SEYMOUR-CAPILANO WATER FILTRATION PROJECT
STEEL - THE PRODUCT OF CHOICE

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1.0 ABSTRACT

The Greater Vancouver Water District (GVWD) is constructing the $600 million Seymour-Capilano water filtration project to enhance drinking water quality in the Vancouver metropolitan area. The project comprises the Seymour-Capilano Filtration Plant, the Capilano Pumping Station, the Twin Tunnels with associated shafts and the Capilano Break Head Tank/Energy Recovery Facility. The Twin Tunnels will convey untreated, raw water under pressure from the Capilano Reservoir to the Seymour-Capilano Filtration Plant and return treated water for distribution to the member municipalities. The tunnel system comprises twin 3.7 meter diameter tunnels approximately 7.2 km in length, the 11 meter diameter, 180 meter deep Seymour shaft as the main launch shaft, and two 4 meter diameter, 268 meter deep raisebore exit shafts at Capilano.

Among the numerous complexities of a project of this scope was the selection of pipe materials, including the lined Twin Tunnels portion of the project. Steel pipe was the only tunnel lining material, of several that were considered, that offered the required combination of being completely water tight at the high water pressures associated with this application, capable of resisting the buckling loads, providing seismic properties required and providing acceptable constructability. The GVWD also has a long history and good experience of using steel pipe as the transmission water main material of choice. These items and high seismic design standard led the GVWD to select steel pipe for use on the Seymour-Capilano filtration project.

Project construction commenced in 2003 and is expected to be complete by the end of 2008. Once completed, the GVWD will reliably deliver water of quality in full compliance with the Canadian Drinking Water Quality Guidelines and the Provincial Drinking Water Protection Regulation.

2.0 INTRODUCTION

The GVWD is a wholesale drinking water supplier, providing water to approximately 2 million people in 18 municipalities in the Lower Mainland, British Columbia, Canada. The total land area of the system is over 2000 square kilometers, excluding the watersheds.

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The water is collected from the rainwater and snowmelt that falls on the mountains of the Capilano, Seymour and Coquitlam watersheds, a 585 square kilometer area where access is strictly controlled in order to safeguard the quality and security of the supply. The water is held in six mountain storage lakes and distributed to communities through a network of dams, pumping stations, service reservoirs, and transmission mains, as shown in Figure 1.

