Design, construction and commissioning of the Deep Stream hydro-electric scheme

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Abstract

The Deep Stream hydro-electric scheme is the first green field scheme developed by TrustPower, which has a diverse range of existing hydro electric assets, most of which have been purchased since 1999. Development of the scheme in a cost-effective manner provided a number of challenges that have been successfully overcome. The paper outlines the key features of the scheme, with particular reference to risk-based decisions made during design and construction. The paper focuses on the civil aspects of the scheme and, in particular, major water retaining elements. It concludes with a discussion of the commissioning process and the value of close monitoring of performance.

1.0 Introduction

The Deep Stream hydro-electric scheme (DSH) is located in a remote area to the north of Lake Mahinerangi, which is the key storage for the existing Waipori scheme. This area comprises both tussock vegetation and highly modified pasture. In addition to DSH, which was fully commissioned in 2008, in 2011 the first stage of the Mahinerangi wind farm has been commissioned in the same area.

The scheme is a cascade arrangement that utilises a 310m head difference between an existing diversion weir and Lake Mahinerangi. Two powerhouses generating a total of 6MW have been constructed. The scheme does not involve any new water diversions and, thus, is an efficient use of an existing resource with minor adverse environment effects. The water that supplies the scheme represents approximately 15% of the inflows into the existing Waipori scheme. A locality plan is shown in Fig 1.

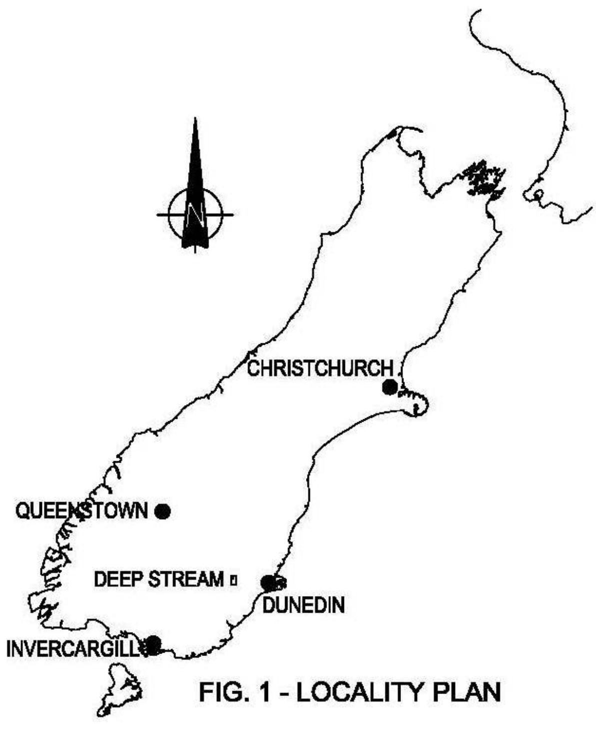

FIG. 1 - LOCALITY PLAN

2.0 Scheme Description

Figure 2 shows the scheme layout. The key civil components include an intake off the Deep Stream pipeline, approximately 8km of conveyance canals, a 1.9 million cubic metre storage reservoir, two penstocks totalling 2.9km in length, and two powerhouses. The reservoir is located on Dunedin City Council land with a long term lease arrangement, which as part of the agreement, provides drought water storage for the city. This enhancement to the city's emergency water supply was at no cost to the ratepayers. Fibreglass penstocks (GRP) were used for the scheme, which we understand is the first application of this type in New Zealand, although they are commonly used overseas. The canal design includes a number of ancillary structures including:

