‘Design and Construction of 7 kilometres of 2.5 cubic metre per second Canal’

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ABSTRACT: The paper describes the process and issues encountered during the design and construction of seven kilometres of canal to convey 2.5 cumecs of flow to two power stations. The location of the scheme above the primary reservoir of the Waipori Hydropower scheme in Otago, New Zealand, utilising an existing stream diversion into this reservoir, means that no new water abstraction or diversion consents were required. This mini hydro development associated with the existing Waipori scheme was partly justified by an allocation of carbon credits. The scheme controls are slightly more complicated than many canal and penstock schemes as the canal lengths are considerable in relation to the gradient.

1 INTRODUCTION

The project involving the canal development is an extension of the Waipori Hydro Electric Power project which stores the flow from a 315 square kilometre catchment in the Lammermoor high country north west of Dunedin. The reservoir stores 243,000 Megalitres and releases the flow through a series of four power stations with a total gross head of 165 metres. The original Deep Stream diversion was added 45 years ago, which diverts the flows from the upper 35 square kilometres into the Waipori catchment. The diversion involves 1.5 kilometres of tunnel and approximately two kilometres of pipeline which discharges the diverted flows of up to 4.8 cubic metres per second into the headwaters of the Lammerlaw Stream. This stream falls approximately 320 metres to the main Waipori reservoir.

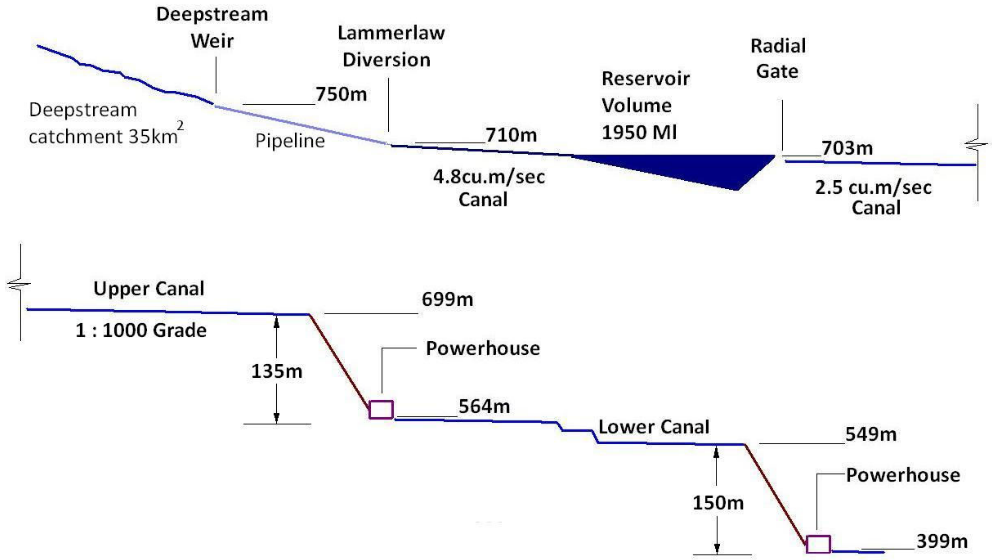
The scheme traverses rolling topography, typical of the upland Otago region. In order to minimise the environmental impact the route was diverted around an important ecological area of endemic tussock grass.

The “ Deep Stream Hydropower' project diverts water from the original diversion pipeline into a reservoir just on the north side of the catchment divide. Flow is released from this reservoir via a radial gate into the 3.3 kilometre upper canal leading to the upper penstock intake, after crossing back into the southern (Waipori) catchment. The upper powerhouse has a gross head of 135 metres and discharges into the lower canal which conveys the flow 3.5 kilometres to the lower penstock intake. The lower powerhouse has a gross head of 150 metres and discharges into North West Creek 900 metres from the reservoir.