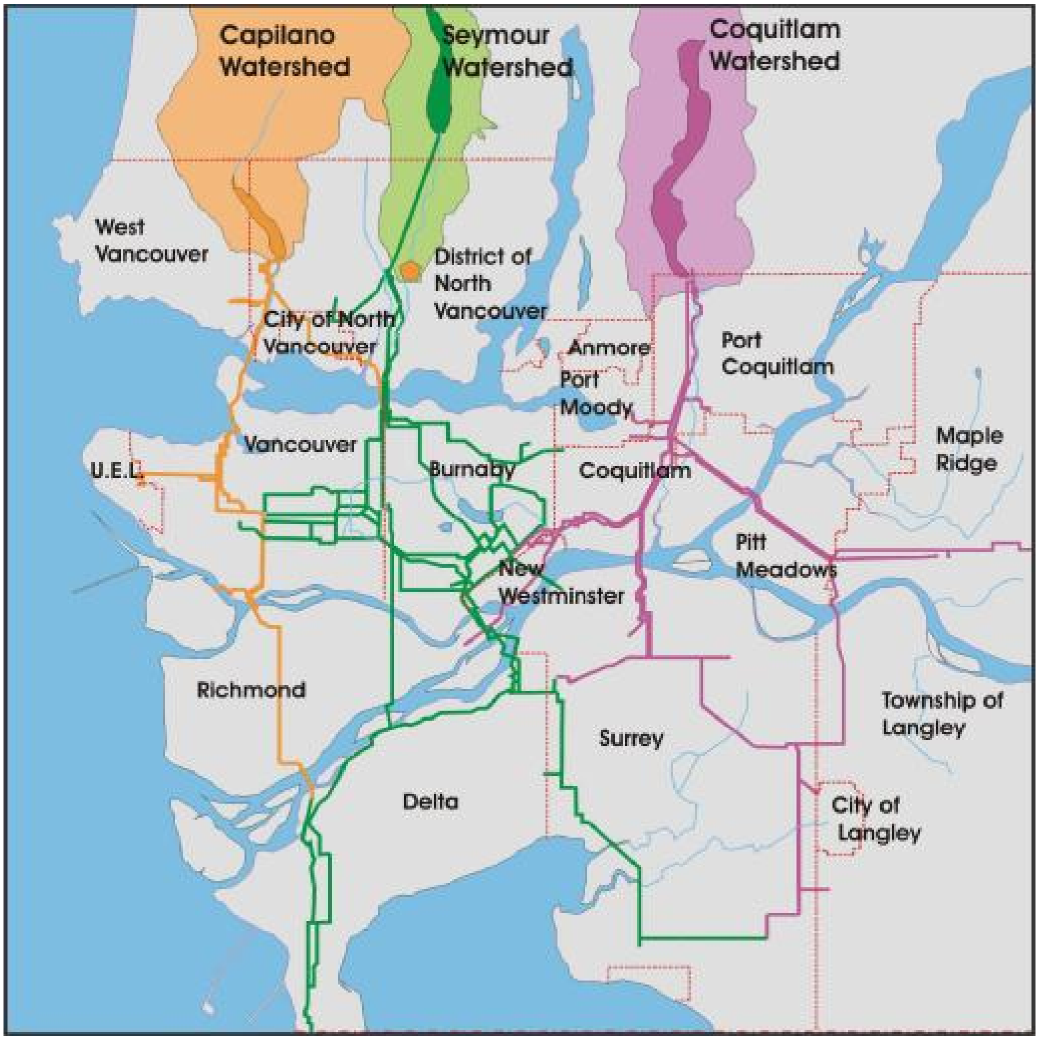


Figure 1. GVWD distribution system

The GVWD is a partnership of municipalities, and as such, the regional water system is in effect owned by the member municipalities. It is operated on a not-for-profit basis, with water delivered to all members at the same rate of 34.80 cents per 1,000 litres (2007 rate). The members, in turn, are responsible for distribution to consumers within their borders. The rate charged to consumers (residential, commercial, industrial, etc.) is determined by each municipality.

An overview of the GVWD and municipal water system is presented is presented in Table 1.

Table 1
The System at a Glance

First water main constructed	1889
Population served	2 million
Municipalities served	18
Distribution system, land area	Over 2,000 square kilometres
Watershed area	585 square kilometers
Dams	6
Storage lakes	6
GVWD reservoirs	22
GVWD pumping stations	15
Supply and transmission mains	Over 500 kilometres (300 mi)
Municipal distribution mains	Over 7,500 kilometres (4660 mi)
Average daily consumption (2004)	1.2 billion litres (317 million gallons)
Record one-day consumption (July 30, 1990)	2 billion litres (528 million gallons)
Cost of water to municipalities (2007)	34.80 cents per 1,000 litres (.13 cents per gallon)
Approximate average municipal water rate (2007)	$160 per household per year
Value of GVWD assets	Over $2 billion

The GVWD has a long history of design and construction of steel pipelines. The existing GVWD water main pipe summary is shown in Table 2. This summary confirms the GVWD preference to use steel pipe in its systems. Over the years, a wealth of practical design and construction experience has been developed. In the early 1960's, the original design engineering standard was established to provide a reference for GVWD pipeline designers.