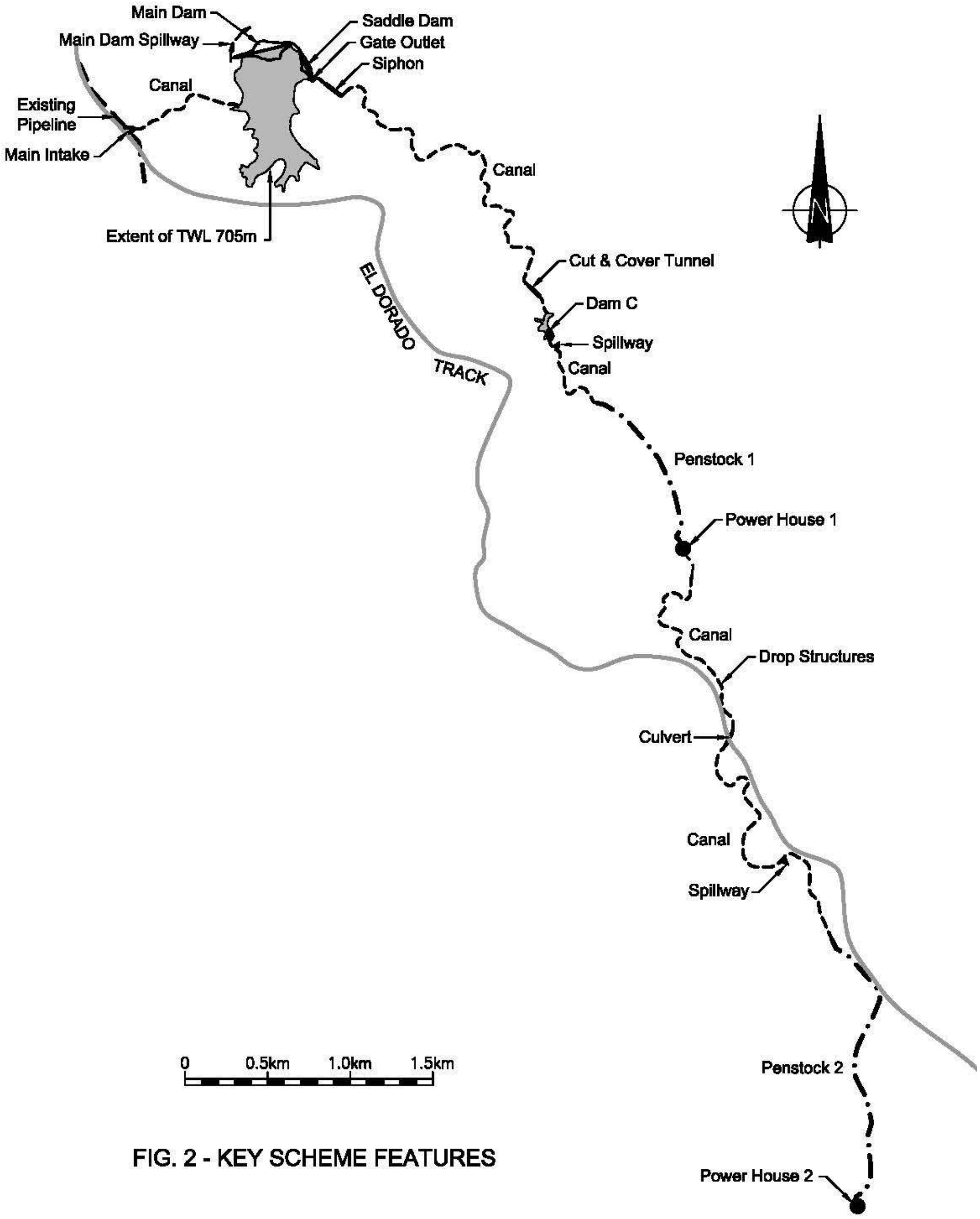

FIG. 2 - KEY SCHEME FEATURES

- A series of culverts that convey small watercourses beneath the canal.
- Two concrete lined spillways, and additional emergency spillways at strategic locations.
- A siphon across a larger stream.
- A section of cut and cover tunnel.
- A series of concrete drop structures.

The turbines for the scheme were designed and constructed in New Zealand, which was a highlight of the scheme for TrustPower. Key statistics are summarised below:

Table 1: Scheme statistics

Maximum diversion flow to lake	4.8m^3/sec
Maximum canal flow	2.5m^3/sec
Total power output	6MW
Average energy output	23GWh

As the scheme relies upon the Deep Stream diversion, which has very low summer flows, power generation is weighted to the winter and shoulder seasons, or when inflows are high. The reservoir provides approximately two days storage at peak generation flow.