2 SCHEME CONCEPT

The original concept of the scheme was developed by TrustPower Ltd; the author has only been involved in the detailed design phase. The route of the canal, penstock and powerhouse locations were drafted using 1:50,000 mapping, aerial photography and on site observation. The topographic survey was modelled with the '12D Model' software package and each canal segment was rerouted several times to optimise cut and fill volumes, canal length and culvert stream crossing fills.

The lugeon permeability tests carried out in the dam foundations confirmed that the basic presumption that the canal could be unlined was correct. So the objective of the canal routing was to have the majority of the canal length in cut. Refer to Figure 1 below.



3 OPERATIONAL CONTROL CONCEPT

The control principle of the scheme is:

diversion from the existing Lammerlaw pipeline is controlled by a vertical roller gate, but as it discharges water into the reservoir it is essentially independent of the remainder of the control system;

the radial gate at the reservoir controls the outflow from the reservoir into the upper canal, and governs the flow in the whole scheme;

- as the water flows down the upper canal the pond level at the downstream end of the canal begins to rise until there is sufficient water within the canal system for the turbine in powerhouse 1 to start operating;
- once the turbine in powerhouse 1 starts generating it discharges water into the lower canal;

the lower canal then operates similarly to the upper canal; water ponds up in the canal until there is sufficient water within the canal system for the turbine in powerhouse 2 to start operating; and

water is discharged from powerhouse 2 into North West Creek, which leads into Waipori reservoir.

This system means the water level at each penstock intake initially ponds up before it then drains down to the steadystate operating level. The level of ponding and drawdown is governed by the timing of the gates opening and the turbines starting. This control and operation has been modelled for the design using MIKE11, a hydraulic modelling software package.

4 GEOTECHNICAL INVESTIGATIONS – GEOLOGY

The following extracts from the geotechnical report describe the area:

'The published geological maps of the area indicates quartzofeldspathic Haast schist forms the bedrock to the area and comprises metasedimentary rocks of volcaniclastic provenance. This mapping also classifies the schist as metamorphic textural zone (TZ) IIIB.

Limited structural data on the published geology maps indicates the schist foliation in the north of the scheme dips gently <10º to the north east, and swings to 18º to the south east at the southern end of the scheme. The site is on the northern side of the regional scale Lammerlaw antiform, which has a south east plunging axis.

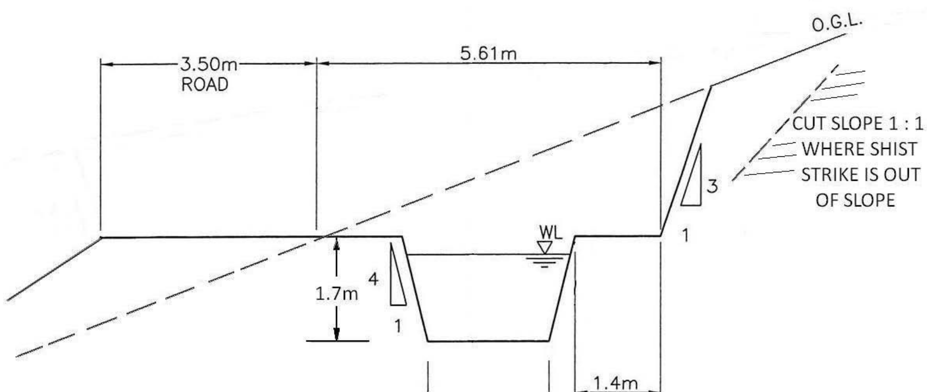
The west dipping Hyde Fault thrust is located on the 1:250,000 published geological map less than a kilometre west of the main dam and reservoir. This mapping records the southern extremity of the fault system where it has surface expression. The fault is likely to be blind further south toward the Waipori reservoir. The nature and southern trace of the Hyde Fault is not well defined and may comprise a complex fold / fault network many tens of metres or hundreds of metres wide. The lateral continuity of the fault trace is also uncertain with recent traces only being locally encountered many kilometres north around Middlemarch.

