

## Small Hydro

# Practical Development: The Story of 940-kW Onekaka

*Four small hydro enthusiasts applied ingenuity and practical thinking to bring the 940-kW Onekaka hydro project in New Zealand — abandoned in the 1950s — back to working order.*

By Bryan W. Leyland

Jim Baird is a hydro enthusiast. In 1980, the resident of Golden Bay, New Zealand, began developing a plan to revitalize a 250-kW hydro scheme on the Onekaka River. The plant was built in the 1920s to supply electricity to the Onekaka Ironworks. After the Ironworks shut down in the late 1930s, the old station kept running. However, in the 1950s, it was abandoned.

Around 1995, Baird joined with a local civil engineer to investigate rebuilding Onekaka. With electricity shortages in 2001 and the resulting higher prices, revitalization of the plant began to look economical. Two other people (including the author) joined Baird in 2001. Together, we set out to rebuild the plant.

The new Onekaka facility, which began operating in November 2003, uses the existing concrete dam, a new penstock on the same route, and a new powerhouse 200 yards downstream from the original powerhouse. The new plant has a capacity of 940 kW and annual production of 3.5 gigawatt-hours. The power is sold on the New Zealand electricity market at the "spot" price.

This story of a hydro redevelopment shows what can be achieved through the application of ingenuity and practical thinking. With proper planning and development, abandoned hydro plants can again become producers of valuable renewable electricity. However, if the authorities impose significant restrictions for environmental reasons, the cost of construction and operation can negatively affect the economics of the project. In New Zealand, this is a major risk for any investor in small hydro.

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### Construction issues

The old penstock was made of riveted steel plate, most of which was rusted through. The major construction problem for this project was installation of a new penstock, following the same route as the old penstock. The penstock route led up a steep ridge to a surge pipe. From there, 600-millimeter-diameter pipe traversed a steep and unstable slope about 400 meters to the dam. The pipe was buried for the length of its route.

After the old penstock was removed and before the new penstock was installed, we used the bench formed for the pipeline to access the dam. This allowed us to dig out the silt and debris that had completely filled the reservoir. We had to dig this out using an excavator and cart it away at considerable expense.

We chose an "A" frame design for the new powerhouse because it suited the use of a single monorail hoist for installation and maintenance. The powerhouse has curved beams in the ceiling to minimize the floor area and improve the appearance.

### Equipment acquisition

For the powerhouse equipment, we salvaged two 500-kW turbine-generator sets. These initially were used to generate electricity used during construction of Tuai, a 90-MW station built in the 1920s. They then provided the station auxiliary power, until they were no longer needed. Each Pelton turbine drove a direct current (DC) generator and a 400-volt alternating current (AC) generator on the same cast iron foundation. At Tuai, the DC generator provided power for the station crane and acted as a spare exciter for the main machines.

The manufacturer of these turbines had claimed efficiency of about 82 percent. However, judging by the shape and size of the buckets, it was probably nearer to 80 percent. We hired Mhylab in Switzerland, a hydraulic laboratory specializing in small hydropower schemes, to design a new runner for one of the units. We did not replace the runner in the second machine because it would only operate 20 to 30 percent of the time.

Mhylab provided excellent service. The company provided all the drawings and data files needed to have the runner buckets cast in New Zealand from high-tensile bronze and then machined under computer control. In this way, we are absolutely sure that the bucket shape is exactly as it should be and that the efficiency matches the 89.2 percent verified by model tests. Casting, machining, and assembly of the runner was carried out by a New Zealand firm. The company weighed and assembled the individual buckets to balance out the difference in individual weights.

The turbine runs smoother than the unit did with the original runner. An inspection and crack testing after five years of operation showed that the new bronze buckets were in perfect condition.

The turbines originally had belt-driven governors and low-pressure hydraulic servo motors driving the jet deflector and needle. The inlet valve was manually operated. We purchased a new high-pressure hydraulic power pack, together with hydraulic rams to operate the jet deflector, needle, and inlet valve. This has proved to be quite a successful arrangement. However, in hindsight, it would have been better to have used the lower cost alternative of electrical actuators. These would have made position control easier and would have eliminated the potential environmental problems associated with having about 60 liters of oil in the powerhouse.

In spite of their age, the generators were in good condition and only needed to be cleaned and have the windings varnished. The original excitation system was replaced with solid-state excitation to take advantage of reduced maintenance and better overall efficiency. The DC generators were scrapped.

The new electrical system is designed to be as simple as possible. The two generators are switched at 400 volts using air circuit breakers. They are direct connected to the step-up transformer.