3.0 Investigations and Design

3.1 Resource and Building Consents

The scheme required the usual suite of resource consents under the Resource Management Act (RMA). In comparison with more recent (and far larger) consent applications for hydro schemes the process was relatively straightforward. Consents were required from Otago Regional Council (ORC) and both Dunedin City and Clutha District Councils as the territorial local authorities. Four submissions were received, and only one opposed the application. Undoubtedly the remote location of the scheme, the lack of any new water diversion, and the unobtrusive small scale nature of the project were key factors. The Department of Conservation and Historic Places Trust were also involved throughout the planning stages to ensure that conservation and preservation of the Black Rock Scientific Reserve and historical and archaeological sites received the highest priority. In comparison, the building consent process became very complicated.

Initially, Building Consents for the various dams and structures were obtained from the territorial authorities (Dunedin City and Clutha District). This process took place prior to 2008 when, under the Building Act, jurisdiction for dams passed to regional councils. Thus when the scheme was completed there was lack of clarity as to which authority had jurisdiction for the various scheme components, and who should issue Code of Compliance. This was complicated further by the definition of an appurtenant structure to a dam, and other matters such as the exemption given by the territorial authority for penstocks. At the time of writing, a determination by the Department of Building and Housing is pending; the key task was to define which authority has jurisdiction for the various scheme components.

3.2 Civil Components

As with any small hydro scheme, the economics for the project required a cost-effective investigation and design. The design philosophy for the project followed the NZSOLD Dam Safety Guidelines and based on the Potential Impact Classification (PIC) for the various scheme components. The major civil structures were the main dam and saddle dam impounding the main reservoir (25m and 10m height dams respectively), which were designed in line with typical criteria for a medium PIC structure. The canals were low or very low PIC and were thus designed to a lower design criteria than the larger dam. Due to the significant canal lengths (8km), design of this component to, say, a medium PIC standard would have been prohibitively expensive. TrustPower commissioned an independent peer review of the main dam and saddle dam design, in line with accepted industry practice for these more significant structures. The peer review commission was carried through the construction and commissioning stages. In our experience, peer review input often does not proceed beyond the design stage. The wider brief undertaken at Deep Stream is, in our opinion, a more effective use of peer review input. This was particularly important at Deep Stream where a different perspective to the risk based decisions made by the designers added significant value, and challenged that risks were being managed appropriately.

The site geology comprises schist rock and its weathered constituents. Locally in streams soft sediments were encountered. Schist is not an ideal material for water retaining structures and several hydro schemes or major engineering works have encountered problems, particularly with slope instability.

Main Dam and Saddle Dam Design

The key design features of the major dams on the scheme included:

- A silt low permeability core with schist rockfill shoulders.
- A fully intercepting chimney drain, linking to a three layer base drainage blanket.
- A series of strip drains up the abutments.
- Founding on schist bedrock throughout.
- Open channel spillway designed for probable maximum flood (local catchment is very small 0.7km^2).

The above are usual features for a dam of this type. A typical cross section is shown as Fig 3. Some of the more contentious risk based design decisions are listed below.

