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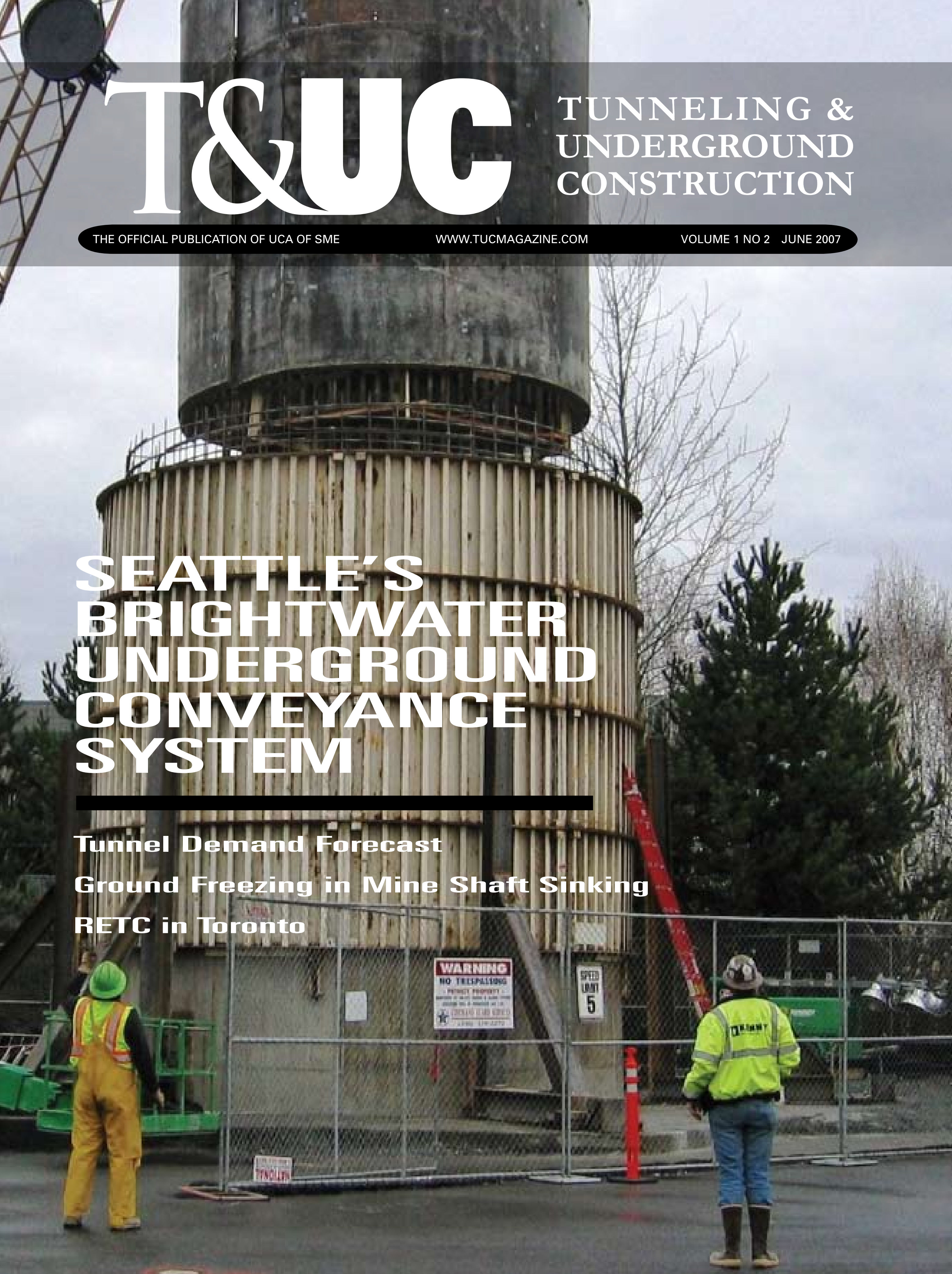

SEATTLE'S BRIGHTWATER UNDERGROUND CONVEYANCE SYSTEM

Tunnel Demand Forecast

Ground Freezing in Mine Shaft Sinking

RETC in Toronto

Brightwater Conveyance System will expand Seattle's wastewater treatment

The final lining blockout forms for the influent structure to the influent pump station connector tunnels at the North Creek Portal influent structure.

