Appendix 23: Hydro Dams

1. Introduction

This appendix outlines the influences of the hydro dams on the health and wellbeing of the Waikato River and regional and national economic prosperity.

The eight hydro dams along the Waikato, from Aratiatia to Karaapiro (Table 1), have drowned important cultural and geothermal sites, altered fisheries, changed the river's ecology, hydrology, sedimentology, morphology, water clarity and quality, temperature regime, and recreational uses. These changes have impacted on the relationship of iwi with the river (see Appendix 26: Significant sites for discussion of hydro dam impacts on significant sites). However the dams have also contributed significantly to the development of the Waikato and national economies, supplying about 13 percent of the electricity and providing important system flexibility to meet daily variations in energy needs. Furthermore, they contribute to flood control and support fisheries and recreational amenities, including an international rowing facility. This appendix summarises key issues related to the Waikato hydro dams and their operation, as identified at the consultation hui (meetings) and in available literature.

Table 1: Waikato hydro dams and their significance amongst moderate-large (more than 10 megawatts) stations for NZ hydro-electric generation (Young et al., 2004).

Name	First operated	Installed capacity (MW)	%mod-large dam capacity
Karaapiro	1947	90	1.76
Arapuni	1929–46	197	3.86
Waipapa	1961	51	1.00
Maraetai	1953–62	360	7.05
Whakamaru	1956	100	1.96
Atiamuri	1958	84	1.65
Ohakurii	1961	112	2.19
Aratiatia	1964	84	1.65
All Waikato	–	994	21

1.1 Sediment and channel morphology

The dams act as sediment traps, storing on average 280,000 tonnes of sediment per year (167,000 tonnes per year is sand and gravel that previously would have nourished the bed of the lower Waikato and 112,000 tonnes per year is silt and clay that would previously have been transported along the lower Waikato as suspended load) while 37,000 tonnes per year of fine suspended load pass downstream from Karaapiro (Hicks and Hill, 2010). Lake Ohakurii makes the greatest single contribution to this sediment storage, at about 125,000 tonnes per year, followed by Maraetai, Karaapiro and Whakamaru, at about 40,000 tonnes per year each. The reservoir lifetimes before being completely in-filled with sediment have been estimated to be in the range one thousand to several thousand years (Hicks et al., 2001). The interception of the bed-material load upstream is a major cause of falling riverbed levels downstream of Karaapiro in recent decades. The reduction in suspended sediment as water passes through the hydro dams would have increased water clarity; however, increased water residence time within the reservoirs allows more time for growth of algal phytoplankton that reduce water clarity (particularly during summer).

The accumulation of sediment within the hydro dams has important implications for restoration options involving removal of the dams or opening the dam outlets to create a non-impounded flow regime. It was estimated in 2001 that it would take at least 35 years for the stored sediment to move past Ngaaruawaahia if the river reverted to a natural flow without dams scenario (McConchie, 2001) – resulting in a corresponding period of very high turbidity, particularly during floods. This would also cause bed aggradation in the lower river, flooding and reduced drainage of the lower river land, reducing production and increasing drainage costs. Sediment scour would also release stored arsenic.

The reduction in downstream sediment transport below Karaapiro Dam also results in downcutting of the riverbed at least as far downstream as Ngaaruawaahia. Since Karaapiro Dam was built in 1947, riverbed surveys have shown that the downcutting has advanced downstream as a wave. Initially, the downcutting was focused upstream from Hamilton and the bed-material scoured from there served to replace that trapped in the reservoirs upstream. However, with time a cobbly 'armour' has formed on the riverbed between Karaapiro and Cambridge, and by the 1960s the downcutting had advanced past Hamilton. Over recent decades, at Hamilton, the downcutting rate has averaged 25–35 millimetres per year; some sections have deepened more while others have been more stable, apparently in response to at least partial armour development. The downcutting wave now extends past Ngaaruawaahia, although downcutting there proceeds at a lesser average rate owing to restoration of the bed-material load from the sediment scoured from upstream and from fresh inputs from the Waipa River. Further downstream, riverbed downcutting has for the most part coincided with sand extraction; when this has ceased, riverbed levels have generally recovered.