Table 2
GVWD Water Mains – Pipe Length (km)

Age / Pipe	0-24 years	25-49 years	50-74 years	75-99 years	>100 years	Total	Size mm (inch)
AC		3				3	300-1050mm (12-42 inch)
Cast Iron			1			1	<450 mm (<18 inch)
Ductile Iron	3					3	600 mm (24 inch)
PVC	1	1				2	<400 mm (<16 inch)
Steel	137	194	93	32		456	600 -2400 mm (24-96 inch)
Stainless Steel	1					1	3000 mm (120 inch)
PCCP & Cast in Place concrete	20	2	7			29	1000-1650 mm (39-66 inch)
Other	3	3				6	<300 mm (<12 inch)
System static pressure varies 700-2300 kPa (100-330 psi)						Approx. 500 km	

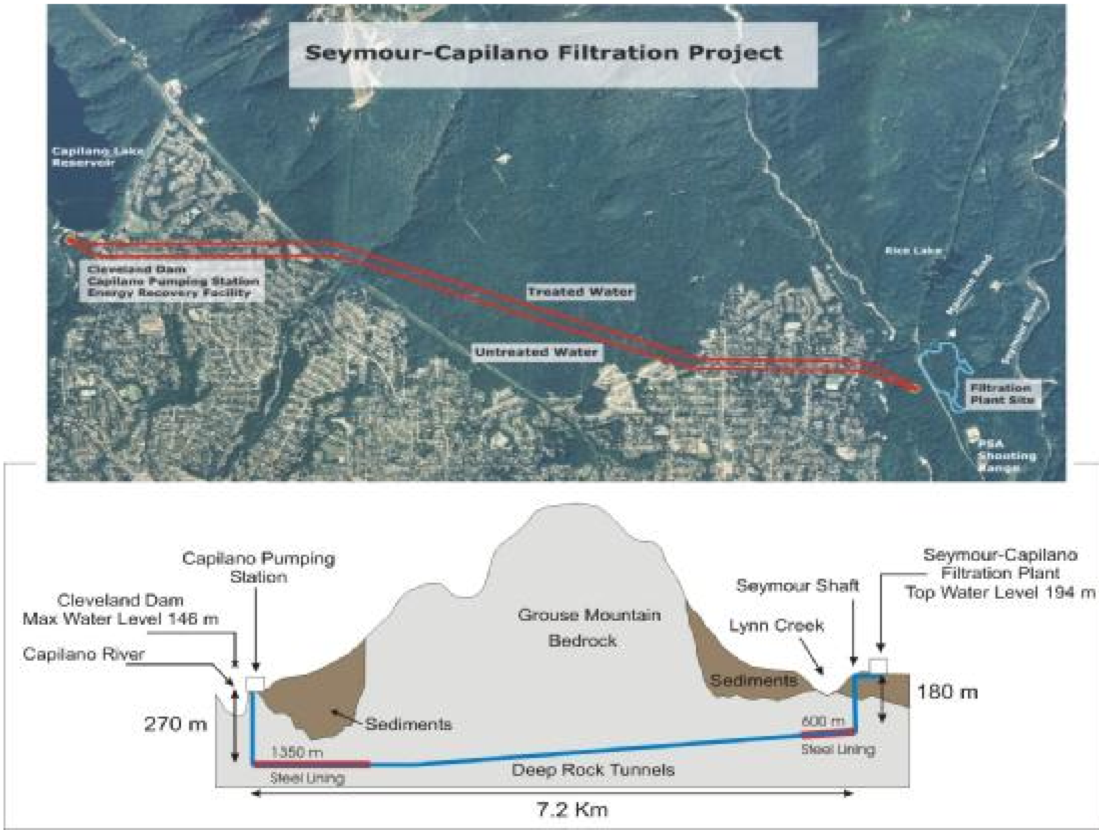
3.0 FILTRATION PROJECT COMPONENTS

Greater Vancouver's water system – which had its beginnings in the late 1880s as a single main from the Capilano River to downtown Vancouver – has grown to become a network of highly complex infrastructure.

An extensive program is currently underway to upgrade water supply and treatment facilities over the next decade to meet water quality standards and the needs of an expanding population. Waters from the Capilano and Seymour sources provide about 70% of the region's drinking water.

Filtration of the Seymour and Capilano water sources will provide significant benefits to the region. In addition to improving drinking water by removing microorganisms, organics, and silts and clays caused by heavy rainfall, filtration and UV primary disinfection reduces the amount of chlorine required to maintain water quality.

