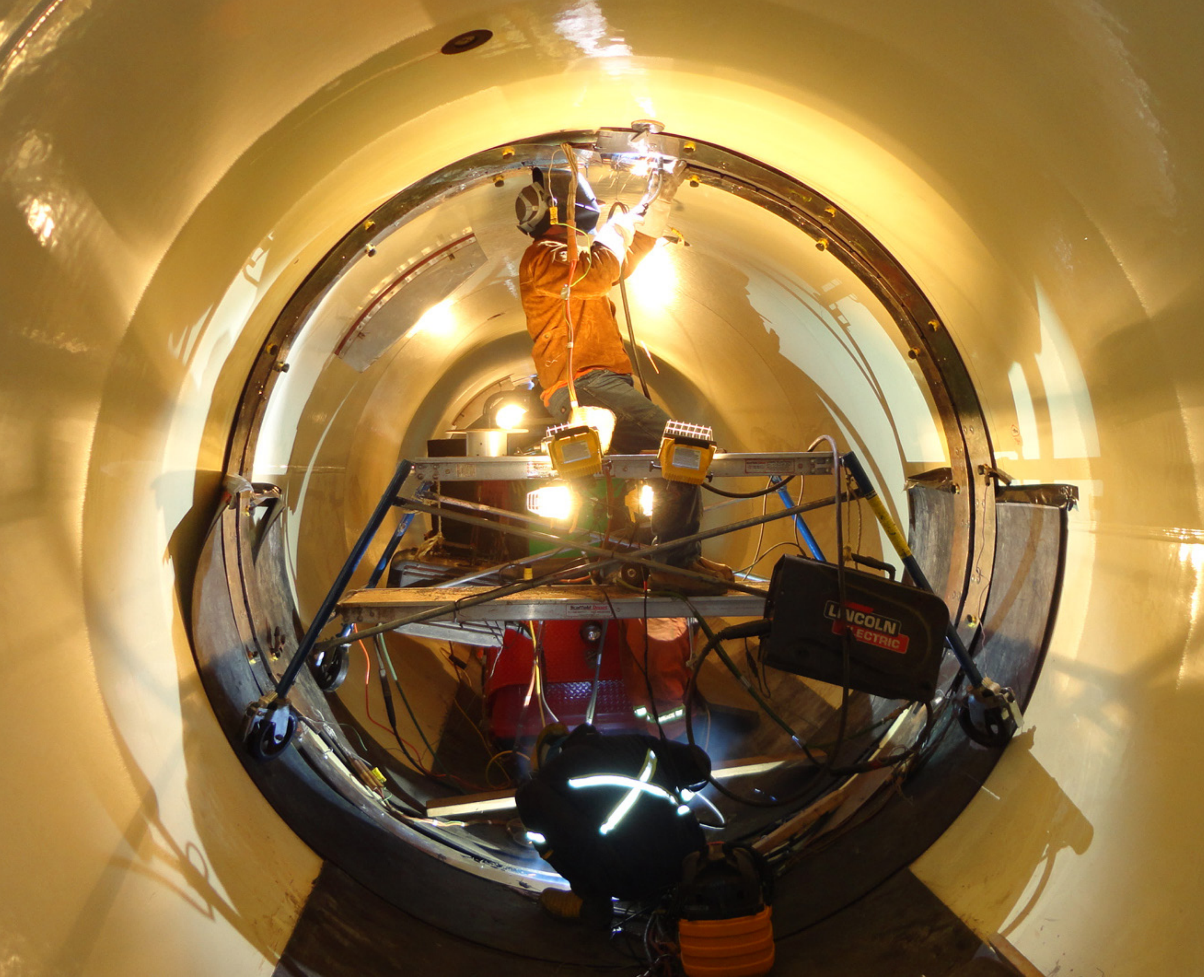


Seymour-Capilano Twin Tunnels

Canadian Consulting Engineering Awards 2016

Submitted by:
Hatch Ltd.
Suite 1000 - 1066 West Hastings Street
Vancouver, BC V6E 3X2
T: +1 604 689 5767
F: +1 604 689 3918
www.hatch.ca