Washington's King County is constructing a new regional wastewater treatment facility, called Brightwater, in response to growth in the greater Seattle region. Planning conducted in the late 1950s identified the need for two regional treatment facilities. Constructed in the 1960s, these plants have served the region well. However, an eventual need for a third facility was also recognized.

The Brightwater project implements the final phases of the long-term plan. The project includes a new treatment plant and an extensive conveyance system. When completed in 2010, the Brightwater facilities will treat sanitary sewer flows from growing populations living in northern King County and southern Snohomish County. The new system will fulfill commitments to provide wastewater services to local jurisdictions and sewer service providers in the King County Service Area. It will also provide more flexibility in the operation of the King County regional wastewater system.

The Brightwater wastewater treatment plant will provide secondary treatment capacity using membrane bioractor technology in 2010 for 36 million gallons per day (mgd), with anticipated expansion in 2040 to 54 mgd, using membrane bioreactor technology. These capacities are for average wet-weather flows. The plant will also accommodate peak hourly flows of 130 mgd by 2010 and 170 mgd by 2040.

The Brightwater Conveyance System consists of more than 8.1 km (13 miles) of tunneled influent and effluent conveyance lines, five tunnel portals/shafts, microtunneled influent and outfall connec-

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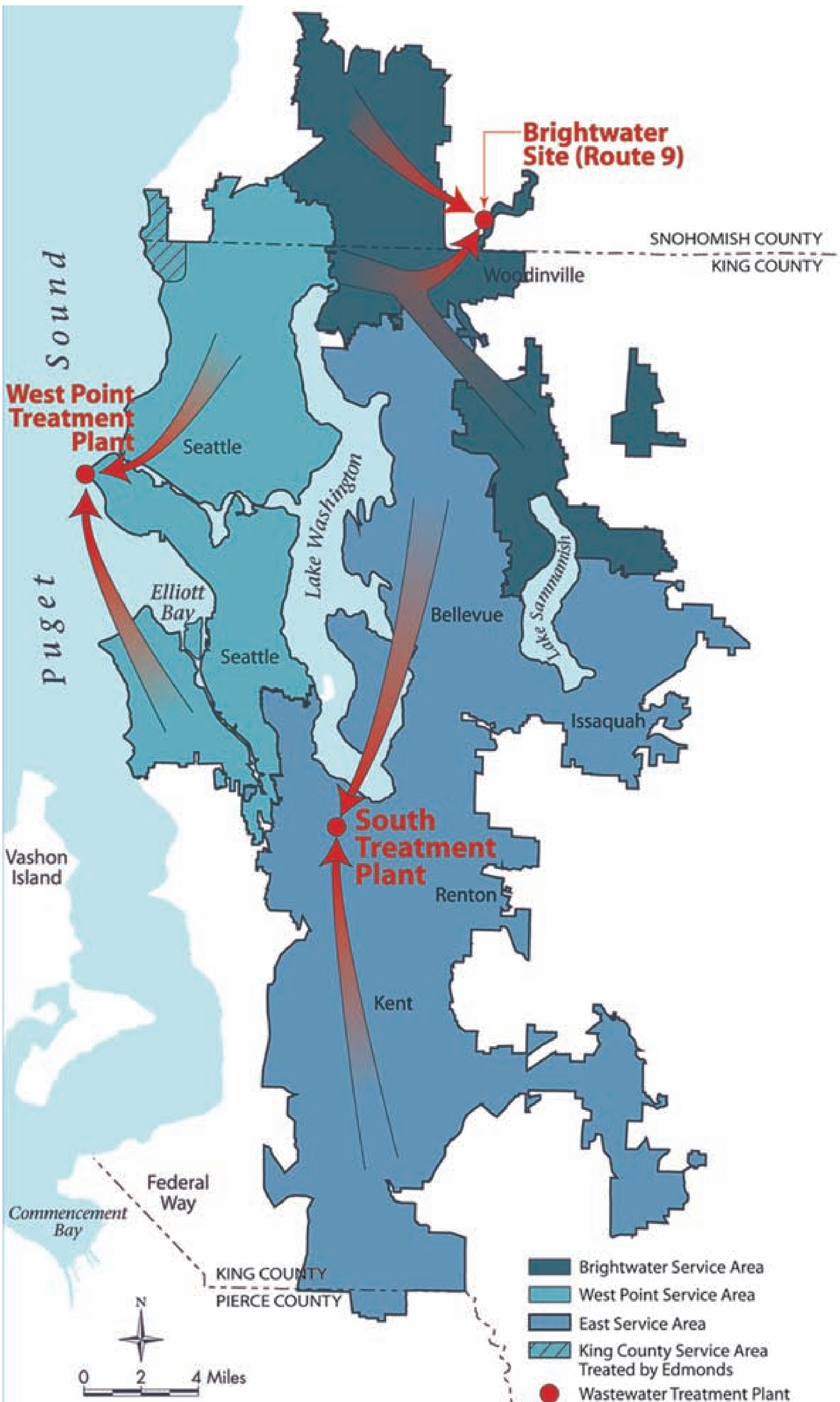
King County's wastewater service area.



