HIGHGATE 300

20-Jun-07

Total project cost, millions $CAN.

150.9

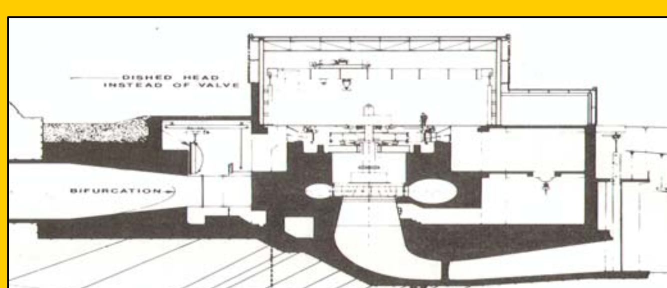
INCREMENTAL COST OF POWER FACILITIES, INCLUDING ALL EQUIPMENT

Powerplant design rated flow in m3/s.

300.00

Powerplant output at rated head and flow, MW.

114.0



Power conduit and powerhouse generation, costs and dimensions developed with HydroHelp 2 Francis.
An EXCEL program for optimizing hydro powerhouse capacity and conduit size.

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22nd June, 2007

HIGHGATE DAM HYDROELECTRIC PROJECT

Dear Dr. Bender,

I am attaching a final draft of the Highgate report, in a format such that it can be attached to your report as an appendix.

No references have been made to the project hydrology, since it is understood that Golder Associates will be undertaking this work.

Please advise whether it is suitable. If further data on the project is required, or clarification of the work is needed, please email or call. I am available to discuss the draft at your convenience.

Sincerely,

J. L. Gordon.

1. Introduction.

The Highgate Dam project is a proposed water storage development on the North Saskatchewan River. The project concept was outlined by the Prairie Farmland Rehabilitation Association (PFRA), in a report titled “Highgate Dam Investigations, North Saskatchewan River” dated August 1970. This report comprises a pre-feasibility assessment of the cost of adding power facilities to the development.

2. Project concept.

Location. Google Earth – 52-52-27.39N 108-24-24.55W El. 1525ft.

The storage project. As developed by the PFRA, the project comprises the following structures:-

- A large embankment dam with a crest at El 520.4m (1707ft), about 55m above river level.
- A seven-gated spillway structure on the left bank, capable of discharging 7,740m^3/s, with the water level 0.3m below dam crest, followed by an 860m long concrete-lined spillway chute down to river level.
- Three low level outlets, each 6.1m (20ft.) in diameter, equipped with control gates. The outlets would consist of concrete pipes through the overburden and concrete lined tunnels bored into the left embankment where the rock cover is adequate. The pipe-tunnel outlets would also serve as the diversion conduits during construction of the dam. Total length of the conduits, from intake to outlet would be about 1,630m.

The power facilities. The addition of a powerplant would make use of two of the low level outlets, retaining one outlet for riparian water release when the generating units were out of service, and the reservoir water level was below the spillway sill.

Since the outlets are used during river diversion, construction of the powerhouse, located at the downstream end of two of the outlets, would only commence after completion of the dam and spillway structures. This would require dewatering the powerplant area, and to facilitate this, the two downstream outlets (#2 and #3) would be moved slightly downstream and away from the remaining outlet (#1), to allow the construction of a sheet-pile cellular cofferdam around the powerplant footprint. Specifically, changes to the dam design required by the addition of the powerplant would be:-

- The separation between Outlet #1 and #2, would be increased to about 25m.
- The stilling basin at Outlets #2 and #3 would be changed to conform to the underside of the powerhouse, as shown in Figure 3. This requires lowering of the concrete slab from El. 460.4m to a stepped structure with bottom at El. 446.6m, followed by an armored sloping tailrace excavation up to river bottom level.

- The elevation of the centerline of Outlets #2 and #3 would be lowered by 6.0m to match the elevation of the turbine spiral casings at about El. 460m.
- The centerline of the outlet pipes at the gate control structure is at El. 462m. In effect, this means that for two outlets, the discharge pipe centerline at the control gate would slope upwards at a flatter grade.
- A powerhouse access road would be required on the downstream face of the dam, with a ramp across the remaining low level outlet at El 474m (El 1,555ft.) to reach the powerhouse repair bay floor level at El 475.4m. (Figure 3)
- The addition of some steel lining within the two low level outlet pipes, to accommodate the increased internal pressure imposed by the turbines.