CANADIAN CONSULTING engineer

ASSOCIATION OF CONSULTING ENGINEERING COMPANIES | CANADA
ASSOCIATION DES FIRMES D'INGÉNIEURS-CONSEILS | CANADA

HATCH

Confirmation Receipt of Official Entry Form/ Project Outline

Entry Consent Form

Full Project Description

HATCH

Executive Summary

Delivering clean drinking water for Metro Vancouver residents

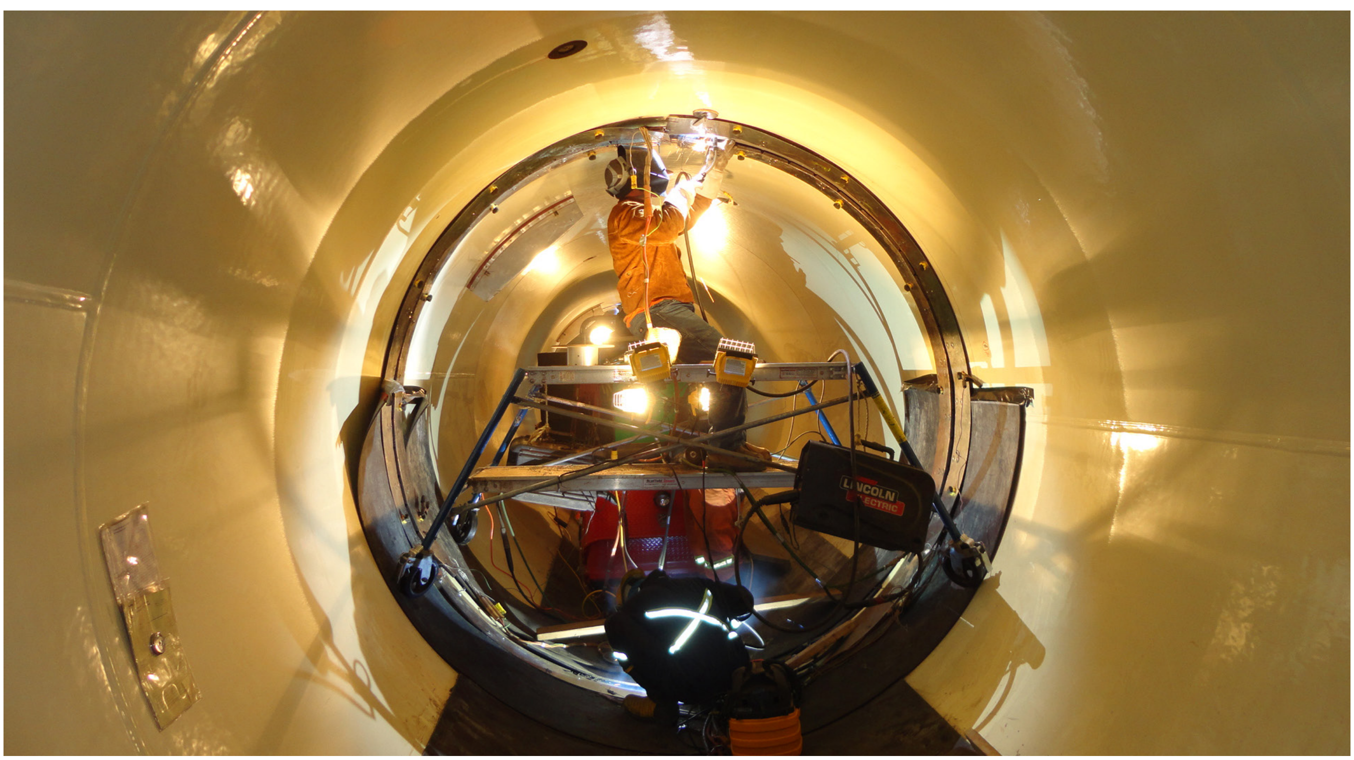
Drinking water for Lower Mainland communities comes from rain and snowmelt collected by three mountain watersheds. Metro Vancouver is responsible for storing and treating this vital resource and supplying clean, safe drinking water to over 2.4 million residents.