Courtesy of King County, WA

tions, a large pump station, and a 1.6-km- (1-mile-) long marine outfall extending to a depth of 184 m (605 ft) in Puget Sound. The conveyance alignment traverses topographically complex terrain developed and numerous suburban residential communities. Almost all of the conveyance system pipelines are being constructed using tunnel boring machines (TBMs) and microtunnel boring machines (MTBMs) to limit impacts to roads, residences and commercial assets along the conveyance route.

The Brightwater tunnels include about 20,376 m (66,850 ft) of large diameter tunnels being constructed in four segments. And about 1,390 m (4,570 ft) of microtunnels are being constructed in six segments. Wastewater influent is conveyed through the microtunnels from existing trunk sewers in the Swamp Creek Valley and North Creek Valley to portals in the respective valleys, the North Kenmore Portal and the North Creek Portal.

Influent flows by gravity in a deep tunnel from the North Kenmore Portal to the North Creek Portal. An influent pump station constructed adjacent to the North Creek Portal will pump all influent to the treatment plant through force mains placed in another deep tunnel.

Effluent from the treatment plant will flow by gravity through effluent pipelines constructed within tunnels as carrier pipes to the North Kenmore Portal, then by the tunnel structure itself to the Point Wells Portal. Another microtunneled pipeline will carry the effluent from the portal to the cut and cover and surface laid marine outfall.

Conveyance system design and construction

To meet the requirement that the project be operational by 2010, preliminary design began in November 2002 shortly after King County identified a preferred project alternative. It included the treatment plant site and a conveyance alignment corridor generally following State Route 9 and 195th Street. The preliminary design refined the conveyance horizontal alignment within the corridor, selected a vertical alignment from a range of force main and gravity alternatives, completed other work necessary to further refine the project and develop permit applications, and determined how to contract for the construction work. The preliminary design was immediately followed by final design of the project, which included numerous contract packages. Plans and specifications for the major contract packages were completed by mid-2006.

The design and construction of the Brightwater project is being led by the King County Department of Natural Resources and Parks, Wastewater Treatment Division (WTD). It has a long history of successful tunnel projects. However, this project is the largest the department has undertaken. It involves some of the deepest tunnels and shafts in soft ground constructed in the United States.

Recognizing the importance of consistency in addressing geotechnical issues associated with the deep tunnels and shafts, WTD selected a single geotechnical engineering team to perform all the conveyance geotechnical work. This geotechnical engineering contract was awarded to CDM, which provided geotechnical services throughout the preliminary and final design. CDM is now supporting WTD during construction. Professional teams with strong tunnel design experience were also selected by King County – the preliminary design team was led by HDR and the final design team was led by a joint venture of MWH and Jacobs Associates. CDM led a collaborative effort among CDM, WTD and the final design team to prepare geotechnical baseline reports (GBRs) for each of the tunnel contracts.

MTBM launch and BT-2 TBM receiving blockout, North Creek Portal.

Slurry wall hydromill, North Creek Portal.

Construction of the tunnels and shafts is being performed under three major contracts with a single contract for the 140-mgd pump station. There are several other contracts for construction of smaller portions of the conveyance system and existing plant modifications. WTD retained a team led by Jacobs Engineering Group for construction management for all conveyance contracts except for the design-build marine outfall for which Vanir Construction Management is the construction manager.