This riverbed downcutting issue was reviewed at the time of the Mighty River Power Limited (MRP) consent hearings in 2003. Potential issues due to downcutting include erosion around engineered structures, such as bridge supports, long-term erosion of streambanks along the main stem and in tributaries as they adjust to the lower riverbed levels and perched infrastructure associated with falling water levels. It was concluded (Rogen, 2001) that the downcutting had no significant effects on the structural performance of the bridges, and that any future issues relating to pile exposure could be managed with engineering solutions. Studies of riverbank erosion then (McConchie, 2001), and since (Fellows et al., 2007) have shown no clear evidence of increased bank erosion associated with hydro-power effects. However, geomorphic responses typically take decades to develop, and since the degradation is expected to continue for the foreseeable future, continued monitoring of bank stability appears to be prudent (Hicks and Hill, 2010). As water levels have fallen with the lower bed through the Hamilton area, facilities such as water intakes, drains, boat ramps, and jetties have been perched higher than their functional levels and some have required maintenance/repair.

1.2 Arsenic

The dams also store about seven to eight percent (15 tonnes per year) of the total input of arsenic to the river (c. 204 tonnes per year) (Kim, 2010). As with sediment, arsenic storage is greatest in Lake Ohakurii (c. eight tonnes per year; Aggett and Aspell, 1980), where the bed may have accumulated up to 380 tonnes of arsenic since the lake was formed in 1961 (Kim, 2010). Under oxygenated conditions, arsenic is bound to sediment components (e.g., iron and manganese), but low oxygen conditions at the lakebed during summer stratification of the hydro lakes can result in arsenic release back to the water column and summer increases in arsenic have been observed at Hamilton (see Appendix 21: Toxic contaminants).

1.3 Power supply

Mighty River Power operates the Waikato River hydro system (installed capacity 994 megawatts) according to resource consents granted for 35 years in May 2006. The eight dams and nine power stations (with two at Maraetai) provide 4,200 gigawatt hours on average to the New Zealand electricity requirements, representing about 13 percent of the national electricity supply and up to 25 percent of daily peak supply[1], which is strategically located closer to the centres of peak electricity demand than other major hydro-electric power sources (located in the South Island). The Waikato hydro system also provides key ancillary services to the functioning of the New Zealand power supply, including frequency control, power reserves (to cover interruptions in supply elsewhere in the system), voltage support for the central and

[1] T.J. Truesdale evidence, Mighty River Power Resource consent hearing.

upper North Island and black start capacity.[1] This suggests that the Waikato River hydro-electric system is a keystone asset in the New Zealand economy.

1.4 Infrastructure built around the presence of dams

The hydro system has had a fundamental impact on the development of the Waikato region. Roads and towns developed as the dams and power stations were constructed, and the dams provided road access across the river. Many water supply intakes have been designed taking advantage of the hydro system and the dams play a role in moderating the effects of floods. The international rowing facilities rely on the Karaapiro dam, and the control of water levels and flows that is now possible. Housing has been built around the lakes and property values have risen as a result of lake views. These assets and the benefits they bring to the wider community would be severely affected if the Waikato River was to be managed in its 'more natural state' or if the dams were removed or operated as a 'run of river' system. The costs of mitigating such risks would be substantial, involving for example, flood protection works, re-engineering infrastructure and compensation.

1.5 Water levels and flow peaking regimes

The resource consent conditions under which Mighty River Power operates have set maximum and minimum levels at the Taupoo Gates (357.25 and 355.85 metres ASL), minimum flows at Karaapiro outlet (more than 140 cubic metres per second as half hour average and always more than 120 cubic metres per second, with some seasonal variations) and requirements to assist Environment Waikato in its role as flood manager. An example of the latter is condition 5.9 that requires that when the discharge from Karaapiro exceeds 500 cubic metres per second and/or the flow at Ngaaruawaahia exceeds 850 cubic metres per second Karaapiro hydro reservoir is operated so that flows downstream of Karaapiro are similar to or less than those that would have occurred without the hydro operations in place.