Twin tunnels deep beneath Grouse Mountain and Mount Fromme convey water from the Capilano Reservoir to the new Seymour-Capilano Filtration Plant, before being returned to the Capilano system for distribution. The tunnels measure 3.8 m in diameter and 7.1 km in length, with shafts up to 275 m deep. Mined westward using hard rock tunnel boring machines, the tunnels were designed with steel-lined vertical shafts and end sections, and central sections in solid rock or lined with shotcrete.

Designing tunnels in BC's rock conditions required a leading, world-class tunnel designer. Hatch implemented innovative approaches that produced a resilient tunnel design and employed new technologies. Computation fluid dynamics aided the design of rock traps at the ends of unlined sections, and infrared technologies provided quality assurance for the grout backfill behind the steel liners.

Sustainability was a core project value that helped guide design and construction decisions and future operations. The tunnels were connected to an energy recovery facility to offset energy used to pump water to the filtration plant, and optimizing the length of unlined tunnel reduced the amount of steel and backfill materials.

With a hydraulic capacity of up to 1,250 ML/day, this feat of deep-rock tunnel engineering is a lasting contribution to the region's water infrastructure.



TBM breakthrough joining the two tunnels in the Capilano chamber.

Twin tunnels branching off from the Seymour chamber.

Sharing in the Legacy: the design and construction of the twin tunnels have become a legacy for the 20 Hatch team members who not only studied the initial concepts, but also went on to prepare the detailed design and cost estimates, as well as undertake the resident engineering.

Project Highlights: Innovation

Controlling and Monitoring Ground Water Levels

An important design innovation was to minimize the extent of steel tunnel lining for the project. Due to the high quality rock in the area, this design decision considerably reduced the cost of the tunnels.

The ground water levels directly above the Seymour-Capilano Twin Tunnels follow the local topography, which varies from 130 m above sea level at Lynn Creek to over 500 m above sea level at Mount Fromme, whereas the hydraulic gradeline in the twin tunnels is approximately 200 m above sea level. For areas where the hydraulic grade line in the tunnel would be known to exceed ground water levels, Hatch developed a tunnel design to avoid increasing local hydrogeological water levels. The team designed a steel tunnel lining for these areas capable of isolating the ground water from the influence of water pressures in the tunnel. The majority of the tunnel length is situated under high ground cover and remains in solid rock or shotcrete lined rock.

The Hatch team also implemented a ground water monitoring program for pre-construction, construction, and post-construction activities to evaluate the tunnels' effect on ground water levels and to mitigate any adverse effects. Water levels in the rock above the tunnels were monitored and compared to pre-tunnel conditions to ensure that ground levels were not adversely affected by the tunnelling. Notably, historic ground water levels have not been exceeded during operation of the tunnels.

Optimizing Support

Designing in mountainous terrain with rock cover up to 640 m in depth required Hatch to design permanent rock supports as required in the unlined section of the tunnels. The rock support consists of traditional rock bolts combined with reinforced shotcrete. Deeper voids are filled with a cementitious grout behind the shotcrete. This was a delicate operation; pressures had to be closely monitored to ensure the voids were completely filled and with no damage to the shotcrete layer. All materials used in the tunnel conform to drinking water standards.

As well, British Columbia's high seismic risk required the Hatch team to design the shafts and tunnels based on the maximum credible earthquake seismic event.

Installing steel pipe in Capilano shaft, with temporary rock support.

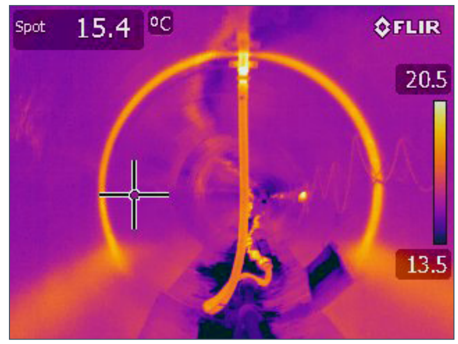
Designing Rock Traps for a Water Supply Tunnel

Even with the rock support, there was still the possibility of small rock potentially being transported through the tunnel with the flow of water and transported up the shaft. To mitigate this risk, Hatch designed rock traps to capture loose material travelling down the tunnel bed. Prior to this project, tunnel rock traps were primarily used for hydroelectric projects, to prevent damage to turbines and valves from rock transported by the flow of water. While the velocities in the Seymour-Capilano Tunnels were planned to be lower than those found in hydroelectric projects, our team proceeded with installing rock traps in the tunnels to capture even finer particles.