The power project design assumes the prior existence of the foregoing facilities. The power cost includes the extra excavation work at the two outlets for the lower stilling basin, and the extra cost of the steel lining in two conduits. Various options are costed. However, the base case is for a plant flow of 300m^3/s, with relief valves on Francis turbines, as at Gardiner Dam.

3. Turbine hydraulics.

Turbine design flow. The average annual flow in the North Saskatchewan River at Battleford is 200m^3/s. With 20ft = 6.097m diameter conduits, it was decided to try for an installation as large as possible, bearing in mind the flow limits imposed by the conduits. A rule of thumb, is that the penstock diameter for a low to medium head hydraulic turbine should be about 1.4 times the runner throat diameter. This would produce a runner diameter of around 6.097/1.4 = 4.355m. Also, the throat velocity in such a turbine is around 10.0m/s. This produces a design flow through the turbine of 149m^3/s. This flow was rounded off to 150m^3/s. Hence flow in 2 units would be 300m^3/s, comfortably above the average annual flow. To allow for variations, design flows 11% above and below this flow were also selected, producing a flow range of 333m^3/s, 300m^3/s and 267m^3/s.

Reservoir operating levels. The reservoir low supply level used in the PFRA report is at El. 1590ft for a nominal 100ft of drawdown. For this report a low supply level has been assumed at El. 505.2m for a nominal drawdown of 10m below the full supply level of El 515.2m. This small drawdown permits the use of Francis turbines. Increasing the drawdown will not affect the power cost significantly. However, if the drawdown is increased to more than about 15m, it would be preferable to install Kaplan turbines, as discussed in more detail later. The turbines were rated at the 1/3 reservoir drawdown level, a normal criterion where detailed reservoir operating data is not available.

Tailwater levels. The PFRA report does not provide any water levels in the river. For this report, the tailwater level at turbine flow has been assumed equal to the Google Earth level of 464.9m (1,525ft). Extreme flood level was assumed to be 10.0m higher, based on the tailwater increase at flood, for the downstream development at Nipawin. (Reference – Dobson, F. J. and Pashniak, D. A. “Nipawin Hydroelectric Project” CANCOLD, Saskatoon, June 18, 1984.)

Surge tank. The long conduit, with a length to head ratio of almost 36, will require the inclusion of either surge tanks or relief valves to mitigate conduit surges. If surge tanks are used, the two steel orifice type surge tanks will be located about 200m upstream of the powerhouse, within the dam downstream toe berms, connected to the conduits with a vertical riser pipe. Waterhammer and surge allowance would be 45% positive and 35% negative. For a flow of 150m^3/s in each conduit, the tank diameter would be 27m, with the spring line at El. 499.6m and roof at El. 522.9m. Upsurge would be just less than 10% of turbine net head, a reasonable amount. Surge tanks are expensive, see Table 7.

Relief valve option. If powerplant operation isolated from the grid, and "black start" is not a requirement, the turbines could be equipped with relief valves, as at the Gardiner Dam. Relief valves are used in the base case.

Waterhammer. The conduit waterhammer allowance is for a positive 25% and negative 15% values, the usual design parameters for turbines equipped with relief valves.

4. Turbine and generator.

Kaplan option. If reservoir drawdown is more than about 15m, Kaplan units would be required to accommodate the variation is flow and head. Two Kaplan units would add between $13 and $16 million to the cost, as shown in Table 7, but would contribute more energy due to the flat efficiency curve and the larger storage volume in the reservoir. Francis units are retained for the base case scenario.

Generator inertia and system regulation. Assuming that surge tanks are included in the design, the powerplant could operate isolated from the system, supplying a local load if the generator inertia is increased to a value of H = 5.2. The extra cost would be about $17 million, including the extra costs associated with a larger and heavier generator rotor. A normal generator inertia is used in all cases. Unit characteristics are shown in Table 1.