We purchased second-hand cables and a 1 megavolt ampere (MVA) transformer from an old paper mill. These cost less



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Thanks to a recent revitalization, the 940-kW Onekaka hydro facility is generating 3.8 gigawatt-hours of renewable electricity a year for New Zealand power users.

than half the price of new equipment. We connected a voltage transformer to the 33-kilovolt (kV) line to detect earth faults. The conventional alternative of a transformer with a delta 400 volt and star 33 kV winding would have been much

with excellent versatility. A feature of the equipment is the ability to send and receive text messages over the cellular telephone system. (For more on operating the plant using a cell phone, see "Operation of the plant," below.)

more expensive.

The control system for the Onekaka plant uses programmable logic controller (PLC) equipment from Unitratics in Israel. This proved to be an excellent choice. The equipment combines unusually low cost (about US\$5,000)

The metering equipment operates at 400 volts. Every month it transmits half-hour readings of active and reactive generation to the electricity market administrator by cellular telephone.

#### Operation of the plant

The Onekaka station is automatically controlled. It operates on water level control from the head pond, and it can use the storage in the pond to increase output during peak demand periods when the prices are usually highest. A radio transmitter at the head pond sends the water level to the PLC every ten minutes. The station operating program ensures that the pond is full by about 6 a.m. At 7 a.m., the plant output increases by 100 kW to provide extra power during the morning peak period. At the end of the

peak period (about 9 a.m.), the control system holds the water level constant until the evening peak, when it again increases output by 125 kW and draws the head pond level down further (until 7 p.m.). Then, until about 1 a.m., the operating program runs the plant at an output that will hold the water level constant. The output is then backed off to allow the pond to refill before 6 a.m.

Through the use of text messaging, it is possible to monitor the status of the Onekaka station. The PLC is programmed to respond to text instructions. We can send it instructions to change the peaking duration and output and shut it down remotely in the event of an emergency. For example, if an "S" is sent, the PLC responds with the station output, pond level, etc. As far as we know, controlling a power station like this by a cell phone is a "world's first."

At the plant intake, a simple chain-and-rake-type screen cleaner removes leaves and similar debris from the screen. We designed the cleaner, which was built by a local engineering company. The cleaner is driven by the drive mechanism from a 12-volt winch, of the type used on recreational vehicles. A simple differential pressure detector at the head pond monitors the water level upstream and downstream of the intake screen and starts the screen cleaner if the differential is above about 200 millimeters. Another detector measures the differential across the penstock guard valve. If the differential is greater than 900 millimeters, the PLC closes the guard valve and trips the station. This precaution is necessary, in case the cause of the high differential is a burst penstock. A small PLC at the intake monitors alarms and opens a motor-driven scour valve every time there is a large flood. This allows silty water to pass through the dam, rather than accumulating in the head pond.

Originally, we used a 120-watt solar cell and a 24-volt battery to supply station service power at the dam, at a cost of more than \$2,000. This arrangement cost about \$1 per kilowatt-hour (kWh). However, in the winter, the solar cell was unable to supply the 6-watt standing load

of the PLC and radio transmitter. We have supplemented the solar cell with a micro hydro unit provided by EcoInnovation in New Zealand. The unit comprises a two-jet Pelton turbine driving a generator made from the permanent magnet low-speed drive motor from a

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The new powerhouse for the 940-kW Onekaka facility contains two 500-kW turbine-generator sets. These units initially were used to provide power during construction of a 60-MW power station in the 1920s and, later, for station service.

"Smart Drive" washing machine. The turbine cost \$1,200 and gives a steady output of more than 90 watts.

For environmental reasons, we release a nominal 20 liters per second from the

transmitted to the station by radio, and the PLC sends a signal to the dam, where four valves are opened and closed as needed to ensure that flow is maintained at 30 liters per second, as required by

dam to maintain the flow in the 1-mile section of the river between the dam and powerhouse. Because there is no suitable measuring site in the rapids and waterfalls just downstream of the dam, we monitor the flow just upstream of the power station. Flow measurements are

our revised water right. Tributary flow between the dam and the measuring weir provides 10 liters per second.

As a result of this arrangement, we release more water than under the original water right during a dry period and less flow when the tributary flows just downstream from the dam are high. If the station trips off line, all four valves open automatically to increase flow downstream from the station.

#### Commissioning the plant

Commissioning the Onekaka facility took several weeks. Getting the machines to synchronize successfully was quite difficult because the hydraulic system was unable to position the needle with sufficient accuracy. We solved this problem by opening the needle a small amount

and then using the jet deflector to control speed by moving it either "in" or "out." This means that the unit speed cycles above and below synchronous speed and the auto synchronizer eventually finds a situation when the speed and phase match, allowing synchronization. The process is rather interesting to watch, but it never fails to synchronize successfully.