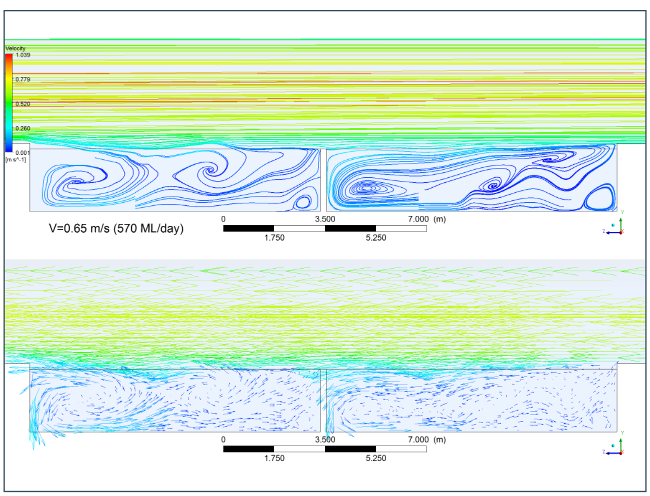
Hatch's modelling experts used computational fluid dynamics (CFD) to design the rock traps and ensure any loose rock generated in the unlined section of the tunnel would be captured in the rock trap.

Visualizing With Infrared Technologies

One of the greatest challenges facing tunnel construction is monitoring backfilling activities for the steel pipe portion inside the tunnels. It is critically important that the steel pipe is completely surrounded by cementitious grout and that no voids are present in the backfill. Traditionally, the search for voids was done by tapping and sounding the steel pipe with a hammer. Due to the thickness of the steel pipe and the potential for damaging the polyurethane lining, the Hatch team devised other methods to test the backfill. For the first time in a tunnel application, tests were completed using infrared cameras capable of a measurement accuracy to within 0.1°C. The team found this test method to be highly successful, and lift heights and voids were easily identified using this method.



Infrared image of grout being injected through a port in the steel lining.



CFD analysis of flow through the designed rock trap.

The underground excavation for the treated water rock trap.

Complexity

Studying the Path Forward

Finding ways to best serve the future water needs meant exploring how to improve water quality and availability. In the early 2000s, Metro Vancouver engaged Hatch to study the feasibility of twin tunnels between the Capilano Reservoir and the Seymour-Capilano Filtration Plant. Hatch conducted comprehensive investigations on alignment, geotechnical conditions, project delivery alternatives, future operations and maintenance, and tunnel hydraulic design. A design of primarily unlined tunnels was selected.

During this planning stage, Hatch studied how the tunnels would convey raw water from the Capilano Reservoir to the new filtration plant and return treated water to major distribution points in the Capilano system. A tunnel boring machine (TBM) was preferred, as it would create smooth granite pipes in sound rock and eliminate a drill-and-blast operation and the overbreak of rock, which would have resulted in extra material to transport and dispose, as well as tunnels that were not as hydraulically efficient. The TBM option would reduce the rock support required and provide a safer environment inside the tunnel during construction.

Steel liner beginning its journey into the tunnel.

