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Issues and Mitigation Options Associated With Water Storage in the Lee River

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EXECUTIVE SUMMARY

The construction of a reservoir in the upper Lee River has been suggested as the best way of enabling further irrigation of the Waimea Plains and alleviating the current pressure on instream values. This report discusses the potential effects of the proposed water storage dam on the flow regime downstream of the dam, water quality in and downstream of the reservoir, and fish passage past the dam. We focus on likely ecological effects of the dam and suggest potential approaches to mitigate these effects.

The effect of the dam on flows in the Wairoa River downstream of the confluence with the Lee, and in the Waimea River, is expected to be largely positive with higher minimum flows predicted during summer. This effect would be more pronounced in the Lee River with substantially higher minimum flows in summer than present. These higher flows are expected to have positive ecological effects, however, habitat modelling would need to be conducted to confirm this. With the augmentation scheme, flows in the Lee River would be 'flat-lined' for extended periods in summer and autumn with any small natural freshes during this period being 'captured' within the reservoir. This removes the potential for these freshes to flush any excessive algal growths that may have accumulated during the preceding stable flows. However, previous surveys have shown that algal growth in the Lee River has not reached nuisance levels even after extended periods of natural low flow, so the likelihood of nuisance algal growths occurring after the augmentation scheme is relatively low. However, if algal growth became a problem, flushing flows equivalent to 6-8 times base flow (i.e. 3-4 m^3/s) may be necessary to remove accumulations of algae. It is expected that such flows would be required only once or twice per year. The loss of these natural freshes may also affect fish migrations which are often associated with high flows.

Changes in the level of augmentation from the reservoir have the potential to result in sudden decreases in flow in the Lee River. The effect of these flow reductions depends on how suddenly they occur, and their effects could be minimised by "ramping" flow down gradually over several hours.

The sediment supply below the dam may be reduced, as sediment from upstream is impounded behind the dam. This could lead to armouring of the bed downstream, which may encourage periphyton proliferation and reduce the availability of gravels suitable for trout spawning. However, the coarser substrate size and greater substrate stability may be beneficial for benthic invertebrate production, as long as they are not smothered by excessive periphyton growth. One potential remedy for this issue would be to periodically dredge out sediment built up behind the dam and place it on the downstream side of the dam so it would be carried downstream during subsequent flood events. However, the costs and benefits of such an initiative would need to be considered carefully before proceeding.

The Lee River currently delivers high quality water to the Wairoa and Waimea rivers downstream. The construction and operation of the proposed water storage dam in the Lee has the potential to have some negative impacts on water quality. These impacts need to be avoided or mitigated so that there are no negative effects on ecological, cultural, recreational and abstractive values of the water in the reservoir and/or downstream. In particular, inputs of fine sediment to the river during the construction phase may have a variety of ecological effects on the river downstream. However, these effects are

likely to be relatively short-lived since any deposited sediment should flush out of the system reasonably rapidly once construction is completed. Effects can also be minimised by good construction techniques and sediment control measures. More serious effects may be related to storage of the water within the reservoir. Generally, the more time that water is retained within a reservoir, the greater the potential effects on water quality. Based on preliminary hydrological modelling, the average residence time for water stored in the proposed impoundment will be around six weeks, which is more than sufficient to allow for thermal stratification of the impounded water, deoxygenation of the bottom waters, and for phytoplankton blooms to develop. However, there are mitigation measures that can be put in place to minimise these effects. The temperature of water released from the dam may be able to be controlled by manipulating the level from which the released water is sourced and the use of multiple release levels may also enable management of iron- and manganese-rich water that can become a problem in reservoirs that become anoxic near the bottom. Thorough removal of terrestrial vegetation and top soil from the dam footprint prior to filling will help reduce the chances of deoxygenation occurring within the reservoir and will also reduce the possibility of nutrients being released into the water column and fuelling algal blooms in the reservoir and/or downstream. The geology of the catchment for the proposed reservoir does not include ultramafic rock types (which contain toxic metals) so adverse effects related to geochemistry of the catchment are unlikely.

Again, based on preliminary storage modelling it appears that the operation of the augmentation scheme will see fluctuations in the water level behind the dam. This will limit the development of a productive ecosystem within the reservoir and may result in some erosion along the shoreline of the reservoir. Given the function of the reservoir, these variations in water level are inevitable. However, a drought management plan will help to mitigate the effects of lake level fluctuations

A dam has the potential to restrict upstream and downstream migration by fish. Seven species of fish have been found in the vicinity of the proposed dam site and five of these require access to and from the sea during part of their life cycle. If upstream migration were blocked by the dam, the self-sustaining fish community in the reservoir and upstream would be restricted to brown trout, upland bullies and possibly land-locked koaro. Remnant populations of the other species upstream of the dam would either die out or migrate downstream. At a structure as high as the proposed dam on the Lee River (>48 m), it is only practical to provide upstream access for the strongest of migrants such as elvers and young koaro. A fish pass could be developed as part of the spillway to provide an uninterrupted wet surface that leads from the downstream base of the dam to permanent water in the reservoir. During periods when the reservoir is not completely full a small flow of water would need to be pumped across the weir crest to form the continuous wetted surface. An alternative trap and transfer system could also be developed to manually move fish over the dam wall. However, a manual system would require continual effort and maintenance.