Rated flow per unit, m^3/s.	166.5	150	133.5
Total installed capacity, MW.	124.4	114.0	102.8
Rotational speed, rpm.	128.6	138.5	150.0
Peak turbine efficiency, %.	94.1	94.0	93.9
Generator efficiency, %.	98.0	98.0	98.0
Conduit head loss, %	10.4	8.4	6.7
Generator inertia, "H" value.	2.25	2.22	2.18
Generator casing diameter, m.	11.4	10.7	10.0
Peak efficiency flow, m^3/s.	141.4	127.4	113.3
Runner throat diameter, m.	4.432	4.207	3.969
Turbine casing inlet diameter, m.	5.71	5.39	5.07
Relief valve diameter, m.	4.09	3.85	3.61
Turbine casing centerline elev. m.	462.01	461.95	461.89

Table 1.
Turbine and generator characteristics.

Powerplant efficiency. The estimated efficiency curve for the base case Francis turbine is shown in Figure 1, and the overall plant efficiency, including the conduit, turbine, and generator is shown in Figure 2. Conduit head loss at rated turbine flow of 150m^3/s is estimated at 8.4%, on the high side for such a development.

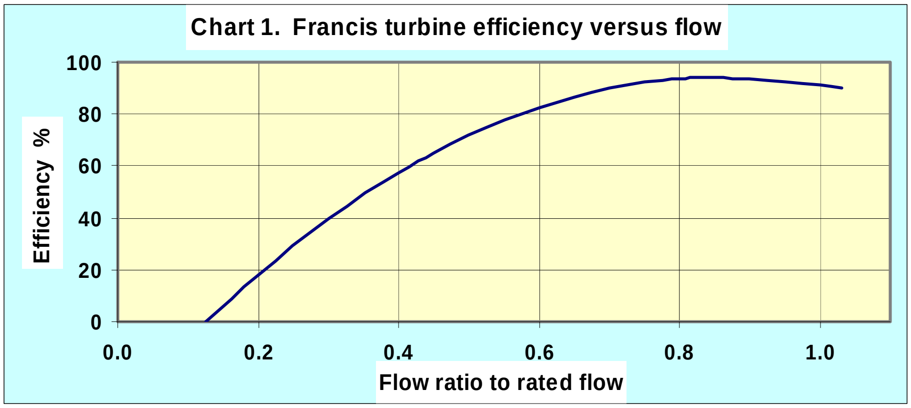


Figure 1.

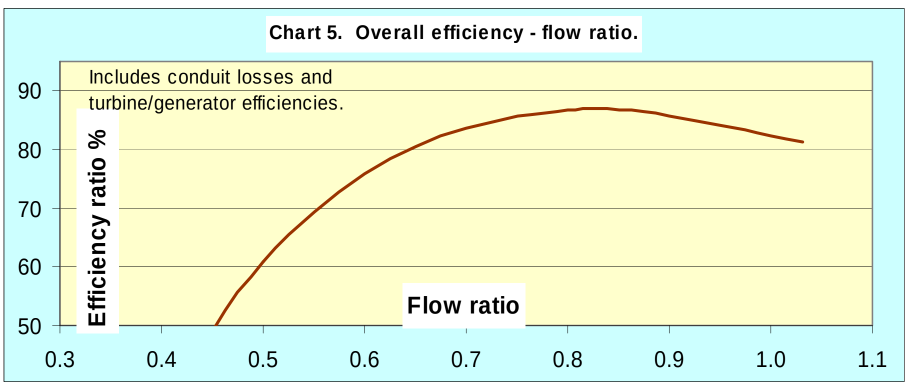


Figure 2.

5. Powerhouse.

The powerhouse would be built within the stilling basin at two of the outlets. Dewatering of the area would require the construction of a sheet steel pile cellular cofferdam in a broad U-shape plan. Cofferdam height would be about 20m, with the crest at about El. 469m. Cofferdam crest length would be about 160m. Data on the powerhouse is included in Table 2, and a section through the base case powerhouse is included in Figure 3.