Knowing the Ground Conditions

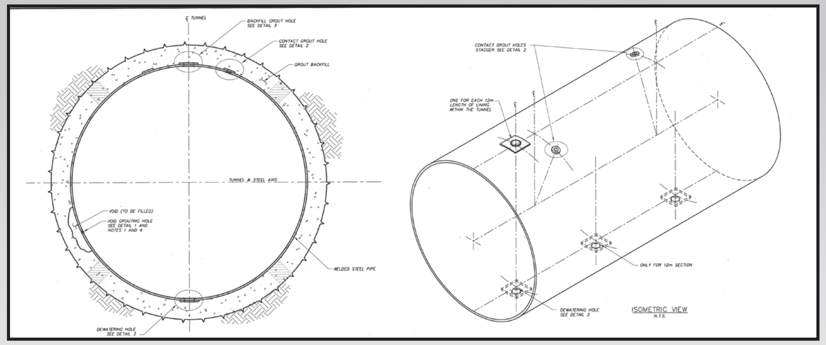
Before any substantial design and construction work could begin, Hatch took on the challenging task of preparing a comprehensive geotechnical baseline report. The project area was known to have deep valleys filled with glacial soils, and investigations were undertaken where the bottoms of these deep valleys were located. As a result, the tunnel depth, alignment, and shaft locations were chosen to minimize tunnelling in fractured rock areas and to avoid potential glacial soil-filled valleys. The tunnel depth and grade of tunnels were designed to be a minimum of 50 m below the interpreted top of rock. The alignments were developed to provide a 100-m separation in the unlined sections to eliminate the possibility of cross tunnel flow.

Unlined tunnels in granite bedrock filling muck cars with TBM mined rock to transport out of the tunnel.

Seymour-Capilano Twin Tunnels

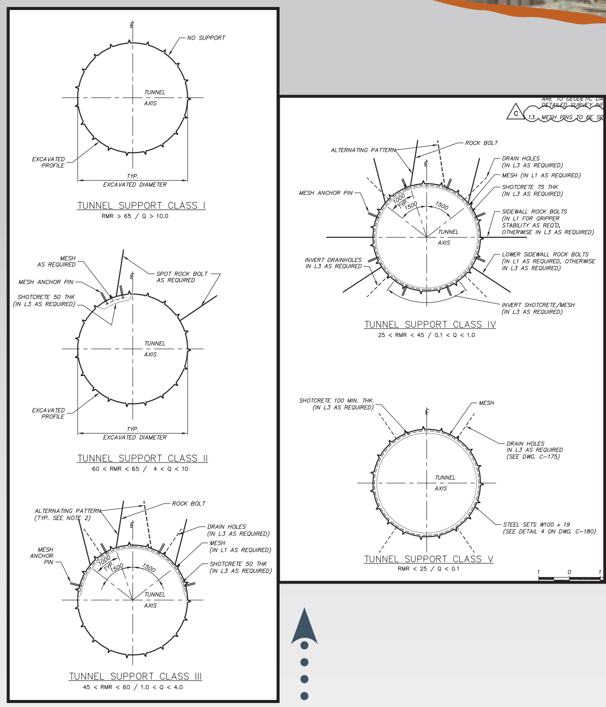
Twin Capilano Shafts

275 METRES BELOW



Steel Pipe Installation

- Steel liners were required where tunnel pressures exceeded ground water levels.
- Designed for up to approximately 300-m head pressures.

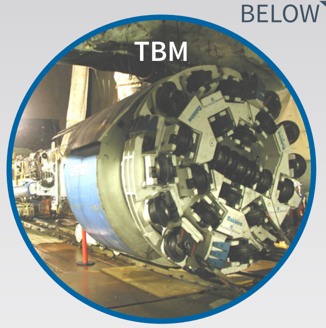


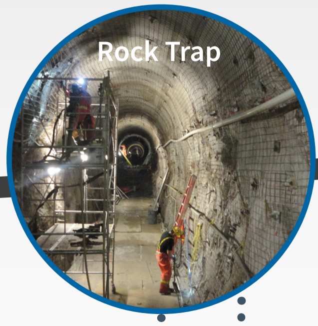
Unlined Tunnel

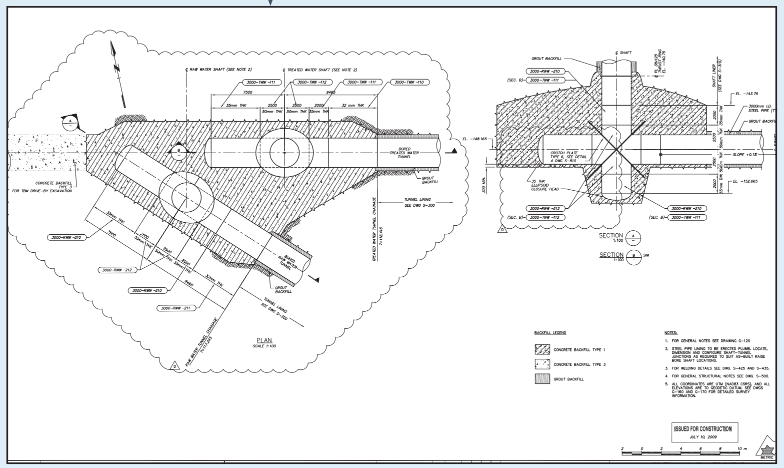
- Using unlined tunnels made of natural sound granite saved approximately $40 million and 10 km of pipeline materials.