Mighty River Power's consents place no restrictions on rates of flow ramping (the rate at which flows are varied) to generate hydro-electric power to meet fluctuations in power demand. Ramping results in higher flows at Karaapiro outlet during the daylight hours that influence natural water levels downstream to about Ngaaruawaahia. Due to travel time over the 30 kilometres to Hamilton, this results in typically highest flow in the city at midnight and lowest flows during the day. Since the mid-1990s the hydro-electric scheme has been run in a manner that has increased daily flow fluctuation and hydro lake water levels (Figure 1). The magnitude of flow fluctuations at Hamilton increased between the mid-1990s and 2003. Between 1975 and 1997 median weekly flow fluctuations were 100 m^3s^{-1} or less. Since the beginning of 2000, the annual median flow fluctuation has been 135 and 160 cubic metres per second, about 50 percent higher than the 1975–1997 median (Figure 1).

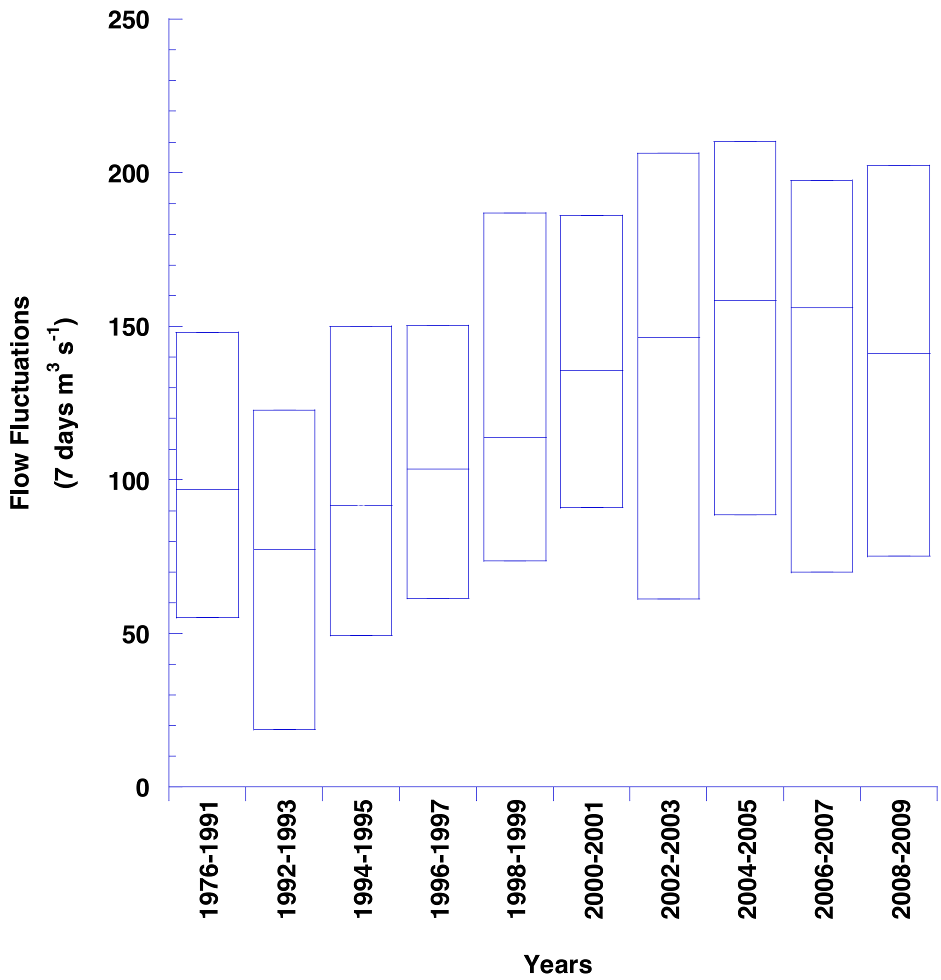

Figure 1: Box plot of weekly flow fluctuations in the Waikato River at Victoria Bridge 1976-2009. The box shows the magnitude of flow fluctuations that are exceeded 10 percent (top) and 90 percent (bottom) of the time and the bar indicates the median weekly flow fluctuation**.**