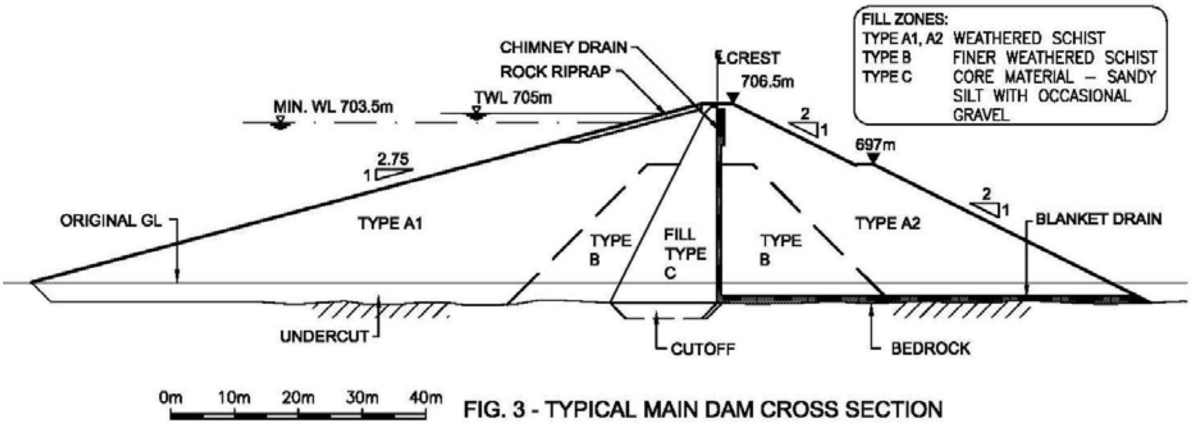

FIG. 3 - TYPICAL MAIN DAM CROSS SECTION

- The extra cost of grouting dam foundations was not considered warranted based on the permeability tests carried out in the investigation phase. It was acknowledged, however, that geological defects were present with seepage potential and grouting was included as a construction contingency.
- The foundation filter protection was not continuous, except in the valley base. Again, this was to be reconsidered when the site was fully opened up.
- A geotextile was used beneath the coarse riprap wave protection in lieu of a granular filter. This led to a considerable cost saving and was justifiable on technical grounds because any damage was readily repairable and a robust fabric was specified.
- A permanent low level outlet with the ability to fully draw down the reservoir in an emergency situation was not considered justified. Such a facility is not a requirement of NZSOLD Guidelines and some drawdown capability is available at the outlet gate.
- There was considerable debate on the earthquake strength properties of the saturated schist rockfill. Specification requirements were made more stringent to mitigate this uncertainty by a reduction in the allowable fines content.

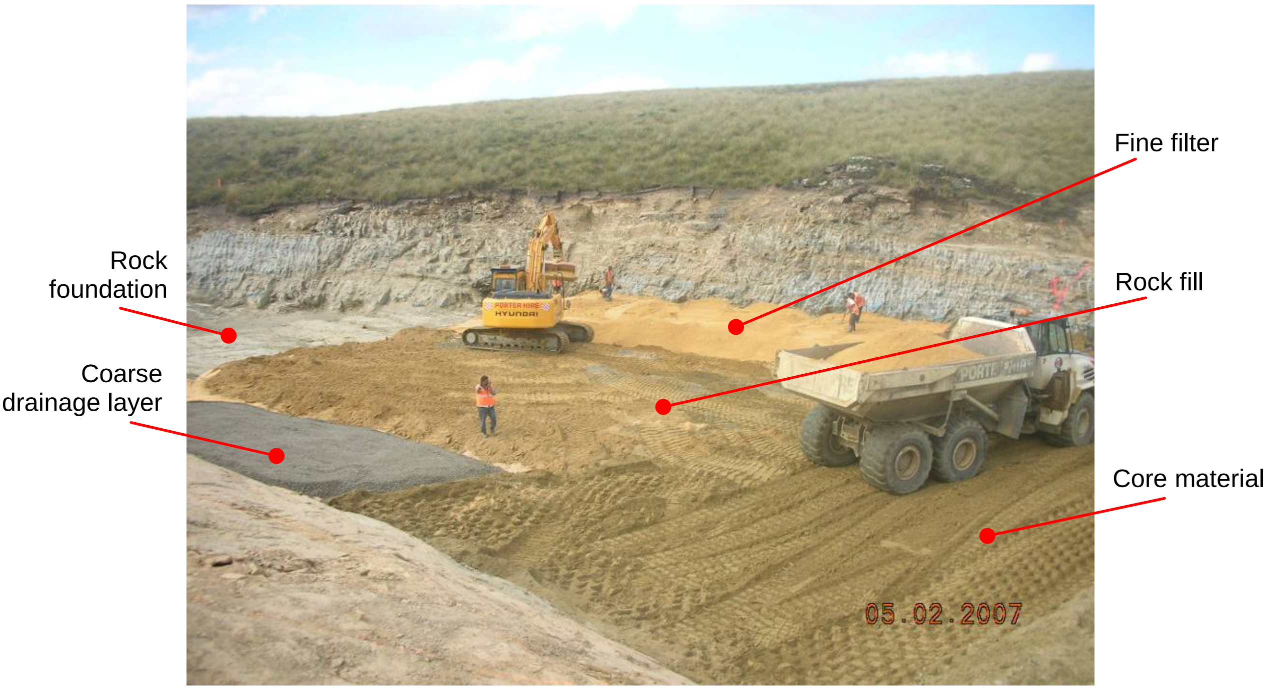

Photo 1: Main dam showing the dam core and the various drainage layers

Canals

The canal totalled about 7.4km in length, 6.5km in cut and 0.9km of filled sections. A significant number of gullies were crossed and, for most of these, the water course was piped beneath the fill embankment. A risk based design philosophy was adopted; some of the key elements of the design were:

- Cut batters were made as steep as possible to minimise earthworks. Adverse geological features, however, were judged to be likely at some locations with some risk of instability
- The design of canal cut sections did not include a low permeability liner, as the overall seepage loss was assessed to be acceptable without a liner. It was accepted that localised seepages may occur in areas of adverse geology.

- Fill embankments generally had relatively steep batter slopes of 1:1.5 V.H., as it was considered schist rock had a reliably high strength, and most fills were less than about 10m height. The largest fill of 20m height was flatter at 1:2. Toe drains were specified at the toe of the larger fills.
- Average canal velocities were just over 1m/sec, and thus a coarser rockfill layer was specified to limit erosion losses. A degree of self-armouring was expected as the finer fraction is washed out initially.
- The canal is subject to potential blockage from slippages but, more significantly, snowdrifts or icing up in winter conditions. The only possible mitigation was strategically placed emergency spillways. Once the scheme was running, knowledge would also be gained in managing this risk.
- Freeboard above the maximum operating level was kept as low as practicable (minimum of 300mm). Concrete lined spillways were constructed at strategic locations to discharge the full canal flow with a station trip. Excess inflows from flooding was considered unlikely due to the small catchment sizes; multiple culvert failures were also considered unlikely.

Photo 2: Canal at largest fill embankment.

Penstocks

Initially conventional (in-ground) steel penstocks were designed. GRP penstocks were promoted as a possible cost-effective alternative in the latter design stages, and were ultimately adopted by TrustPower. The penstock design was altered to accommodate the nesting of pipes for transport which resulted in a significant shipping cost saving.

The pipe sections were comprised of 1,100mm and 1,000mm diameters with pressure ratings of PN6, PN10 and PN16. Station 1 had a gross head of 135m with 1,100m of buried penstock and Station 2 had 148m of gross head with 1,900m of buried penstock. Each penstock line incorporated inspection hatches to surface at approximately 200m intervals. During construction, the jointing of the penstock sections was done either via an outer coupling joint on straight sections, or on site fibreglass jointing. QA testing was performed on all joints during installation. It is noted that the installation and backfill criteria was more stringent as compared with steel, and anchor block designs were much larger than with steel, but a net saving was still achieved with the use of GRP.

Photo 3: Penstock construction.

Powerhouses and Turbo Machinery

The turbines for the project were designed and fabricated in Christchurch. With this, close involvement by TrustPower in the design and fabrication process ensured a high quality, fit for purpose result. Each station's turbine was an identical design based on a mid-point between the 135m and 148m gross heads for Station 1 and Station 2 respectively. The design flow was 2.5 cumecs based on the resource consent discharge requirements from Station B into Northwest creek. The turbines were of a Francis type with an "X" blade runner design. The turbines did not employ the use of a governor (not required by the System Operator) and are actuated. A full flow bypass was also designed and installed, allowing for each station to continue to function if the other Station was inoperable due to maintenance, etc. The turbine designer also designed all of the station services and hydraulic systems. The installation and alignment of the turbine / generator package was carried out by TrustPower's regional staff and commissioning was a combined effort by Hydroworks and TrustPower staff.

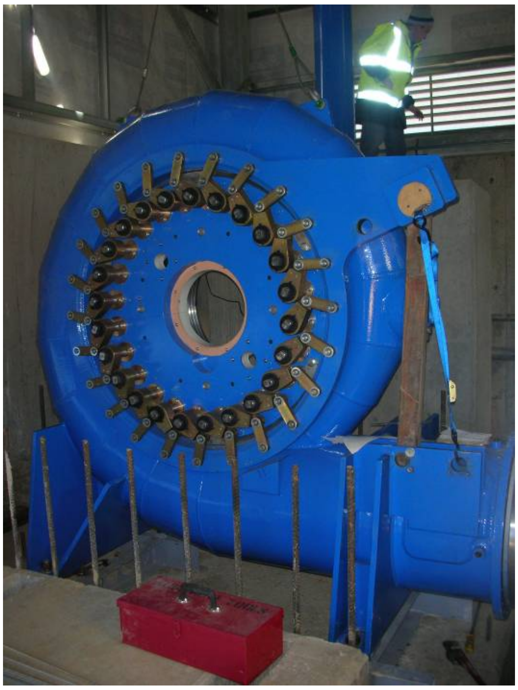

Photo 4: Powerhouse 1 turbine.