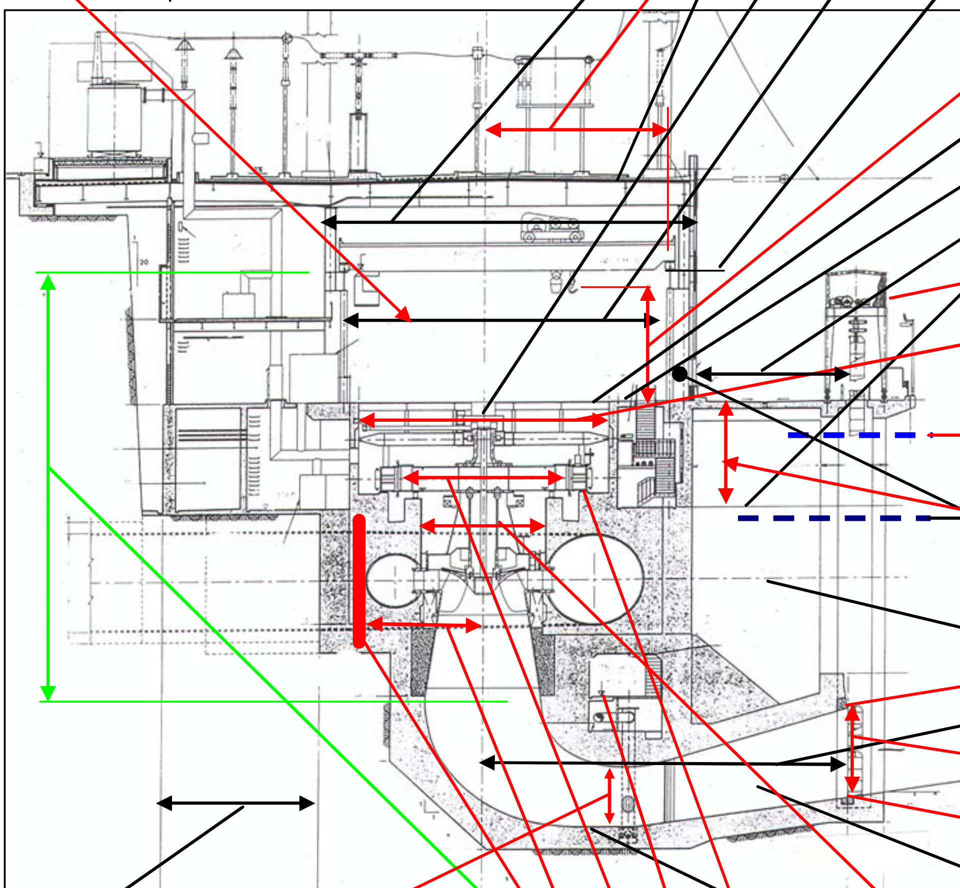
		Base case	
Powerplant flow m^3/s.	333	**300**	267
Powerhouse length, m.	61.4	**58.6**	55.6
Powerhouse height to roof, m.	39.7	**38.4**	37.1
Crane capacity, tones.	213.4	**194.6**	175.1
Concrete volume, m^3.	19,290	**17,180**	15,090

Table 2.
Powerhouse characteristics.

HIGHGATE 300

Figure 6. Section through large vertical axis francis unit. Runner diameter larger than about 1.8m. More than one draft tube gate per unit.

Generator capacity, MVA. **63.3**
Powerhouse width, m. 16.20 EL. Crane rail
Distance unit centerline to downstream crane rail, m 7.36 482.851
Elevation of roof. 486.53
Minimum elevation of top of generator, m. 471.83 Crane span 14.73
Note:- crane span will increase to cover valve if needed. Crane hook clearance - 7.45



Top of Gen. El.
475.40
Repair bay El.
475.40
14.05
Turbine floor El.
465.46
482.91
Generator case
10.73
Diameter, m.
Flood TWL
474.9
Normal TWL
464.90
Column width.
0.74
Casing CL. El.
461.95
455.06
20.47
4.90
DT sill Elev.
450.16

6.27 Pier width, m. 1.45
Elevation, bottom of draft tube 448.12
Number of draft tube piers = 1
Total width of draft tube, **EXCLUDING** end piers, m. 13.18
2.99 Draft tube gate width, m. 5.87
Elevation of bottom of generator lower bracket. 468.46 *
Elevation of draft tube access gallery 456.90 Pit diam = 6.52
Elevator travel distance, m. 25.95
Distance between valve flanges, if required, m. 0.00 Valve not shown.
Min distance downstream valve flange to unit centerline, m. 5.39 if required. Comment
Elevation of top of draft tube gantry, or elevation of monorail hoist rail, m. -----------> 482.91
Approximate generator rotor diameter, m. ------- > 7.51 Comment
* Drawing shows generator thrust bearing mounted on cone from turbine, and no lower bracket.

Figure 3.
Section through powerhouse.