Mighty River Power argued at the 2003 hearing for renewal of its consents to operate the Waikato hydro system[2] that the ability to use hydro peaking freely is vital to the profitability of the company and important for efficiently managing the smooth supply of energy within the country and reduce the need to use greenhouse gas emitting energy sources. This need has likely increased with the increased use of wind power that fluctuates markedly in supply, requiring buffering by other sources.

Issues relating to the effects of increasing ramping that were raised in evidence to the Mighty River Power hearings and the consents Assessment of Environmental Effects (AEE) (NIWA, 1999) included:

- Potential effects on increased streambank and riverbed erosion (although this appears to be a minor issue (see Hicks and Hill, 2010)).

[2] Evidence of D. Heffernan and J Truesdale, Mighty River Power resources consents hearing.

- Reduced macrophyte abundance in lakes and the river between Karaapiro and Ngaaruawaahia (with flow on effects on invertebrate and fish habitat and food supply).

- Increased size of the varial zone on lake and river margins, where sediments are exposed to air for part of the day, with potential negative effects for sediment character, invertebrates (particularly non-mobile net-building caddis-flies at Aratiatia and Arapuni tailraces and snails), fish spawning (particularly smelt) and strandings, and aesthetics.

Table 2 shows the predicted effect that ramping has on the varial zone and river habitat.

Table 2: Predicted effects of Karaapiro flow regimes on width of varial (daily dewatered) zone through Hamilton city (Jowett, 2003).

Flow fluctuations (m^3s^{-1}) (median, 10 and 90% range)	Varial zone width (m)	Area of suitable macrophyte habitat (m^2/m)	Representing
100, 180–280	10	1.43	1975-95 average
140, 160–300	13	1.1	early 2000s
200, 140–340	17.5	0.56	max. allowed pre-consents

Anecdotal evidence on ramping effects presented at consultation hui identified additional impacts of low flow levels during the day and unpredictable changes in water level on waka ama (boat strandings/groundings), swimming and potential effects on kooura (freshwater crayfish) that use river edge habitats in medium to large rivers (Hicks, 2003). The abundant common freshwater snail *Potamopyrgus antipodarum*, that was considered a core component of the Waikato River fauna but is vulnerable to ramping effects (due to its preference for macrophytes and slow velocity areas that occur along margins (Jowett et al., 1991)), has declined at the Hamilton traffic bridge over the period from 1991–2009 (National Rivers Water Quality Network, NIWA unpublished data).

The hearing commissioners to the Mighty River Power consents took the view that the potential impacts described were insufficient to outweigh the overall benefits of the hydro-electric scheme and granted the consents with the level controls described above and requirements for ongoing monitoring and review of impacts.[3]

[3] Mighty River Power Taupo-Waikato Consents Decision Report (2003) Environment Waikato Document #: 852012.

1.6 Impact of hydro dams on fish movement

Prior to the construction of the hydro dams, the Hora hora Falls (near the current Hora hora Bridge, 15 kilometres upstream of Karaapiro Dam) would have been a natural barrier to upstream movement by non-climbing fish (e.g., smelt and iinanga (whitebait)), whereas the Arapuni Falls (25 kilometres upstream of Karaapiro Dam) were the likely barrier to most climbing fish (tuna, lamprey, climbing galaxiids), although kooaro (climbing galaxiids) appear to have been able to move throughout the river system. Thus the Karaapiro Dam has limited natural upstream fish movement by 15–25 kilometres. However this is mitigated by the elver transfer programme that collects migrating elvers at the Karaapiro dam face in December to March each year and transfers them to each of the hydro dams except Ohakurii (avoided due to potential for geothermal-derived metal contamination of tuna).