East Tunnel contract

This contract consists of the combined conveyance tunnel between the North Creek Portal and the Brightwater treatment plant. This first Brightwater tunnel (BT-1) is 4,282 m (14,050 ft) of 5.87 m (19.25 ft) inside diameter (ID) concrete segmental-lined tunnel. It contains 1.2 m and 1.6 m (48-in. and 66-in.) ID influent force mains, a 2.13-m- (84-in.-) ID effluent pipe and a 686-mm- (27-in.-) ID reclaimed water pipe, all encased in cellular concrete. Included is an influent structure/tunnel portal excavation approximately 22.5 m (74 ft) deep and 24.3 m (80 ft) in diameter with slurry diaphragm walls 40 m (130 ft) deep; an influent pump station excavation approximately 25.3 m (83 ft) deep with twin intersecting 25.6-m- (84-ft-) diameter cells and slurry diaphragm walls 49 m (160 ft) deep; and a receiving portal at the treatment plant approximately 12 m (40 ft) deep. The contract also includes 741 m (2,430 lineal ft) of 1.8-m-(72-in.-) ID microtunneled influent sewer con-

"Y-Panel' reinforcement for the diaphragm wall between shaft lobes, Influent Pump Station.

necting the influent structure to the North Creek trunk lines at the existing North Creek pump station and two 3.66 m (12 ft) ID connector tunnels between the influent structure/tunnel portal and the influent pump station.

A joint venture of Kenny, Shea and Traylor (KST) with a bid value of $130.9 million, was given notice to proceed with the East Tunnel contract in January 2006. KST selected a Lovat Earth Pressure Balance TBM for the work. The launch shaft is complete and launch is set for the summer of 2007. Two of the three sunken caisson shafts are completed for the North Creek Connector and microtunneling is under way. The contract completion date is late 2009.

Central Tunnel contract

This contract consists of the combined tunnel between the North Kenmore Portal and the North Creek Portal (BT-2) and the effluent tunnel between the North Kenmore Portal and Ballinger Way Portal (BT-3). BT-2 is 3,536-m- (11,600-ft-) of 5.12-m- (16.8-ft-) ID long segmental-lined tunnel with a 1.8-m- (72-in.-) ID effluent pipe, 1.3-m- (54-in.-) ID influent pipe and 607-mm- (24-in.-) ID reclaimed water pipe. BT-3 is 6,126-m- (20,100-ft-) of 5.12 m (16.8 ft) ID, long segmental-lined tunnel with two 356-mm- (14-in.-) ID reclaimed water pipes encased in concrete with a 1,280-m (4,200-ft) section of 3.2-m- (126-in.-) ID effluent pipe. Included is a 15.8-m (52-ft) finish ID, launch portal structure 27 m (90 ft) deep. It is constructed using a slurry diaphragm wall. The 7.31-m (24-ft) finish ID receiving portal structure is more than 61 m (200 ft) deep and was constructed using a shallow ground water contamination cutoff wall and a full-depth frozen soil wall. This contract also includes the Swamp Creek Connector. It consists of 488 m (1,600 lineal ft) of 1.2-m- to 1.8-m- (48-in.-to 72-in.-) ID microtunneled influent sewer and 549 m (1,800 lineal ft) of 914-mm- to 1.2-m- (36-in.- to 48-in.-) ID open-cut influent sewer pipeline.