The Seymour-Capilano Filtration Project, which will filter up to 1,800 million litres of water per day from the Seymour and Capilano sources, includes the following facilities:



3.1 Seymour-Capilano Filtration Plant

The plant, with UV disinfection and clearwells (reservoirs), will be located in the Lower Seymour Conservation Reserve, a natural area south of the Seymour Falls Dam.

The facility will treat raw water through the processes of flocculation, direct filtration, UV primary disinfection, chlorine secondary disinfection and corrosion control. It is expected to be the largest filtration plant in Canada and the largest UV disinfection plant in North America until the planned New York City plant is operational in 2010.

3.2 Capilano Pumping Station

The 16,000 hp Capilano Pumping Station is located in the Capilano River Regional Park immediately below the Cleveland Dam and east of the Capilano River. The station will pump Capilano water to the filtration plant site through one of the tunnels.

3.3 Twin Tunnels

Twin Tunnels, each 7.2 km long and approximately 3.8 m in diameter, will be located approximately 130-640 m underground in bedrock and will convey water between the Seymour and Capilano sites. One tunnel will deliver raw water from the Capilano Reservoir via the pumping station to the filtration plant for treatment, and the second tunnel will convey the treated water by gravity from the plant back to the Capilano distribution area. The tunnels are being constructed by two tunnel boring machines and will pass beneath the slopes of Grouse Mountain and Mount Fromme.

The quality of the rock that the tunnels will be bored through is expected to be sound, such that only a portion (up to 2 km in each tunnel) is expected to require steel lining. The tunnels are being constructed from a single shaft on the Seymour end, with individual pipe risers connecting each of the tunnels to surface pipelines to either the filtration plant inlet or outlet of the clearwell. At the Capilano end, separate shafts will connect each tunnel to the surface piping that leads either from the pumping station or to the Energy Recovery Facility/Bread Head Tank.

3.4 Energy Recovery Facility/Break Head Tank

A 2 MW Energy Recovery Facility, to be located near the Capilano River Regional Park public parking lot, will convert excess water pressure from the return tunnel water into electrical energy for load displacement or re-introduction into the BC Hydro grid.

The break head tank, a turbine tail and pressure reducing valve water tank downstream, of the energy recovery facility, will maintain a constant (improved) pressure on the Capilano distribution system. Pipelines will connect the treated water tunnel to the energy recovery facility and break head tank, and then to the Capilano distribution piping.

4.0 STEEL PIPE – WELDING AND JOINT DESIGN

Since the early 1960s, design standards have evolved and it has become apparent that more conservative design is necessary for certain applications. For the majority of applications, the GVRD continues to tender for bell and spigot joints and completes installation through a double joint design with great success and a proven history. Butt joints are typically considered by the GVRD for those projects that have a high degree of importance/cost or are subject to extreme conditions such as marine crossings, inaccessible tunnels, and low strength soil conditions where a high degree of settlement may be expected, etc.

Issues associated with bell and spigot pipe joints fabricated prior to 1986 were first encountered at highly difficult and extreme conditions installations, specifically marine crossings. In 1986, the American Waterworks Association (AWWA) standard for steel pipe was upgraded to require bell transition radii that minimize inherent stresses. While the butt joint represents the best possible/practical joint for highly difficult water transmission applications such as river crossings, the changes associated with the AWWA standard in 1986 for bell and spigot joints has made this type of joint the most common in steel pipe installations and has a proven history.