Topsoil forms a thin surficial layer across the site and is generally less than 0.2 metre thick, but may locally grade into, or is replaced by peat deposits (see below). Topsoil generally comprises soft, damp, organic sandy silt. Fibrous saturated peat to peaty clay locally underlies shallow depressions and the aggraded valley floors along the scheme route, and may be interbedded with alluvium but generally overlies colluvium. This may be up to 1.5 metre thick but is typically <0.5m. Significant tracks of surficial peat were encountered in depressions around the dam site and dam core borrow areas.'

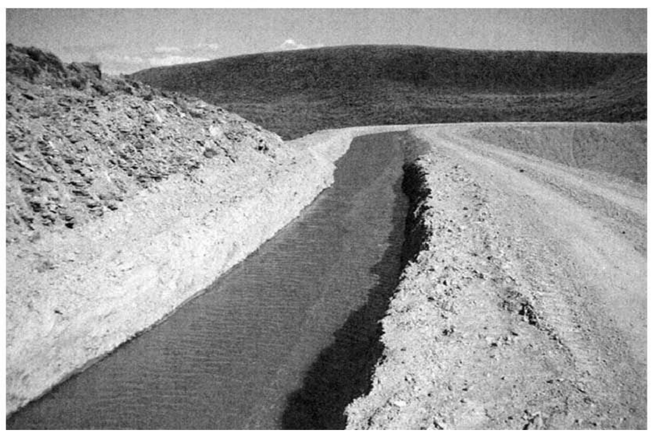
Adversely orientated foliation shears within the schist bedrock were considered to be the most significant constraint on the canal construction earthworks.

CANAL SECTIONS

The fundamental canal section is as shown below as Figure 2, with the section cut into the weathered schist along as much of the canal length as possible.



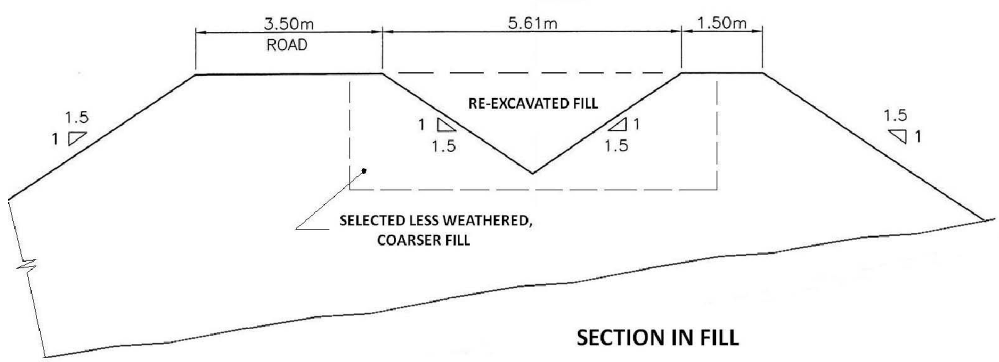
SECTION IN CUT 1



The canal gradient of 1 : 1000 generates a flow depth of 1.34 metres and velocity of 0.76 metres per second assuming a Manning's coefficient of 0.03 which was the slightly conservative figure used in the design. The coefficient was back calculated for a similar smaller canal in the same rock type. This canal shape is close to but not the most hydraulically efficient. It was considered to be the easiest to excavate which was a more important consideration.

The cut slope in rock is steep in order to minimise earthworks. A strategy was adopted in accepting that small wedge type failures were likely to occur, but were a maintenance risk and unlikely to create a significant operational problem. Flatter slopes were adopted where strike of foliation was adverse and particular larger failures could occur.

Where the canal route crosses deeply incised stream lines the canal is excavated back into placed fill. There was some concern about the permeability of the fills but early work on the dam construction indicated that the canal fills would be adequately impermeable. The canal section in fill is shown below as Figure 3.