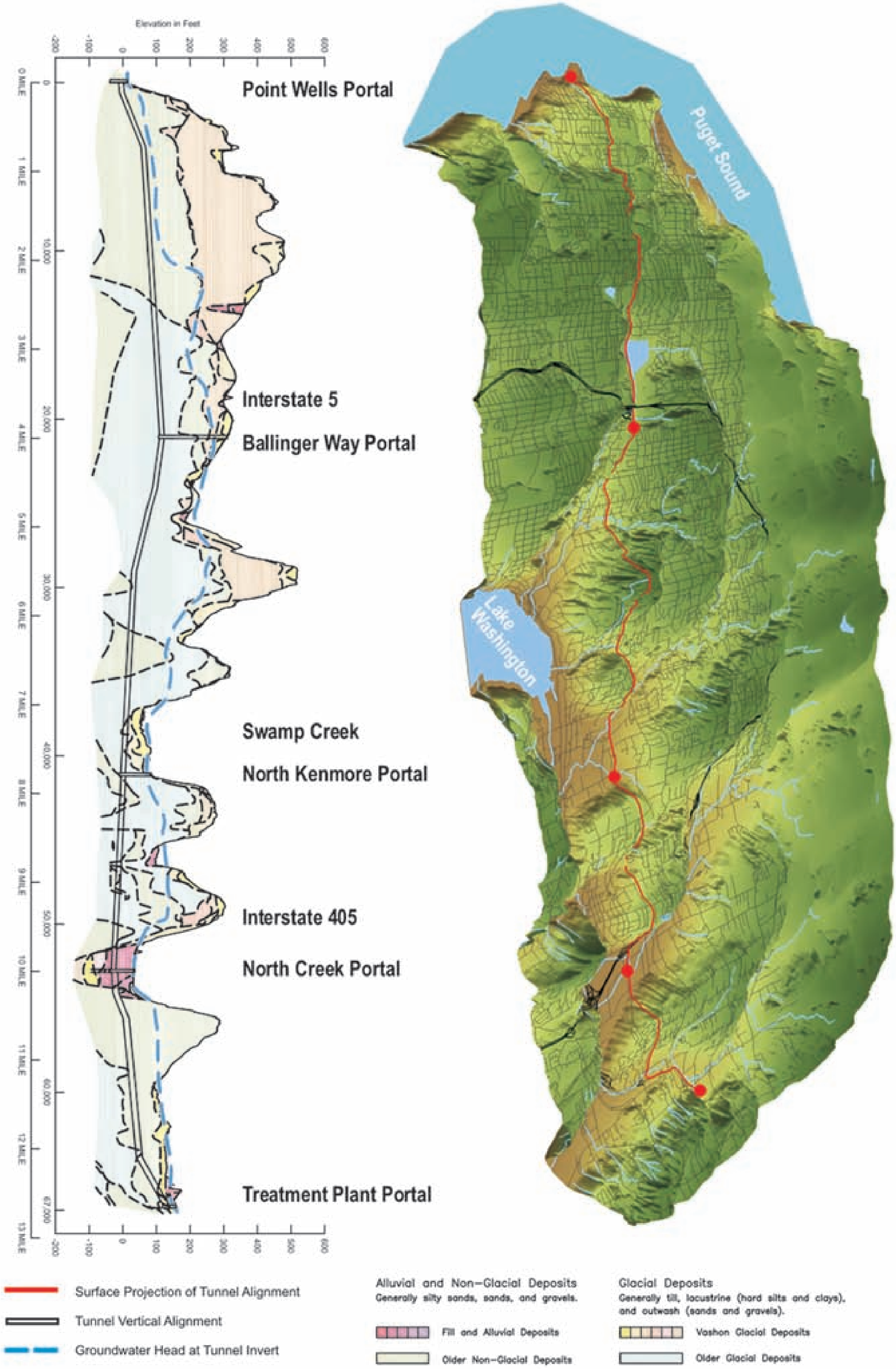
In July 2006, a joint venture of Vinci, Parsons and Frontier-Kemper (VPFK) with a bid value of $209.8 million, was given notice to proceed with the Central Tunnel Contract. VPFK selected Herrenknecht mixshield slurry TBMs to excavate the highly variable ground conditions with ground water heads varying up to 4.9 bars (165 ft) at the tunnel invert along BT-2 and 7.3 bars (245 ft) along BT-3. Slurry TBMs have been a successful technology in Europe for years and have recently been successfully used in Portland, OR. The launch shaft is nearly complete with TBM launch of BT-2 planned for this summer. The Swamp Creek Connector construction is in progress. Ground freezing was selected by VPFK for temporary support of the 62.5-m (205-ft) Ballinger Way Portal excavation, which has been designed by Moretrench American. The completion date for the Central Contract is late 2010.