The GVRD developed a construction method where pipe was assembled on shore and pulled through a trench dredged across the water course. All of the bell and spigot pipe joints were double welded (i.e., welded both on the inside and outside of the pipe). This double welded design was originally thought to produce a joint stronger than the pipe wall. However, ruptures at the curve in the bell during the installation and initial pressure testing of some river crossings constructed prior to 1986, indicated that the processes to manufacture the bells created additional stresses in this portion of pipe. This type of problem in part initiated the bell and spigot bell transition radii related changes to AWWA 200 and increased designers awareness and opportunity to switch to butt-welded pipe joints for most marine crossings. More recently, problems began to occur in soft soil areas of land based pipelines where significant settlements (i.e., settlements in the order of metres) resulting from construction activities of others caused failures at bell and spigot joints. Due to these problems, GVRD began re-considering the design criteria for pipe joints as well as the specified steel yield strength in these extreme conditions. Consideration of the capacity of bell and spigot joints was carried out through a number of initiatives during the mid to late 1990's. Initiatives included literature review, attendance at various conferences, discussion with other agencies, review of pipeline design codes and finite element modeling and physical testing. Revised general guidelines for the design of new facilities and upgrading of existing infrastructure are summarized in Table 3. It is suggested that designers use these recommendations as a guideline for welded steel pipeline design. Users are to recognize that there will be situations where the recommended solutions will not be appropriate and professional judgment will be necessary to develop the design.

Table 3 – Welding and Joint Design Guideline

Item	Description	Recommendations
1.	Tube turn bends	Up to 24 inch dia. – YES > 24 inch dia. – No (use only if practical/required)
2.	Fabricated max. mitre bend angle per cut	22.5° (horizontal and combined) 11.25° (vertical)
3.	Pre-fabricated bends	Not required. Use of field fabricated bends is acceptable.
4.	Pipe wall thickness	Determine using GVRD Engineering Standards, "Steel Pipe Calculations, Pipe Wall Thickness".
	a) mitres	Potential movement area subject to further

		investigation. Increase F.S. in hoop stress formula from 2.0 to 2.5 at Engineer's discretion.
	b) bell and spigot joints	Do not increase wall thickness in firm ground. See item 5 for recommendations for soft soil.
5.	Geotechnical Conditions – soft soil conditions or conditions where significant movement can be anticipated	Avoid poor ground conditions where possible during route selection, improve poor ground where feasible and cost effective, increase pipe wall thickness (by using ASME Section VIII Division Joint efficiency factors) or change joint type (from bell and spigot to butt welds) or strengthen the pipeline by increasing yield strength.
6.	a) Welding	Qualify welding procedure (WPS/PQR) and welder operator. Testing and welding defects/repair to CSA Z662 (field) and to CSA Z245 (shop).
	b) NDT	Radiograph 10% of field mitres in accordance with AWWA C206 plus all mitres at major road crossings. Radiograph 100% of butt welded joints.
7.	Pipe Hatches	GVRD "boiler" type hatch.
8.	Pulled Joints	$\text{Tan } \text{Ø} = \dfrac{\text{1.5 inch}}{\text{D}}$ (Min. 1.5 inch from the cold worked transition in the bell, min. 1 inch overlap or 3 x t whichever is greater) (based on 4 inch flat bell)
9.	Skewed Joints	Avoid Skew Joints. Use mitre cuts.
10.	Bell and Spigot Tolerances	5/64 inch (2 mm) all around max., gap, equally spaced. 2/64 inch (0.8 mm) all around min., gap, equally spaced.

5.0 SEISMIC DESIGN CRITERIA

The Greater Vancouver Regional District owns, operates and maintains the large-scale systems for storing, treating, and supplying potable water and for collecting, conveying, and treating wastewater and as such, it provides an essential service.

These systems are expected to survive a moderate earthquake with minimal disruption and a severe earthquake with manageable disruptions. GVRD standardized the seismic criteria to which all new and remedial works are to be designed. The Seismic Design Criteria have been established based on the District's post disaster operating objectives and review of the public safety consequences of failure for each facility.

The seismic design criteria are provided as a guide for the designer and are to be considered as desired levels of seismic resistance rather than absolute minimum requirements. When designing new facilities or upgrading existing facilities, the cost of meeting the seismic design criteria must be weighed against the importance of the facility for system operation (i.e. redundancy in the system), and any life safety issues associated with damage to the facility. The table below presents the facility class and the expected performance levels for the NBCC and MCE levels of earthquake.