Whilst the transfer programme has facilitated the tuna fisheries in impoundments above the lakes, it does not contribute to the spawning runs to the sea because most downstream migrating tuna are killed on passing through the power station turbines (see Appendix 5: Tuna).

1.7 Impact of impoundments on traditional features

The hydro dams have drowned many natural features (e.g., rapids, cliffs, geothermal features) and sites of cultural significance to Maaori (see Appendix 26: Significant Sites).

1.8 Impact of impoundments on algal growth

The eight Waikato River hydro dams have the vast majority of the total storage within the Waikato catchment, totalling 570 million cubic metres equivalent to 16.5 days of the average Waikato flow at Mercer (400 cubic metres per second). Impoundment increases the residence time of water flowing from the catchment to the sea, thus allowing more time for phytoplankton biomass to develop in response to light and nutrients, with associated changes in water colour and clarity (Rutherford et al., 2001).

The Waikato River Catchment Water Quality Model (WRWQM; Rutherford et al., 2001) has predicted the influence of the dams on factors including water travel times and water quality along the river main stem. The WRWQM predicts that the dams increase the travel time between Taupoo and Karaapiro from 62 hours to 830 hours under summer low flow conditions and from 48 hours to 375 hours under winter high flow. These increases in residence time were predicted to result in three- to four-fold increases in suspended algal biomass (phytoplankton, measured as chlorophyll *a*) at Karaapiro and to reduce the water clarity at Karaapiro by 35 percent (two metres to 1.3 metres) during summer low flows and 10 percent during winter high flows.

2. Actions

Possible actions raised during the consultation process and during the Mighty River Power consent hearings include the following:

1. Reducing the magnitude of flow peaking below Karaapiro Dam: Restricting the hydropeaking operation of Karaapiro Dam to the 1976-1991 level, whilst allowing the existing permitted operating regime of the dams upstream to continue.

2. Ceasing use of all the hydro dams for electricity generation and opening their sluice gates so that the river reverts to natural levels.

3. Removing all the hydro dams so that the river reverts to natural levels and natural longitudinal connectivity is restored.

These actions would be accompanied by complex resource consenting and other legal issues.

3. Costs

Direct costs to the Waikato River Authority would be relatively low (mainly legal) for the reduction in hydro peaking to 1976–1991 levels. However, there would be high direct costs to Mighty River Power and substantial flow on costs to the economy from likely higher electricity prices, the difficulty finding a replacement system that can respond to hourly fluctuations in peak power demand and to increased GHG emission taxes arising from the use of non-hydro electric generation.[4] Costs would be at least an order of magnitude higher for the options of returning the river to a natural level and flow regime and dam removal. This would create a need to replace 13 percent of the national electricity supply (up to 25 percent of daily peak supply) that is strategically located closer to the centres of peak electricity demand than other major hydro-electric power sources (located in the South Island). Evidence presented at the Mighty River Power hearings suggested that the cost of replacing the Waikato hydro system generating capacity would be in excess of $4 billion in 2003 dollars assessed over the next 35 years.

Dam removal or natural flow options would require substantial expenditure to rehabilitate the exposed areas of dam bed and the dam removal option would involve further engineering expenses for dismantling and disposing of the dams.

[4] T.J. Truesdale evidence to Mighty River Power Resource Consent Hearings.

These options would also have substantial lost opportunity costs due to the loss of utility of amenities that have developed around the hydro dams, including cycleways, outdoor education and boating facilities, and the international rowing facility at Karaapiro. Furthermore, they would also incur costs downstream to deal with the increased flood risk due to downstream movement of sediment stored in the dams and to manage and compensate for effects on infrastructure built around the presence of dams.