Seymour Shaft

180 METRES BELOW

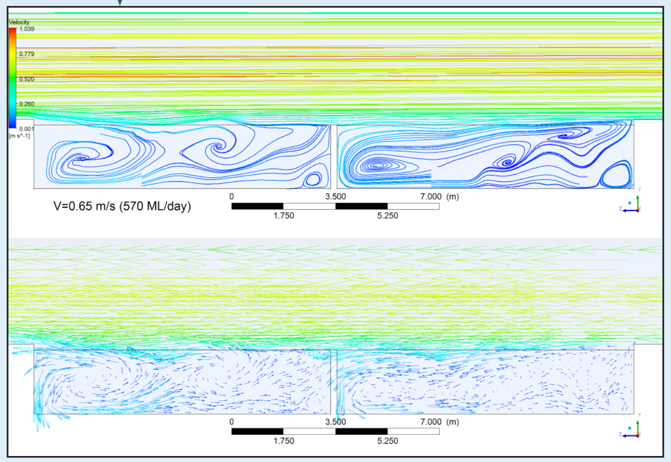


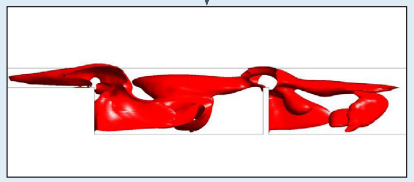




Capilano Cross

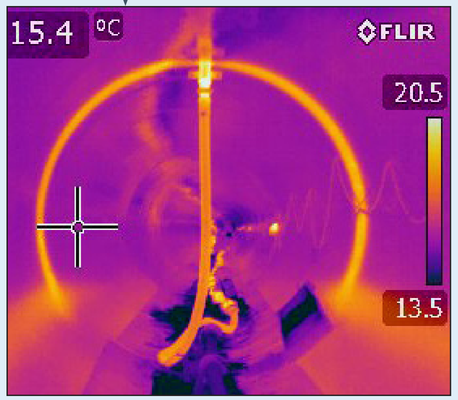
- The junction of the shaft and tunnel junction was designed to allow maximum access and include a sump resulting in a cross.
- The cross was designed with the aid of FLAC3D software to optimize the structure for the enormous forces and pressures.





Rock Trap

- CFD modelling was used to optimize a rock trap to capture any loose material travelling through the tunnel.



Infrared Technologies

- Used to monitor backfilling of the steel pipes - a world's first!
- The bright regions on the image show the location of the new cementious grout.

Social and/or Economic Benefits

Choosing Sustainable Project Solutions

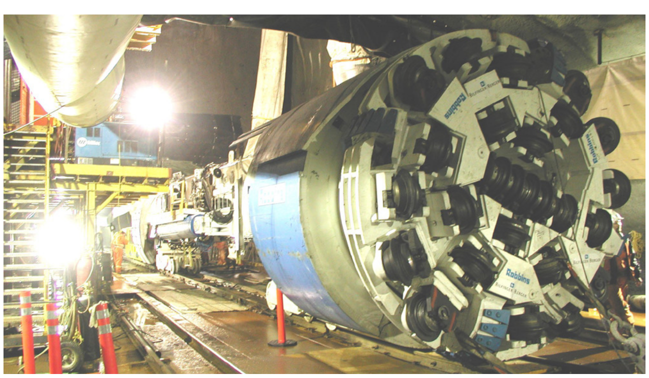
Pipelines versus tunnels: The alternative to conveying water through tunnels was to build large-diameter buried water pipes between the Capilano Reservoir and the Seymour-Capilano Filtration Plant. The Hatch tunnel design is a long-term, less-invasive solution; by choosing the tunnelling option, the project eliminates the need to fabricate and install more than 20 km of steel pipe and to mine and process pipeline bedding and backfill material. The design minimizes traffic disruption associated with surface activities in North Vancouver. It has eliminated detours and road closures necessary for buried pipeline installation and the resultant increase in traffic delays and consumption of fuel and other non-renewable natural resources. Tunnels are by nature lower maintenance than buried pipelines, so further eliminate roadworks and disruption to the community over the life of the facility.

