed. The baffled piers of the spillway partially obstruct the flow, dissipating energy as the water flows down the chute. The advantages of baffled chutes include low cost, low terminal velocities of the flow regardless of the height of the drop, and effective stilling action, even when the depth of the water body into which it is flowing, that is, the tail water, is low.

A balancing reservoir is planned for the high point of the pipeline route. This high point controls the storage between the Benbrook booster station and at the Eagle Mountain flow control vault. Just south of the reservoir, the pipeline diameter reduces from 96 in. (2,438 mm) to 84 in. (2,134 mm).

The Eagle Mountain balancing reservoir will provide storage for a water treatment plant currently being designed for the west side of the city of Fort Worth and will also provide backup storage for the Tarrant Regional Water District’s existing customers. Storage is needed for routine maintenance, emergen- cies, and pump station downtime. The reservoir also has the benefit of providing an open water surface to block surge waves in the pipeline, easing pipeline operation. The reservoir will have a capacity of 318 million gal (446,630 m³).

The interior of the reservoir will have a high-density polyethy- lene (HDPE) liner beneath a 9 in. (229 mm) thick soil-cement. The HDPE liner controls leakage while the soil-cement is used for mechanical protection, providing a hard surface on which...
One potential problem with bypassing the reservoir is that shutoff head could be introduced into the pipeline if the valves at the future west-side water treatment plant or at the outlet structure were closed while the pumps were in operation. A standpipe has been installed on the bypass pipeline to alleviate this concern. The standpipe will also help alleviate surge pressures during bypass operations.

The Eagle Mountain connection pipeline discharges up to 280 mgd (1.06 million m³/d) into Eagle Mountain Lake through the Eagle Mountain flow control vault. The hydraulic grade line at this facility is controlled by the water elevation in the 118 mgd (446,630 m³/d) Eagle Mountain balancing reservoir and by pipe friction in the 45,000 ft (13,716 m) long, 84 in. (2,134 mm) diameter pipeline. The flow control facility was designed to discharge flow rates ranging from 30 to 280 mgd (113,550 to 1.06 million m³/d) with head conditions in the pipeline ranging from 230 ft (70 m) for low flows to 35 ft (10.6 m) for high flows. The flow control valve options, evaluated for their ability to handle these hydraulic conditions, included in-line sleeve valves, submerged discharge sleeve valves, and multiple butterfly valves with orifice plates.

In-line sleeve valves require positive pressure conditions on the downstream side of the valve. Unfortunately, the best loca-
tion for a flow control facility in this application did not meet this condition. Several modifications and alternative sites were evaluated for positive downstream pressures, but they added significant cost to the option. The submerged discharge sleeve valves require installation in large, deep sumps. The difficulties associated with constructing and maintaining these deep discharge chambers made this option very costly.

Multiple lines containing butterfly valves and orifice plates proved to be the preferred solution. Nine parallel lines branch off from an 84 in. (2,134 mm) header at the end of the 84 in. (2,134 mm) Eagle Mountain connection pipeline. The lines, ranging from 18 to 36 in. (457 to 914 mm) in diameter, extend through the Eagle Mountain flow control vault and connect to a 78 in. (1,981 mm) discharge header. Each line contains a butterfly valve and one or two custom-designed orifice plates supplied with an aeration system. The lines are designed to be opened and closed one at a time and in a particular order to control cavitation and to minimize hydraulic currents in the pipeline while the desired flows are being discharged. The 18 in. (457 mm) line is opened first and is therefore subject to maximum pressure conditions. As each succeeding line is opened, the flow increases and the head in the system is reduced. Each line is custom designed to control cavitation to meet its particular head and flow requirements.

Even so, some cavitation occurs as the butterfly valves open and close. This occurs only at the small valve openings because the larger orifices provide adequate back pressure to prevent cavitation once the valve is partially open. Because the capacity of each line is small in relation to the capacity of the pipeline and because the other open valves provide transient pressure relief, changes in flow caused by operating one valve do not create excessive hydraulic transients in the pipeline.

The valve operating times were determined through computer simulations of the system.

The first four lines contain two multihole orifice plates located two pipe diameters apart, each containing a number of 2 in. (51 mm) diameter holes. The fifth line has one multihole orifice with 3 in. (76 mm) diameter holes. The remaining lines have single-hole orifices. The multihole plates reduce flow noise and allow the orifices to be spaced closer together than conventional single-hole plates. The first four lines have two plates in series because they operate at the highest differential heads. Dissipating the head in two stages reduces vibrations and cavitation potential for the downstream orifice. As more lines are opened, the head continues to decrease and a single orifice plate is sufficient to provide cavitation-free operation.

The valve flow control vault is located 20 ft (6 m) above lake level, so open-channel flows occur in the discharge pipes at most flow rates. This created a potential erosion problem inside the pipe because the jets from the downstream orifices, when operating at full velocity, will impinge on the lining of the discharge header unless the jets are submerged. To solve this problem, several wet plates were installed in the discharge header to create enough tail water to submerge the orifices.
Manufactured in the shop and shipped to the jobsite. Four piles were positioned in the lake to receive the outlet box. The structure slid down the four piles and was suspended above the lake bottom while a concrete pad was poured below the box. Concrete was then placed within the box. With the box in place, cables were strung from the outlet to the shoreline. The Hobs pipe was joined onshore, and a crane on a barge then pulled the cable and the string of pipe to the inlet on the box.

Construction of the Eagle Mountain Connection Project was completed this summer. The project was broken into four construction contracts and three equipment contracts. The total construction cost, including prepurchased equipment, was just over $139 million.

The project has already increased the district’s ability to meet demands in the West Fork service area and has increased system reliability and system yield. The connection project has helped contain power costs and has increased the water district’s flexibility with respect to both current operations and future expansions.

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Project Credits

Owner: Tarrant Regional Water District, Fort Worth, Texas

Primary consultant: Freese and Nichols, Inc., Fort Worth, Texas

Engineering subconsultants: Camp Dresser and McKee, Inc., Cambridge, Massachusetts (electrical and instrumentation engineer); Corrosion Control Technologies, Inc., Sandy, Utah (corrosion engineer); and Tullis Engineering Consultants, Logan, Utah (hydraulics engineer)

Contractors: Bar Constructors, Inc., Lancaster, Texas (Eagle Mountain 96 in. [2,438 mm] pipeline); Garney Construction, Inc., Kansas City, Missouri (Eagle Mountain 84 in. [2,134 mm] pipeline); Archer Western Contractors, Ltd., Atlanta (Benbrook booster pump station and Rolling Hills booster pump station)

Construction subcontractors: Preload, Inc., Hauppauge, New York (prestressed-concrete tanks), and Boyer, Inc., Houston (subaqueous pipe installation)

Pump and pipe manufacturers: Hitachi Pumps, Tokyo (Benbrook booster pump station pumps); Sulzer Pumps, Winterthur, Switzerland (Rolling Hills booster pump station pumps); Hanson Pressure Pipe South-Central Region, Grand Prairie, Texas (Eagle Mountain 96 in. [2,438 mm] pipe); Northwest Pipe Company, Saginaw, Texas (Eagle Mountain 84 in. [2,134 mm] pipe)