West Tunnel contract

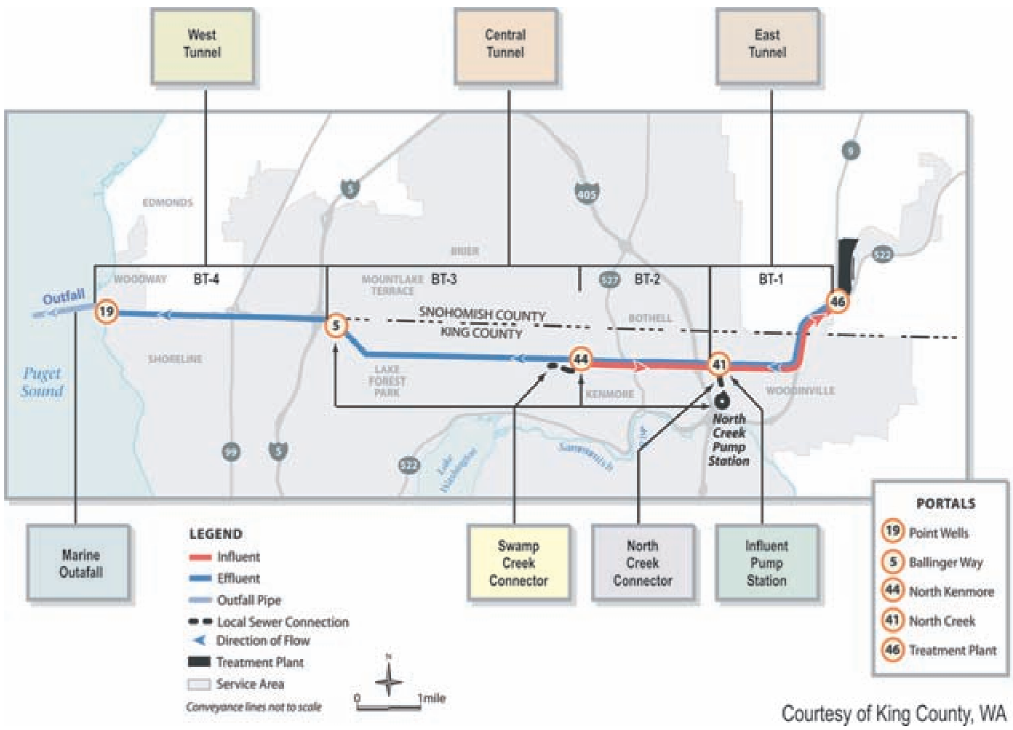
This contract consists of the effluent tunnel between the Ballinger Way Portal and the Point Wells Portal (BT-4). BT-4 is 6,431 m (21,100 ft) of 4-m (13-ft) minimum diameter segmental-lined tunnel, 762 m (2,500 ft) of which is secondarily lined with steel to a 3-m (10-ft) minimum ID. Included is a launch portal at Point Wells approximately 11 m (35 ft) deep with watertight shoring. A below-grade sampling facility and flowmeter vault will be constructed

Clamshell with a boulder removed from the slurry wall excavation, North Kenmore Portal.

Brightwater Conveyance perspective view and geologic section.



King County's wastewater service area.



Courtesy of King County, WA

within the portal excavation. This contract also includes 165 m (540 ft) of 2.1-m (84-in.) microtunneled effluent sewer between the portal and the marine outfall.

In February 2007, a joint venture of Jay Dee, Coluccio and Taisei, with a bid value of $102.5 million, was given notice to proceed with the West Tunnel contract. The joint venture plans to use a Lovat EPB TBM. The completion date for this contract is early 2011.

Other conveyance contracts included:

- Influent pump station: Construction of the 140-mgd expandable to 170 mgd influent pump station within the lined excavation installed by the East Contract. It includes above-grade structures for generators, odor control and chemical storage. Bids have been received and the awarding was expected in the spring 2007.
- Marine outfall: A design-build contract for the outfall, including the diffuser (about 152 m or 500 ft long) located in about 184 m (605 ft) of water and the 1,500 m (4,920 linear ft) of outfall pipeline consisting of about 274 m (900 ft) of buried pipe constructed near and onshore and about 1,256 m (4,120 ft) laid directly on the Puget Sound seabed offshore. This contract is currently in the request for proposal (RFP) stage with selection of the design builder anticipated this summer.
- Other conveyance facilities: Three additional contracts are in the final design, bidding or solicitation stage for above-grade facilities at the North Kenmore and Ballinger Way portal sites, the reuse pipeline in the North Creek Valley and improvements at the existing North Creek pump station and improvements to the nearby Hollywood pump station.

Tunneling challenges

Complex geological conditions. At least three different glacial advances and retreats have created a series of north-south trending ridges and valleys perpendicular to the general east-west conveyance tunnel alignment. The tunnels and shafts will be excavated through a variety of glacial deposits and interglacial deposits, which include regional aquifers. Each of these deposits varies with respect to soil type and consistency. The complex geology, depth of the tunnels and shafts and high variation of overburden and ground water head along the tunnel alignment all contribute to one of the most challenging soft ground tunnel projects in the United States tunneling practice.

Geotechnical investigation. The exploration program included more than 200 exploration borings to an average depth of 81 m (265 ft). Drilling was done primarily by mud rotary and sonic drilling methods with continuous sampling near the tunnel zone and for the full depth of the portal excavations. In addition to these borings, cone penetration testing (CPT), pressuremeter testing (PMT), slug testing and pumping tests were performed at selected locations along the overall alignment to evaluate in situ soil characteristics, ground water and ground permeability. The high degree of glacial consolidation, along with the artesian conditions in the valleys, made sampling of the soils a challenge during the site investigations.