FACILITY	**NBCC 1:2475 Return Period**	**MCE 1:10000 Return Period**
Dams	IO	LS
Water Treatment Plants	IO	LS
Wastewater Treatment Plants	LS	-
Primary Water Disinfection Facilities	IO	LS
Secondary Water Disinfection Facilities	LS	-
Pump Stations – Level 1	IO	LS
Pump Stations – Level 2	LS	-
Pipelines[1]– Level 1	**IO**	**LS**
Pipelines[1] – Level 2	**LS**	-
Segmental Pipe [2]	LS	-
Chambers and Portals - Level 1	IO	LS
Chambers and Portals – Level 2	LS	-
Reservoirs – Level 1	IO	LS
Reservoirs – Level 2	LS	-
Ancillary Structures	CP	-

1) High pressure continuously bonded pipes such as welded steel, polyethylene or flanged steel.
2) Consult with pipe manufacturer on the recommended allowable deflection at the joint.

NBCC The National Building Code of Canada provides an Earthquake spectrum, which can be used for analytical modeling.

MCE The "Maximum Credible Earthquake" is site specific. The MCE design level is only appropriate for those facilities that present a high hazard to properties and life.

Level 1 Facility is critical to system operations, has little or no redundancy, and may result in substantially reduced service for an extended period (months) if failure occurs. This level includes pipelines for marine crossings.

Level 2 Facility is important to the system operations, however some level of redundancy exists, service will only be marginally impacted for a limited period (days to weeks) if failure occurs.

IO Immediate Occupancy, no damage
LS Life Safety, minor damage, operational at full capacity, repair duration 2 months
CP Collapse Prevention, moderate damage, operational at less than full capacity, repair duration 6 months

The summary table below gives the applicable category, according to the GVRD Seismic Design Criteria Engineering Standard, for each for the major project areas.

Project Element	Level	NBCC 1:2475	MCE 1:10,000
Filtration Plant	n/a	IO	LS
Capilano Pumping Station	1	IO	LS
Pipeline	1	IO	LS
Energy Recovery Facility/Break Head Tank	1	IO	LS
Twin Tunnels	1	IO	LS

6.0 STEEL THE PRODUCT OF CHOICE

6.1 <u>Design Considerations</u>

- Geotechnical
- Tunnel diameter
- Pipe diameter
- Internal pressure
- External pressure
- Cost
- Water quality
- Infiltration
- Exfiltration
- Raw water/treated water tunnel cross flow
- Future dewatering
- Seismic
- Social

- Environmental

Construction Considerations
- Pipe wall thickness and weight
- Pipe lengths
- Joint connection
- Corrosion protection
- Needs for mitering of tunnel liner
- Fittings and specials

Operation/Maintenance Considerations
- Reliability
- Consequences of failure
- The ease and convenience of operation and maintenance

6.2 Surface Pipe Selection

From evaluation of the items identified to be significant to the GVRD's needs, steel pipe meeting the requirements of AWWA C200 standard was chosen as the preferred pipe for this project. While all the considerations listed were assessed, the primary reasons for the GVRD to choose steel pipe were as follows:
- pipe diameter (2.7 m to 3.0 m)
- seismic performance
- long term service history for potable steel watermains in GVRD system
- design consultant and GVRD engineering/operation experience related to steel pipe

6.3 Tunnel Steel Linings Selections

The hydraulic grade line for both the raw and treated water tunnels is higher than the elevation of the surface topography at both ends of the tunnel alignment. These therefore represent sections of the twin tunnels where leakage may occur. Excessive leakage of both raw and treated water is undesirable and, in addition, such leakage could pressurize the overburden above the tunnels with various undesirable effects. The commonly adopted solution in pressure tunnel design for the prevention of leakage is the installation of steel linings. Reinforced concrete and membrane type lining solutions were reviewed and considered but were not determined as a preferred lining for these small diameter tunnels based on considerations noted above.

The design length of steel linings at both ends of the tunnel alignment has been based on consideration of preventing hydraulic jacking and preventing cross flow between the tunnels at their terminus. Since the hydro-jacking testing results indicated stress levels equivalent to the overburden, the concern was primarily of reducing small expected leakage during operations to control the pore water pressure and insure the surface slope stability.