4.0 Tendering and Construction

4.1 Types of Contract

The construction contracts for the scheme included two separate civil contracts (earthworks and structures). The civil contracts were conventional measure/value contracts using NZS 3910 as the conditions of contract. An initial registration of interest was carried out to identify five bidders. The scope of civil works was diverse, with many different types of structure spread over a large area. It is worth noting that only a few contractors (or individuals) have specific experience in constructing hydro schemes. Also, for a scheme of this nature, many of the specialist human resources will not be local. The major work packages included:

- Maskell for design and supply of GRP penstocks and fittings (installation was largely by the civil structures contractor).
- Turbine design, fabrication and installation by Mace/Hydroworks.
- Electrical design/installation/commissioning by ENS.
- Civil structures and concrete by Civil Construction Ltd. (now Breens Construction)
- Bulk Earthworks by Earthworks Marlborough Ltd.

TrustPower internal resources were utilised for parts of the construction installation and commissioning.

4.2 Civil Construction Aspects

The contractors were required to overcome a number of challenges and risks in the construction phase. These included:

- Weather conditions and winter work. Work was required during the winter months, with snow often occurring at the upper levels of the scheme. Earthworks in particular were only possible for short periods.
- Flooding. The main dam coffer dam was overtopped in an intense rainfall event at an early construction stage. No significant damage occurred and the coffer dam was not breached.
- Undercutting in fill gullies. The canal fill gullies were underlain by up to several metres of peaty soft soil, requiring undercutting. The overall volumes were significantly greater than initial estimates.
- Additional borrow areas. The initial borrow area for the dam core was exhausted and several supplementary sources were required.
- Slips during construction. Some moderately large slippages occurred on adversely orientated foliation shears on the steep canal cut batters. Remedial works were required, such as rock buttressing.

The civil designers had a full time presence on site, concentrating on the major water retaining structures (main dam and saddle dam). Periodic inspections were carried out by geologists, senior personnel, and the peer reviewer for the dams.

A summary of quality assurance testing on the various materials is show below:

Table 2: Results of quality assurance testing for main dam

Rockfill	Average 13% fines (passing 75 micron) Average 100 to 102% of standard Proctor compaction dry density
Clay core	Average 71% fines (passing 75 micron) Non dispersive Average 99% of standard Proctor compaction dry density Average 1 to 2% air voids
Filter material	Average 2% fines (passing 75 micron) D15 in range 0.19 to 0.48mm (required ≤ 0.5mm)

Some key observations from the designer's and principal's perspective include:

- As with any large earthworks project, silt control works were a significant cost element.
- The earthworks construction took considerably longer than programmed for a number of complex reasons. This created difficulties in meeting commissioning targets.
- Meeting quality assurance objectives against the competing parameters of programme and cost targets was a challenge. The Engineer's site representative played a vital part in ensuring specification requirements and design objectives were realised.
- Modern communications made supervision of a remote site easier, for example, photographs of a particular feature requiring resolution could be almost immediately sent to the designer for a decision.
- There were pros and cons in splitting up the civil works into several packages. In retrospect there is no evidence that a single contract would have provided better outcomes, and almost certainly would have been more expensive.