4. Timing

Alteration of the hydro-peaking regime would require variation to Mighty River Power's existing resource consents. This would almost certainly be appealed, delaying its implementation, and the Study team cannot predict the outcome of the Resource Management Act processes involved. There would also be considerable delays before alternative power supply arrangements could be made.

Restoration of natural river levels would also involve considerable legal complexities If these could be resolved it would take two years before a new flow regime was stabilised, but it would take decades before fine sediments were flushed from the system and upstream fish access would still be restricted at Karaapiro Dam. It would likely take decades before alternative electricity generation capacity could be developed. If it was decided to wait until the dams had reached the end of their existing operational life, the removals would likely be staggered over the next century.

5. Outcomes

Reducing the magnitude of flow peaking below Karaapiro would reduce the size of the marginal band of the river that is regularly dewatered (the varial zone) in Hamilton city by about 30 percent and increase the area of suitable habitat for macrophytes by about a similar amount. This is likely to benefit river ecology by reducing the stranding of invertebrates and increasing the macrophyte habitat for them to colonise. However it would also result in the spread of and increased growth of aquatic weed beds which will affect swimming access, and boating and other recreational activities.

The options to reduce the hydro-peaking or remove the hydro-electric function of the dams would have substantial negative impacts on the regional and national economy. The reliability and cost of electricity supply would be affected and if fossil fuels had to be used to replace the lost generation, New Zealand's greenhouse gas emissions would increase.

Returning the river to a natural level would reduce the residence time of water in the river (and hence algal growth and biomass). However, the net effect is likely to be further reductions in water clarity throughout the river system for a period of decades as sediment stored within the hydro reservoirs was eroded and transported downstream. The deposition of this large amount of sediment in the lower river would increase flooding and navigation hazards and require considerable additional expenditure on dredging and flood protection.

Other impacts would include:

- Dam removal would remove the ability to control flooding through reservoir manipulation and storage.

- Upstream fish passage would not improve, unless the dams were removed, because the outflow through the dams' sluice gates would likely present a velocity barrier.

- Dam removal would change opportunities for recreation and fishing. The loss of the international rowing facility on Karaapiro would be of particular significance.

6. Uncertainties and information gaps

There is uncertainty about the environmental impacts of the increase in flow variability due to increased hydro peaking since the 1990s. Monitoring required under Mighty River Power's consents will help to establish the nature and extent of possible effects.

The effects on the regional and national economy of altering the operation of the Waikato hydro scheme to reduce flow fluctuations below Karaapiro or removing the dams and returning the river to a natural flow regime are believed to be prohibitively large, based on general information presented to the Mighty River Power consent hearings. A more accurate costing of these effects would require a major economic study, but the preliminary cost estimates presented in the Mighty River Power consent evidence are sufficient for an initial assessment of these options.

7. Recommendations

It is concluded that the keystone nature of the Waikato hydro system to the prosperity of the Waikato region and New Zealand means that placing significant restrictions on the system's operation beyond those decided in the 2003 Mighty River Power resource consent process is not warranted. The Mighty River Power consent conditions include monitoring requirements for specific issues where potential for environmental impacts exist, a review clause if blue-green algal blooms are detected and requirements for consultation and accommodation with river users around flow management to fit in with specific events. These existing conditions appear sufficient to manage issues resulting from the scheme's operation, without need for the Waikato River Authority's involvement. Similarly dam removal would not restore the Waikato River to its original state and there would be considerable negative effects as sediment and contaminants were flushed from the system. Also, the benefits that the hydro system provides in terms of flood storage and flood management would be lost. For these reasons, dam removal is not recommended either. Instead, it is recommended that the Waikato River Authority (i) keeps a watching brief on the outcome of the river monitoring required by the Mighty River Power consents, and (ii) if significant adverse effects are found that compromise the vision and strategy within Te Ture Whaimana, advocates, via Environment Waikato (as the consenting authority), for mitigations and/or appropriate changes to the hydro dam operating regime.

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