Drill-and-blast versus TBM: The use of TBM machines minimizes the conventional drill-and-blast methods. Choosing to use a TBM machine for the twin tunnels reduced the amount of explosive agent gases and residue (including nitrates, nitrites, and carbon monoxide) that are produced during drill-and-blast excavation. As well, the TBMs were driven by BC Hydro-supplied electrical power generated from renewable hydropower rather than diesel power.

Efficient use and re-use of space and materials: Throughout the project, the team looked for opportunities to reduce waste and efficiently use available resources. Mined rock from the tunnel was transported to a stockpile located near the tunnel shaft, reducing the consumption of fuel. Selected mined rock was then processed and re-used in this and other Metro Vancouver projects. As well, the unlined section of the tunnel saves approximately 10 km of steel pipe installation and over 40,000 m^3 of backfill grout or over 25,000 m^3 of concrete lining .

Finally, the tunnels preserve the natural surroundings of the Capilano Watershed, showing minimal disruption to the landscape. The shaft areas and surface works were specifically designed with small footprint areas and to seamlessly blend with the surrounding natural forest environment.

The project's shaft areas and surface works were specifically designed with small footprint areas.



The TBM in Seymour underground chamber as it prepares to drive towards Capilano.

Sustainability was a core project value that helped guide design and construction decisions, as well as future operations.