The selected less weathered material was specified in the expectation that the surface would " self armour" itself more quickly than if no attempt was made to select coarser material. Each transition from cut section to fill section was approximately 10 metres long and not necessarily coincident on either side of the canal. Despite the versatility of 12D's conditional profile feature the chainage of each transition had to be set manually after each change in centreline location.

6 CANAL STRUCTURES

6.1 Lammerlaw Diversion Gate

A roller gate was used just downstream of the pipe bifurcation to release flows of up to 4.8 cubic metres per second into the first canal section leading to the reservoir. The client required that if the reservoir is full then the original pipeline should continue to discharge into the top of the Lammerlaw stream. The head on the gate when closed could be up to 4 metres so the gate (2m x 2m) was designed for a head of 8 metres. The live storage in the reservoir of 630 Megalitres is sufficiently large that the roller gate can be operated in either open or closed positions and no partially open flow control operation is required.

6.2 Radial Gate at Reservoir

The water is released from the reservoir by a radial gate with the water levels in the reservoir varying between

703.5 and 705 amsl (above mean sea level). The gate is operated by hydraulic pistons and remotely controlled from either the power station or the control centre. The flow discharges under the gate at super critical velocities so there has to be a hydraulic jump between the gate and the start of the canal. It would be undesirable to have the turbulence of the jump in contact with the gate and a step down and then up again has been made in the gate structure invert to control the location of the jump. It is possible however that rapid gate closure may cause the jump to move upstream and be in contact with the gate briefly. When the reservoir is drawn down near its operating minimum its level will only be 200 millimetres above the level in the canal, the Froude number will reduce to a point where the jump will extend beyond the structure into the canal. The effect of this turbulence on the canal sides will have to be monitored in the early life of the project and the minimum practical operation head may have to be increased.

6.3 Inverted Syphon

The first valley to be crossed was 15 metres deep and was crossed in a 1500 millimetre diameter concrete piped syphon with a central section in steel on piers. The drainage line is not a perennial stream and its catchment area is only 0.25km^2. The opening in the central span across the drainage line is vastly in excess of any conceivable flood depth. The central span is 12 metres from support to support and the invert 2 metres above ground level.

6.4 Ridge Culvert

The ridge between catchments which had to be crossed was 15 metres above canal level and a 1500 millimetre diameter culvert constructed by cut and cover. The length of the culvert is 120 metres and the need to keep this excavation to a minimum controlled the level of the upstream part of the canal, the storage levels in the reservoir and the size of the embankments required to dam the reservoir. There was another culvert beneath the public road on the lower canal.

6.5 Stream Culverts

A total of six culverts were constructed to pass intervening catchment flows under the canal. The embankments over the culverts had to have controlled drainage systems to be able to cope with the pore water pressures and flows occasioned by the ingress from the canal flowing on the crest. The highest embankment is 21 metres high. The depths of unsuitable material in the valleys under the embankments exceeded expectations and the additional earthworks required had knock on effects on the construction programme.

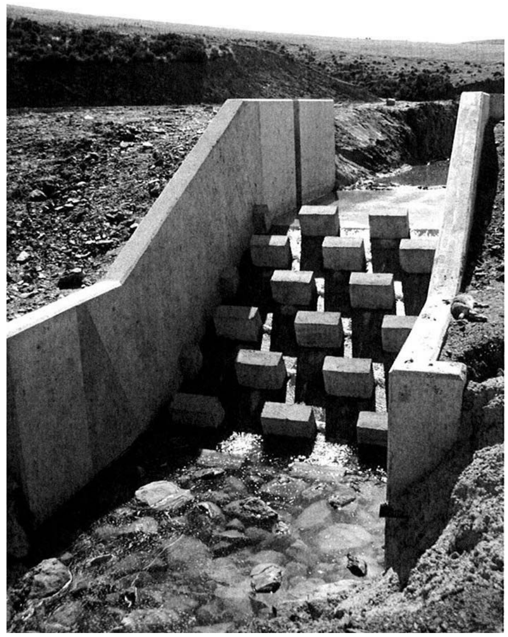
6.6 Penstock Inlet

The penstock inlets simply provided sufficient depth to enable the flow to enter the penstocks with vortex formation. Trash screens are provided to prevent larger debris from entering the penstocks. Small nominal silt collecting recesses have been provided and it may be necessary to pump out the silt during commissioning and early operational period as the fine material from the canal is transported as bed load to the inlets. The climate of the scheme makes the possibility of ice forming on the surface of ponded water at the penstock inlets quite probable.