The depth and number of geotechnical explorations across the entire conveyance alignment provided a unique regional understanding of the complex glacial and interglacial deposits. They also allowed a better correlation between various geologic units and physical soil properties. As additional data was collected, the GDR was updated. A separate GBR was prepared for each contract because of the varying design and construction issues. Data used to develop the baseline parameter values was biased based on the location of the data for each contract.

Addressing ground condition risks

Because of its experience with tunneling, WTD felt comfortable with setting expectations on ground conditions for the contractors and accepting a reasonable amount of risk. The GBRs establish a baseline for various geotechnical conditions that the owner and contractor used to plan the work. Risks associated with the baseline conditions have been accepted and planned for by the contractors while risks outside the baseline are the responsibility of WTD. In some cases, WTD has elected to include in its contracts a certain level of equipment and equipment spares, TBM inspection stops and TBM operational requirements, all to reduce risks by setting minimum requirements in the specifications. Some of the more complex issues addressed in the design and preparation of the GBRs are presented here.

Tunnel soil groups. Baseline soil properties were developed for soil groups selected with similar physical properties and tunnel behavior related to tunnel and microtunnel systems. These tunnel soil groups (TSGs) are distinct from and do not directly correlate with the geologic deposits. To enable the contractors to determine operational requirements and production, baselines were established for ranges in the percentage of different face conditions comprised of the TSGs that will be encountered within entire tunnel segments. Uncertainty is expressed by the fact that the sum of the ranges does not equal 100 percent for each segment (typically varying between about 80 and 120 percent). This reflects the level of risk the contractor must assume for uncertainty in making this evaluation for any individual face condition occurring within the entire length of each tunnel segment. To enable measurement for comparison with the baseline percentages, the specifications require that regular samples be taken as the excavation advances through the ground.

Ground water head. Although ground water head at the tunnel elevation is high, up to 7.3 bars (245 ft) and 3 bars (100 ft) or more over the majority of the alignment, establishing a baseline was relatively straightforward. Ground water elevations monitored throughout the alignment during the several years-long preliminary and final design period generally showed little variation (typically less than 1 m or 3 ft).

Dewatering. Impacts to aquifers and streams were identified as a significant risk early in the environmental impact evaluation. Therefore, it was decided to require construction methods that would have little impact on ground water levels including the required use of pressurized face TBMs and MTBMs for the tunneling and watertight excavation support methods for the portal excavations. Exceptions were made for a couple of the portals where temporary depressurization of deeper aquifers was predicted to have limited impact on shallow aquifers.

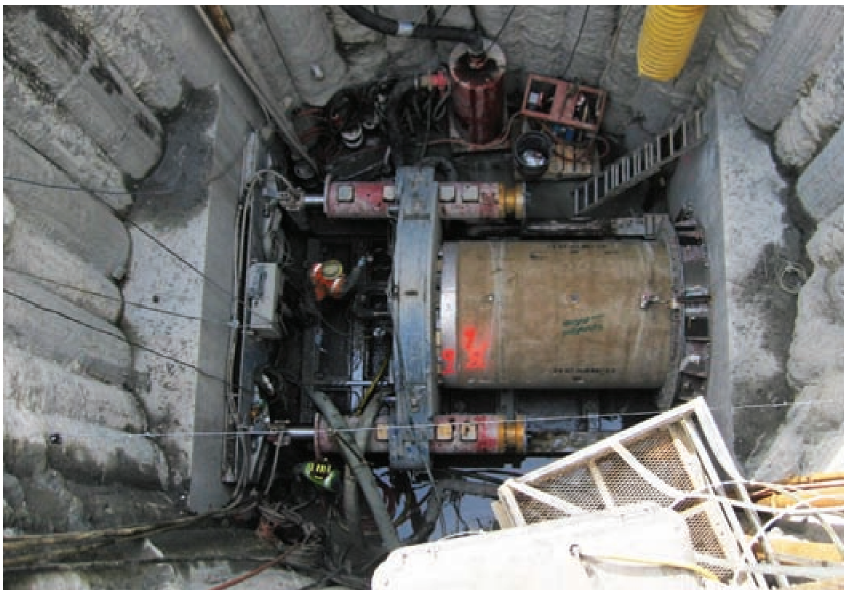
Sunken caisson for the microtunnel receiving pit, North Creek Connector.