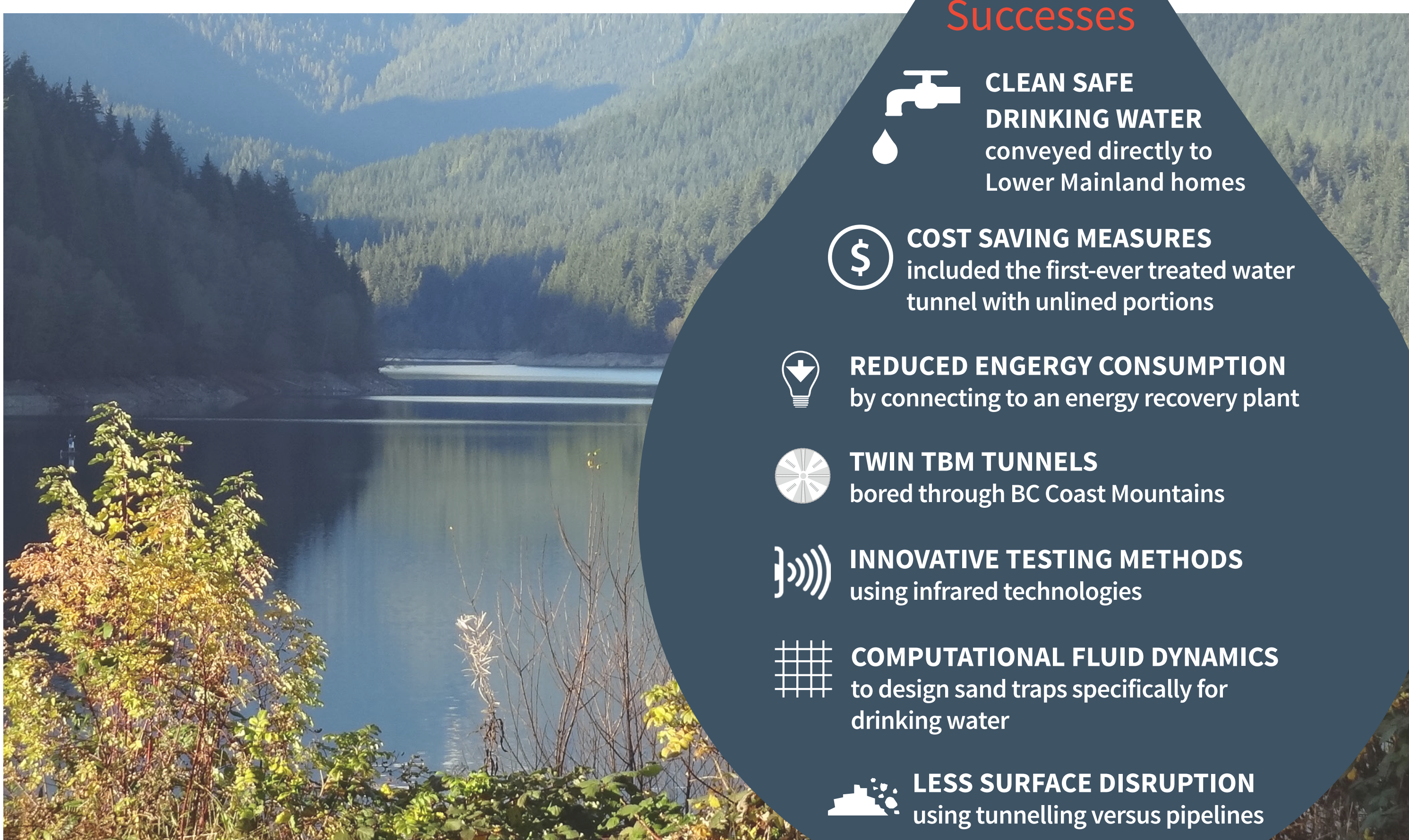
Environmental Benefits

Conserving Precious Energy

The Seymour-Capilano Twin Tunnels are part of a larger water program that seeks to supply water in the most efficient, economical, and sustainable manner. Sustainability is a cornerstone of both Metro Vancouver and Hatch's project delivery approach; this philosophy was prevalent throughout the project, as all project team members looked for opportunities to do the work sustainably and to the benefit of the Lower Mainland communities.

Energy conservation was a key priority for the project. The tunnels were designed to connect to an energy recovery facility (designed by others) at Capilano, which then offset energy used to pump water up to the Seymour-Capilano Filtration Plant. This strategy is estimated to generate 9.6 GW hours of electricity per year—the equivalent energy to power approximately 1,000 homes.

Water treatment plant to treat tunnel construction water before discharging into fish-bearing watercourse.



Project Successes

CLEAN SAFE DRINKING WATER conveyed directly to Lower Mainland homes

COST SAVING MEASURES included the first-ever treated water tunnel with unlined portions

REDUCED ENGERGY CONSUMPTION by connecting to an energy recovery plant

TWIN TBM TUNNELS bored through BC Coast Mountains

INNOVATIVE TESTING METHODS using infrared technologies

COMPUTATIONAL FLUID DYNAMICS to design sand traps specifically for drinking water

LESS SURFACE DISRUPTION using tunnelling versus pipelines

Meeting the Client's Needs

Communities across the Lower Mainland enjoy clean, safe drinking water treated through Metro Vancouver's modern, world-class water treatment facilities. Committed to provide clean safe drinking water, sustainably using resources, and ensuring the efficient supply of water, Metro Vancouver has successfully embarked on a water quality improvement program to ensure an abundant supply of safe, world-class drinking water for future generations in the region.

The Seymour-Capilano Twin Tunnels play an important part of this larger water treatment plan for Lower Mainland residents. As part of the larger Seymour-Capilano Filtration Project, the twin tunnels connect the Capilano source to the new, state-of-the-art Seymour-Capilano Filtration Plant, which is capable of treating up to 1.8 billion L/day of drinking water using a combination of filtration and UV disinfection methods.

The twin tunnels were designed with future generations and Metro Vancouver's long-term goals in mind. Flexibility was key—built into the tunnel design was the potential to change the direction of flow in one of the tunnels. This forethought in design will enable an uninterrupted supply of water from the Seymour-Capilano Filtration Plant should a tunnel be taken out of service for maintenance. As well, British Columbia's high seismic risk required the Hatch team to design the shafts and tunnels based on the maximum credible earthquake seismic event.

The first treated water to come out of the tunnels on March 12, 2015.