6. Cost estimate.

A cost summary for the three alternatives is provided in Table 3. The costs are developed by the HydroHelp 2 program, based on the following assumptions:-

- Use of union labor.
- Design standard to “Utility” quality – the highest (supervision of site work along with inspection/documentation/testing of equipment supply and installation).
- The continued use of contractor equipment provided for dam construction.
- Frost days at site = 210. From WeatherCanada data.

The “Utility” design standard normally adds about 15% to equipment cost, to cover the added expense for testing and inspecting materials, and documentation requirements specified by the utility. Also, there is added concrete in major structures, to provide more working space around the equipment.

The unit costs are based on statistical data from other projects, and on work quantity volume. In this instance, the costs are lower than would be the case for construction of the power facilities by themselves. It is assumed that – for example – the concrete mix plant used for dam construction will still be available for powerplant construction.

Frost days have an impact on cost. More frost implies more winter work conditions, and hence higher costs.

A cost summary for the three cases is provided in Table 3, and for alternatives in Table 7.

		Base case	
Powerplant flow, m^3/s.	333	**300**	267
Cost item.		**Costs in $M Canadian - 2007.**	
Civil work cost.	59.38	**56.56**	53.70
Electromechanical & transmission.	71.27	**65.98**	60.59
Overheads.	22.50	**21.34**	20.16
Interest during construction.	7.73	**7.01**	6.28
Total estimated cost	160.88	**150.89**	140.67
Cost per MW capacity.	1.29	**1.32**	1.37

Table 3.
Project cost summary – in $M Can, 2007.

Unit prices developed by the program, for the base case, are shown in Table 4. Unit costs for the other scenarios are very similar.

Construction time is expected to be about 24 months. Major equipment, such as the generating units would have to be ordered ahead of this time.

Powerhouse.	Cost $/unit.	Quantity.
Concrete, m3. (Excluding forms, re-bar)	534.08	17,176
Formwork, m2.	11.94	24,905
Reinforcing, kg.	7.30	1,782,980
Powerhouse superstructure steel weight, tonnes.	7,582.36	347
Wall area, m2.	129.28	1,666
Roof area, m2.	161.16	1,308
Tailrace overburden excavation cost. (m3).	8.87	49,269
Tailrace rock excavation cost. (m3).	35.49	10,362

Table 4.
Unit costs and quantities for the powerhouse – 300m^3/s flow.

For the base case, the program calculated the return on the investment as follows:-

Project screening - calculation to determine whether incremental power project worth further analysis.			
Operating staff annual manhours.	6,828		
Operating staff average wage cost, including all benefits, $/h.		80	
Annual wages and benefits, $m.	0.546		
Site revenue calculation.			
Total generation capacity --- MW.	114.0		
Calculated plant annual average load factor.	0.668		
Calculated annual generation. (GWh)	666.9		
Value of generation in cents/kWh.	5.00		
Calculated annual value of generation $(m)	33.346		
Calculated opearation & maintenance cost $(m)	1.556		
Calculated annual net revenue before taxes. $(m)			**31.790**
Estimated project payback in years, excluding taxes.			**4.7**

Table 5.
Return on investment – 300m^3/s flow case.

Staff operating hours are based on EPRI statistics. Based on this estimate, the power project is very attractive, providing a return on the investment within less than 5 years.

Costs not included in the estimate are:-

- The access road to the powerhouse across the downstream face of the dam.
- SCADA required by SaskPower to interface with the central control room. Previous experience has indicated that this is one of the most troublesome areas, since the technology is advancing very rapidly, and control engineers are having trouble keeping abreast of developments.
- Hydraulic model testing of the turbines. The turbine size is well within precedent, hence model testing is not considered to be necessary. It would add about $1.5M to the equipment cost, and increase delivery time by about 9 months.
- Special measures required to keep the powerplant and units aligned vertically, due to any differential settlements caused by the dam.
- Hydrology calculations to determine to optimum operating regime for the reservoir, including the extent of drawdown. It is anticipated that this work will be included in the dam engineering costs.