5.0 Commissioning

5.1 Water Retaining Dam Structures

The commissioning process is an important test of the water retaining structures, as quite often incidents occur in a lake filling phase or soon thereafter. For the two main dams, lake filling proceeded prior to dam completion in order to meet overall programme target dates. The monitoring regime included regular reading of piezometers, seepage flows and visual observation. The designers created a procedure document in line with NZSOLD Guidelines, and comments were provided by the peer reviewer. When the lake level reached approximately 75% of full supply level (6m below the specified minimum operating level), increasing artesian pressures in two piezometers at depth in the rock foundation were greater than considered desirable. Some seepage was also observed near the dam toe, bypassing the drainage systems. Although these observations indicated no threat to the safety of the storage, it was considered prudent to implement additional drainage measures. These consisted of a series of inclined wells into the foundation rock. Subsequent monitoring indicated an immediate improvement. Lake filling was completed and the dams considered to be successfully commissioned.

As expected, the vast majority of seepage occurs through the foundations. The pattern of groundwater response had a direct link with the orientation of geological defects within the rock foundations. The total measured seepage was 2 to 3 litres per second at the main dam and 0.3 litres per second approximately for the saddle dam. These are greater than design estimates for the main dam but are not considered of concern because the seepage is controlled by the drainage systems and flows are steady and clear.

Precise deformation monitoring for both settlement and horizontal movement has continued for both dams. The measured movements, consistent with the excellent compaction of the schist rockfill, are very small. Three years after dam completion, maximum settlement at the greatest depth of fill is 12mm, and horizontal movement 4mm in the downstream direction.

Photo 5: Dam reservoir.

5.2. Canals

The commissioning of the civil components of the canal system was challenging, as the linear length of the canal (8km) is considerable. In the design process it was recognised that in cut sections within rock there was a possibility that some seepage would occur beyond design drainage systems. The fill embankments and low PIC structures typically only included drainage at critical locations, and were typically homogenous cross sections. The initial monitoring regime largely relied upon visual inspection and controlled canal filling.

During initial commissioning and early running of the scheme, seepage areas were observed at several locations, leading to a number of improvement and precautionary works being undertaken. Most of the seepages on the whole were not considered to present a risk of uncontrolled breach of the canal (because the rock or rockfill through which the seepage was occurring was not erodible). The exception was a piping incident which occurred in an area of cut just downstream of powerhouse 1. At this location the canal traversed an area of ancient landsliding and very complex geology. The alignment could not avoid the feature. More conservative works undertaken here included a clay liner and a fully intercepting filter layer. The initial uncontrolled leakage was along cracks in the rock, and then through erodible fissures in a clay infill zone. The seepage potential had been recognised at the location and concrete placed locally over the cracks but, unfortunately, the canal flow outflanked this localised protection.

Improvement measures elsewhere primarily consisted of drainage to control erosion/seepage, and clay liners to reduce seepage flows. The details of particular measures were assessed at each location on a case by case basis. Subsequent monitoring has shown that the improvement works were successful and no further significant incidents have occurred. The culvert system, conveying small streams beneath canal fill embankments, was tested by a 80mm daily rainfall event in February 2009. All flows were passed by the culverts; in a few places minor erosion damage occurred at outlets beyond the designed works, which were repaired.

5.3. Discussion

The experience during commissioning and early operation of the civil structures at Deep Stream has reinforced the value of close monitoring of performance. At the main dam, valuable insight into seepage behaviour was gained by a combination of visual observation, and interpretation of piezometer measurement and drainage flows. For the longer linear nature of the canal, visual observation was the main tool and seepages were noted prior to significant problems developing. The exception was the piping incident at C7; where the piping process was rapid. However, a TrustPower employee observed the developing piping tunnel and, by shutting down the scheme immediately, further uncontrolled silt discharge was avoided.

6.0 Conclusions

- The Deep Stream project represented the first green field hydro-electric scheme developed by TrustPower, which has a diverse portfolio of existing hydro-electric assets, most of which have been purchased since 1999.
- The remoteness of the site, coupled with the unobtrusive small scale nature of the project allowed resource consents to be readily obtained, particularly in comparison to recent, larger schemes.
- Development of the scheme in a cost-effective manner presented a number of challenges which were successfully overcome.

- The commissioning process was not straightforward. The main civil issues encountered were seepages at specific areas along the canal alignment, requiring various improvement measures. Once again, close monitoring during commissing and early running of the scheme has proved invaluable in a) initially identifying issues and b) confirming acceptable performance after the improvement works were completed.

7.0 Acknowledgements

We acknowledge the permission of TrustPower Generation Ltd to publish this paper.