Boulders. Boulders are known to be present in the glacial deposits. However, the small diameter of soil drilled in exploration borings makes them essentially useless for predicting boulder sizes and quantities. In fact, only one possible boulder was encountered in the explorations while historic excavations show that numerous boulders can be expected. Surveys of exposed bluffs and nearby excavations and reviews of recent local tunnel projects in similar geologic deposits were performed to develop baseline values for boulder quantities. The baseline number and strength of boulders were conservatively set to assure that the TBMs, excavation equipment and contractor means and methods would be capable of handling boulders. While the majority of predicted boulders are less than 1 m (3 ft) in maximum size, several larger boulders will be encountered. The specifications require TBMs to be capable of handling boulders up to a boulder strength that is at the upper end of the commonly reported range for fresh granite.

Abrasion. Tool life for tunneling machinery and the need and frequency of tool changes is a function of soil abrasivity, tool materials and hardening, and the use of polymers or other ground conditioners. With working conditions in soft ground, especially under high ground water pressure, access to the excavation chamber for tool change can affect tunneling activities and weekly production.

CDM recognized that soil abrasion has been a concern for tunneling in Seattle area granular glacial deposits. While several abrasivity test standards are established

MTBM operation in secant pile wall jacking pit, Swamp Creek Connector.



for rock, few of these test methods are directly applicable for soft ground tunnels. In addition to basic index testing of grain size and soil mineralogy, CDM worked with the design team and Sintef Rock and Soil Mechanics in Trondheim, Norway to adapt the Abrasion Value Cutter Steel test method typically used to evaluate rock abrasion for use in evaluating soil abrasiveness. These test results are provided in the GDR. With experience on the Brightwater project and other projects, this modified test method could evolve into a standard for predicting soil abrasion.

Sticky clays. Sticky clay can adversely affect the rate of production by clogging moving parts of the TBM and by adhering to the exposed steel. It can also increase TBM thrust requirements. About 5,790 m (19,000 linear ft) of the BT-2 and BT-3 tunnel alignments will be driven with a partial or full-face of fine-grained soils that have either moderate or high stickiness potential. The potential for a clay to behave as a sticky material to the exposed steel can be related to the Atterberg Limits of the clay. This issue was evaluated by performing numerous Atterberg Limits tests. They focused on the fine-grained soils within the Central Contract tunnel limits and providing this information in the GDR and a baseline in the GBR for the proportion of the alignment in plastic clays and silts where the stickiness potential is either medium or high. The contractor can use this to evaluate the type and quantity of conditioners, such as polymers, that are required to mitigate this problem, the production rates, the separation plant design and operational issues.

Inspection and maintenance stops. The Brightwater Conveyance tunnel drives are long – BT-3 and BT-4 exceed 6,100 m (20,000 linear ft). This requires good planning and execution of the tunneling systems for this project's tunnels with no intermediate shafts allowed.

Given the abrasive soils and high pressures, even properly designed and operated TBMs will require scheduled inspection and maintenance to complete the tunnels without requiring major repair. The specifications have been prepared with the requirement that the contractor make a minimum number of stops to inspect the TBM face. The number and spacing of required stops varies based on geotechnical conditions and TBM operations.

A stipulated unit price has been established for each of these inspection stops to compensate the contractor for each inspection. The stipulated price is intended to provide a reasonable amount for the contractor to inspect for wear, and then determine its maintenance plans and modify TBM operations as appropriate to ensure the TBM can complete the drive within the scheduled timeframe.

Ground freezing. The Central Contract allowed temporarily support of the deep Ballinger Way Portal excavation by either slurry wall or ground freezing. Experience with ground freezing to this depth of more than 61 m (200 ft) is limited in the U.S.

WTD's philosophy is that the contractor should be responsible for temporary excavation support design as long as the schedule and permanent facilities are compatible with this specifying method. WTD and the design team took advantage of CDM's European experience with ground freezing design for very deep shafts in soft ground to help mitigate the risk of having an inadequate design.

The geotechnical investigation and laboratory testing program (including frozen soil testing) was executed to develop the data necessary for the contractor to prepare a thorough ground freezing design. This led to the minimum ground freezing design requirements being developed based on a preliminary ground freezing system design.

Summary

Construction is now under way on most of the Brightwater Conveyance System. It includes more than 21,700 m (71,400 ft) of tunnels in complex soft ground conditions with a large proportion of the TBM tunnels located 61 m (200 ft) or more below the ground surface and mined under 3 bars or greater ground water head.

Experience gained during the construction of this challenging project will contribute to the advancement of soft ground tunneling technology in the United States and provide valuable lessons in managing underground risk. ■