Design of the steel liner closely followed ASCE 79 wherever possible. Liners in the shafts and tunnels were sized for the governing condition of a future dewatering event, i.e. external pressure on an empty pipeline, which primarily drove liner thickness. Although internal pressure did not specifically factor into thickness selection, hoop stresses for a design internal pressure of static head plus surge were checked to ensure values were within the allowable limits prescribed in ASCE 79.

Allowable hoop stresses were evaluated using criteria found in ASCE 79 and AWWA M11, with ASCE 79 being the more stringent of the two codes. The shaft and tunnel steel liner will be 3 m diameter with the pipe wall thickness between 12 mm and 34 mm.

a) <u>Seymour Section</u>

The maximum differential outward pressure at the Seymour (eastern) end of the tunnel alignment is about 70 m of water. Lining is therefore required along this section to prevent leakage and impacts to any existing surface structures/slopes. The length of steel lining required at the Seymour end of the alignment is approximately 600 m. This has been based on extending the steel lining beneath Lynn Canyon, where a major fault/shear is inferred to be present, to beyond the crest of a natural overburden slope along which residential housing is located. The steel lining along this section of the tunnel alignment has been designed for full hydrostatic loading of about 150 m of water upon dewatering of the tunnels.

b) <u>Capilano Section</u>

The maximum differential outward pressure at the Capilano (western) end of the tunnel alignment is about 60 m of water and therefore lining is also required along this section, both to prevent leakage and to prevent any possible effects on the east abutment of the Cleveland Dam. At the Capilano end of the tunnel alignment the length of steel linings required is approximately 1200 m. This has been based on extending the steel linings eastwards to the location where the hydraulic grade line intersects the groundwater table, beyond which leakage is theoretically impossible. A key requirement is that the tunnels must have no effect on the groundwater pressures in the east abutment of the Cleveland Dam. This length of steel lining extends eastwards across a major inferred fault/shear zone associated with Capilano buried glacial valley. The length and cost of the installation of steel lining at the Capilano end of the tunnel alignment is significant to the Twin Tunnels Project. The steel lining along this section of the tunnel alignment has been designed for full hydrostatic loading of about 305 m of groundwater upon dewatering of the tunnels.

c) <u>Middle Sections</u>

The underground water table in the middle section is higher than the operating tunnel hydraulic grade line, the small leakage is not a concern and the tunnel liner is not required for this purpose.

Also, the potential for metals/minerals to leach into the drinking water supply from the exposed rock in the unlined tunnel section was reviewed. The following is the summary of our review:

1. Preliminary results of exploratory drilling from the ground surface in 2004 before tunnel construction began indicated that there was little or no potential for minerals to leach into water sampled from test bore holes.
2. To date only the Seymour shaft section of rock has been excavated and tested. Testing of the shaft rock to date for leachability potential into water has found no metal concentrations of health concern when compared with the Guidelines for Canadian Drinking Water Quality.
3. As the tunnel boring continues, the excavated rock will be tested on a regular basis, such that where tunnel rock walls are exposed to drinking water (approximately 5 km per tunnel), the potential for leaching of metals/minerals into the drinking water will be determined.
4. Based on the shaft rock results, the potential for leaching of metal/minerals from the unlined tunnel section is believed to be very low (i.e. negligible).

Considering the above noted, the tunnel liner in the middle section will most likely not be required.

d) <u>Shafts</u>

On completion of the steel lining in the tunnels, the 3 m diameter Capilano shafts will be steel lined throughout their depth. Towards the end of construction, the Seymour shaft will be backfilled and, at the same time, two steel riser pipes will be installed within the shaft. At both the Seymour and Capilano ends of the Twin Tunnels short surface pipelines will connect the shaft risers to other surface facilities.

References:

1) *GVRD Engineering Standards*
   - *Seismic design consideration*
   - *Steel pipe – welding and joint design*

2) *Seymour Capilano Filtration: D. Neden, M. Ferguson, G. Oljaca – Innovation March 2003*
3) *The Seymour Capilano Twin Tunnels Project, D. Brox, B. Garrod, T. Morrison, A. Saltis*