The station originally was connected to the local 11-kV distribution system via a 3-kilometer transmission line from the main road to the power station. The connection point is about 10 kilometers from a 66-kV substation. When the first unit went on line and we increased output to about 400 kW, we discovered we were pushing the local voltage from about 10.7 kV to above 11.5 kV. Over the next few days, we discovered that we could export

about 400 kW when the farmers in the district were milking their cows, but we were restricted to about 250 kW for the rest of the time. To limit the voltage rise, we did everything we could to run under-excited — to the extent that the unit often pole slipped and tripped on overcurrent. This is not something that I had experienced before! The lesson here is that even small distributed generators can upset a typical rural distribution system.

We operated in this mode for about five months, until the transmission line company completed a conversion to 33 kV. From then on, we could operate up to full power without restriction. Tests showed that the new turbine had an output of 520 kW when operating on its own, whereas the unit with the old runner could only achieve about 470 kW.

Maximum station output is 940 kW.

Since the conversion to 33 kV, the station has run very reliably with few problems.

The station has now been in operation for six years. The average price we receive from the spot market is about US\$0.05 per kWh. We do not receive any greenhouse credits or other subsidies.

#### Costs

As with most projects of this type, the final cost of US\$1.8 million was well above the original estimate of US\$1 million. The penstock installation and civil works were the main source of the additional costs because the original estimates were old and, in hindsight, should have been re-evaluated by the civil engineers. Nevertheless, I am convinced that following the now-fashionable route of a turnkey design



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and build contract would have made the scheme completely uneconomical. Based on my experience with other turnkey hydropower developments, disputes also would have arisen and the associated legal costs and costs for unforeseen circumstances would have been very high.

As mentioned above, complying with requirements imposed on us under New Zealand's Resource Management Act was very expensive. These included:

- Compilation of a "heritage inventory" that involved scheduling and sketching every one of the rusty old riveted penstocks lying around in the bush;
- Development of a report on the history of the Ironworks;
- Requirements for costly studies of the fish and other life in the stream, which have to be repeated every year.

These studies showed that floods were the major factor in the quantity of marine life. Because the Onekaka scheme has no effect on floods, it has no measurable effect on fish and other life in the stream;

— Compilation of an expensive dam safety report, for a dam that was built 70 years ago and, but for us, would still be holding back thousands of tons of silt and debris, with no one responsible for it;

— Renewal of our water rights for 35 years. This involved lawyers, environmental scientists, and consultants and cost us about \$80,000; and

— Various delays waiting for environmental approvals under the Resource Management Act and complications in the construction process that slowed construction and probably cost us \$100,000 overall.

Monitoring, recording, and reporting costs are ongoing and amount to more than \$10,000 per year.

During construction, very strict requirements were imposed on us under the Resource Management Act. These included limits to the number of trees we could chop down for access during penstock installation. There are half a dozen saplings of a prolific second growth tree no more than 100 millimeters in diameter that we were not allowed to remove. This probably cost us more than \$US8,000, by making it very difficult to excavate and lay the penstock. Without this requirement, we probably would have laid the penstock above ground.

In addition, the start of construction was delayed because it took so long to obtain a multitude of consents and approvals.



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As a result, we finished up doing a lot of work in winter, which is the wet season in New Zealand.

Overall, the above requirements probably added US\$300,000 to the cost of the project. In my view, maybe 5 percent of the sum actually provided a real benefit to the environment. If, instead, we had put US\$50,000 toward fencing off the river downstream from cattle and providing cattle crossings, I am sure the environment would have been far better off.

### Lessons learned

If we could do it again, what would we do differently? Firstly, we would install a single new vertical four-jet Pelton turbine instead of the two old single-jet horizontal units. Although the two second-hand units cost us less than \$US15,000

to purchase, the costs to prepare them for installation in the new powerhouse were unexpectedly high. This included a new runner and new turbine shafts, and the hydraulic system for control of the turbines. In addition, using two units instead of one led to a much larger powerhouse, additional switchgear, and additional complexity in the control system. I am sure that the lowest cost option would have been to commission Mhyllab to design a new turbine, then manufacture all the components in New Zealand.

As already mentioned, we probably would have been better off if we had not had to bury the penstock. Supporting the penstock above ground as though it were a steam or oil pipe, instead of the conventional civil engineering solution of expansion joints and massive anchor



Ingenuity on the part of a small group of hydro enthusiasts allowed the revitalization of an abandoned facility in New Zealand, providing valuable renewable electricity for the country.

blocks, would have saved even more money because it eliminates the need for a large number of expensive anchor blocks and expansion joints. ■

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