HIGHGATE 300		Estimate date	20-Jun-07
Incremental cost of power facilities, in Million of $ Can.			
Powerplant capacity, MW =	**114.0**		
Steel pipelines and penstocks.			
Pipe steel lining cost, installed, ton.		29.555	
Surge tank cost, if required.		0.000	
Sub-total pipelines and penstocks. -- >			**29.555**
Powerhouse.			
Allowance for conduit separation costs.		0.665	
Sheet steel pile cellular cofferdam, pumping.		1.319	
Concrete. (Excluding forms, re-bar)		9.173	
Formwork.		0.297	
Reinforcing.		13.009	
Powerhouse superstructure steel.		2.630	
Walls.		0.215	
Roof.		0.211	
Total powerhouse civil work cost. -- >			**26.201**
Tailrace.			
Tailrace overburden excavation cost.		0.437	
Tailrace rock excavation cost.		0.368	
Sub-total tailrace excavation work. --- >			**0.805**
Total civil work cost, millions $ --- >			**56.561**
Cost of major mechanical equipment, summary.			
Total cost of trashrack equipment.		0.984	
Total cost of draft tube gate guide and hoist equipment.		1.729	
Total cost of powerhouse crane.		0.924	
Total cost elevators.		0.496	
Total powerhouse ancilliary mechanical systems.		3.423	
Sub-total cost of major mechanical equipment, except units and valves.			**7.557**
Generating equipment and transmission.			
Transmission line cost.		3.130	
Local transmission cost (powerhouse-intake)		0.023	
Switchyard cost.		0.414	
Powerhouse station service.		0.105	
W/W cost of generating equipment, switchgear and controls.		54.750	
Sub-total cost of W/W equipment, including transmission.			**58.423**
Total electromechanical work cost, millions $ ---------------------------------- >			**65.980**
Total direct cost, millions $ -- >			**122.540**
Indirect costs.	**% of direct cost**	**Sub-total for %**	
Feasibility studies and site investigations.	2.0	56.561	1.131
Environmental work.	2.0	57.692	1.154
Detailed designs and contract documents.	4.0	58.846	2.354
Site supervision work.	6.0	61.199	3.672
Contingencies on civil and overheads.	15.0	64.871	9.731
Contingencies on electromechanical work.	5.0	65.980	3.299
Sub-total indirect costs.			**21.341**
Total project cost, millions $CAN.	**No interest**	**$143.88**	
Estimated construction time, months.	24		
Interest rate %	5.5		
Interest during construction, $M.			**7.007**
Total power facility incremental project cost, including interest during construction, $M.		**$150.89**	

Table 6.
Highgate Powerplant – 300m^3/s flow – detailed cost estimate.

7. Conclusions.

The addition of power facilities to a water storage dam constructed at Highgate, where there will be three low level outlets, two of which could be converted to power conduits, is very attractive.

The installed capacity will be limited by the size of the conduits, and this preliminary assessment indicates that the optimum capacity will be in the region of 103MW to 114MW. The conduit head loss, as a ratio of the turbine rated head, is estimated at 6.7% for the lower capacity, increasing to 8.4% at the higher capacity. Normal conduit head losses for such plants are in the range of 4% to 8%.

A cost summary for the alternatives investigated follows in Table 7. Costs include interest during construction, and relief valves capable of discharging the full turbine flow. It is expected that more detailed analysis of the conduit hydraulics will result in the use of smaller relief valves, if the effect of the intake gate chamber "surge tank" is taken into account. Note that at Gardiner Dam, the turbine relief valves can only discharge about 10% of the full turbine flow, and are called "Vernier stabilizers" instead.

Installed capacity MW	**124.4**	**114.0**	**102.8**
Turbine net head, m.	**42.55**	**43.33**	**44.03**
Powerplant flow, m^3/s.	**333**	**300**	**267**
Project configuration.	**Costs in $M Canadian - 2007.**		
Development with relief valves.	160.9	150.9	140.7
With surge tanks instead of valves.	185.5	169.4	156.1
Development with relief valves and Kaplan turbines instead of Francis.	176.9	164.5	153.6

Table 7.
Cost summary for all alternatives investigated.

Apart from the question of differential settlement at the powerhouse, there does not appear to be any obstructions to the addition of a powerplant to the development. The conduit length is such that harmonic interaction of the sound wave from the draft tube rope is not an issue, waterhammer can be controlled, and the size of the generating equipment is well within precedent.

As for differential settlement, this can be expected with the soft foundation materials at Highgate. However, measures can be taken to mitigate movements, with the use of expansion joints in the conduit as at Nipawin, and perhaps the inclusion of water balancing tanks, as at Gardiner Dam.