The walls of the structure have been provided with tubes for the installation of instrumentation to measure water levels, the primary operational controls.

6.7 Drop Structures

The lower canal length could not be maintained at grade to the start of the penstock and a total of 9.75 metres of head had to be lost in drop structures due to topographical necessities. The drop structures are standard US Burec designs with staggered teeth. Refer to photograph below.



There is a complex trade off between losing canal head and extending the penstock at a low grade. The decision on the location of the penstock inlet was made on the basis of topography.

6.8 Spillways: Primary and Secondary

The canal system has a series of primary and emergency spillways. These are provided in order to safely release excess flows in the canal system.

Primary spillways are designed to provide a suitable discharge location in the event the water in the canals ponds up at the penstock intakes for whatever reason, i.e. turbines fail to operate or trip out; or due to additional inflows into the canals. These have been positioned a reasonable distance upstream from each of the penstock intakes but are within the flat sections of the canal banks. The issue of canal overflows due to snowdrifts collecting in the canal while the canals are empty cannot be totally avoided regardless of the number of spillways provided so the canal will have to be checked physically after major snowstorm events.

7 SCHEME CONTROL STRATEGY

Detailed design of the control system for the scheme has been undertaken by the system control designer and the electromechanical designers. However, it is useful to have at least a basic overview of the principal controls.

The Lammerlaw offtake will principally be governed by the reservoir level. If the reservoir is not full the gate will be open, diverting water into the reservoir, and if the reservoir is full the gate is shut to direct flow out of the existing outlet into the Lammerlaw Stream.

The actual flows in the scheme will be determined by operational considerations and the required generation, but will be controlled by the radial gate. The radial gate will require a water level gauge in the reservoir to control the outflow.

Generation of the turbines is to be governed by the water level in the canals at the penstock intakes. It is anticipated three instruments will be required at each intake; a pressure sensor at the deep section for primary control and two water level sensors as backups; one just above ponding level and the second below operational level. This control will have to be able to cope with variations in the initial ponding level in the canal which could be due to either variation in the shutdown procedure, local runoff or evaporation. This could be achieved by varying the startup rate of the turbines to allow for the differences in the water levels or by allowing a certain time from when inflows into the canals start, i.e. either when the radial gate opens or when turbine 1 starts generating.

8 CONSTRUCTION ISSUES

The construction started in June 2005 as two separate contracts: earthworks and structures. The client adopted a strong project management approach with engineer qualified, and operationally experienced inhouse staff. The civil engineer had one engineer on site for full time observation of the construction. The civil construction is now complete and commissioning is underway. The volume and depth of unsuitable peat type materials in the valleys was greater than expected and the work of removing it and replacing with fill caused some delay to the programme. Most other quantities were within an acceptable range. Rock hardness in canal excavations proved to be as predicted in the investigations; the Contractor's chosen method (hydraulic jack hammer) of excavating the hard sections proved to be more time consuming than expected.

Four hectares of excavated and constructed slopes were planted with the endemic tussock grasses.

9 CONCLUSION

The canal was the most cost effective way of conveying the water from the reservoir to the start of the penstocks. The construction is now complete and commissioning is underway. This is the first new hydropower development in New Zealand for many years, the fact that no new abstraction or diversion of water was involved no doubt facilitated the issuing of the resource consent for the project. The allocation of carbon credits to the client will take place when commissioning is complete.