Downstream migration also needs to be considered and will probably only occur during periods in autumn when water is released through the spillway. However, many natural autumn freshes may be 'captured' within the reservoir as water levels recover following flow augmentation over the summer. Therefore, spilling is only likely to occur during wet years. If successive dry years result in no spilling during autumn, the only feasible option to facilitate downstream migration would be to trap migrants and manually transfer them downstream over the dam wall.

In order to support a consent application for the construction of the dam some further ecological work would be required. This would include a habitat survey and modelling exercise on the Lee River to determine the effects of the proposed flow regime on habitat availability for key species found in that part of the catchment. This would enable a more detailed assessment of an appropriate minimum flow for this reach of the river and also help determine the flows required to effectively flush sediment and algae from this reach of the river. It would also be wise to sample stream invertebrate communities in the vicinity of the dam to ensure that the results from further downstream can be extrapolated to this section of the river. Collection of pre-dam water quality and temperature data would also be useful for any future monitoring efforts, along with an assessment of the importance of the lower Lee River and tributaries for trout spawning.

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1. INTRODUCTION

Water in the Wairoa/Waimea catchment has come under increasing demand for out-of-stream uses, particularly irrigation, to the extent that water is currently over-allocated in the lower catchment. Augmentation of flow from a water storage reservoir is being considered during periods of low flow. It is hoped that this development would also make it feasible to alleviate some of the pressure on instream values, including recharging groundwater resources, while still meeting the increasing needs of out-of-stream water users.

The upper Lee River catchment has been chosen by the Waimea Water Augmentation Committee (WWAC) as the most promising location for the proposed reservoir (Tonkin & Taylor 2006). Preliminary hydrological modelling has been undertaken, predicting the inflows and outflows from the dam and associated changes in the storage volume required to maintain minimum flow targets downstream under projected levels of abstraction.

This report discusses potential effects of the proposed water storage dam and the augmentation flow regime on:

1. Flow regime downstream of the dam,
2. Water quality, both behind the dam and downstream,
3. Fish passage past the dam,

with a particular focus on the likely ecological effects and some suggestions for potential approaches to mitigation.

2. FLOW RELATED ISSUES

In this section we discuss potential effects of changes in the natural flow regime caused by the dam and augmentation scheme on aquatic ecosystems in the Lee River, and in the Wairoa/Waimea River, below the Lee confluence. Our assessments are based on interpretation of preliminary simulated flow records for two sites, provided by Tonkin & Taylor:

1. The Lee River at the proposed dam site
2. The Wairoa River at the Irvine's flow recorder site

Two simulated flow series were provided for each of these sites; a natural flow regime and the regime under the proposed augmentation scheme. Both were based on historical flow records and span from November 1957 to April 2006. The flow regime under the augmentation scheme was constrained to deliver a minimum flow immediately below the dam of 470 L/s (equivalent to the mean annual low flow (MALF) at this point), and 1100 L/s in the Waimea River at Appleby Bridge.

Our analysis focused on water years (July-June) so that the full summer potential augmentation period was included in a single water year. The first and last years in the record (1957-1958 and 2005-2006) were excluded because neither one constituted a full water year. We examined hydrographs for the highest flow year, lowest flow year, median flow year and average flow year to assess the likely effects of the augmentation scheme on the flow regime at each site. These years were defined by the total discharge summed over each water year (July-June). To assess the effects of augmentation around periods of extremely low flow we also examined the hydrographs for the water years containing the driest February and driest March respectively.

These hydrographs show that during high flow years and even during median flow years relatively little flow augmentation is required and the effects on the hydrograph are comparatively minor (Figures 1, 2a and b). However, during low flow years the effects at both sites are more pronounced (Figures 1 and 2c). As expected augmentation produces higher flows at both sites during periods of naturally low flow and flows are reduced to some extent following periods of augmentation as the reservoir in the Lee is refilled.

These effects are particularly noticeable in the hydrographs for the water years containing the driest February and March, respectively (Figure 3 and 4). In these years the flow in the Lee River immediately below the dam is predicted to 'flat–line' at the minimum flow (470 L/s) for substantial periods, following prolonged episodes of augmentation (Figure 4). It is also evident in these figures that small freshes that occur during periods of augmentation will be effectively removed from the Lee River downstream of the dam, as this water will be used to recharge the storage reservoir (Figure 2).

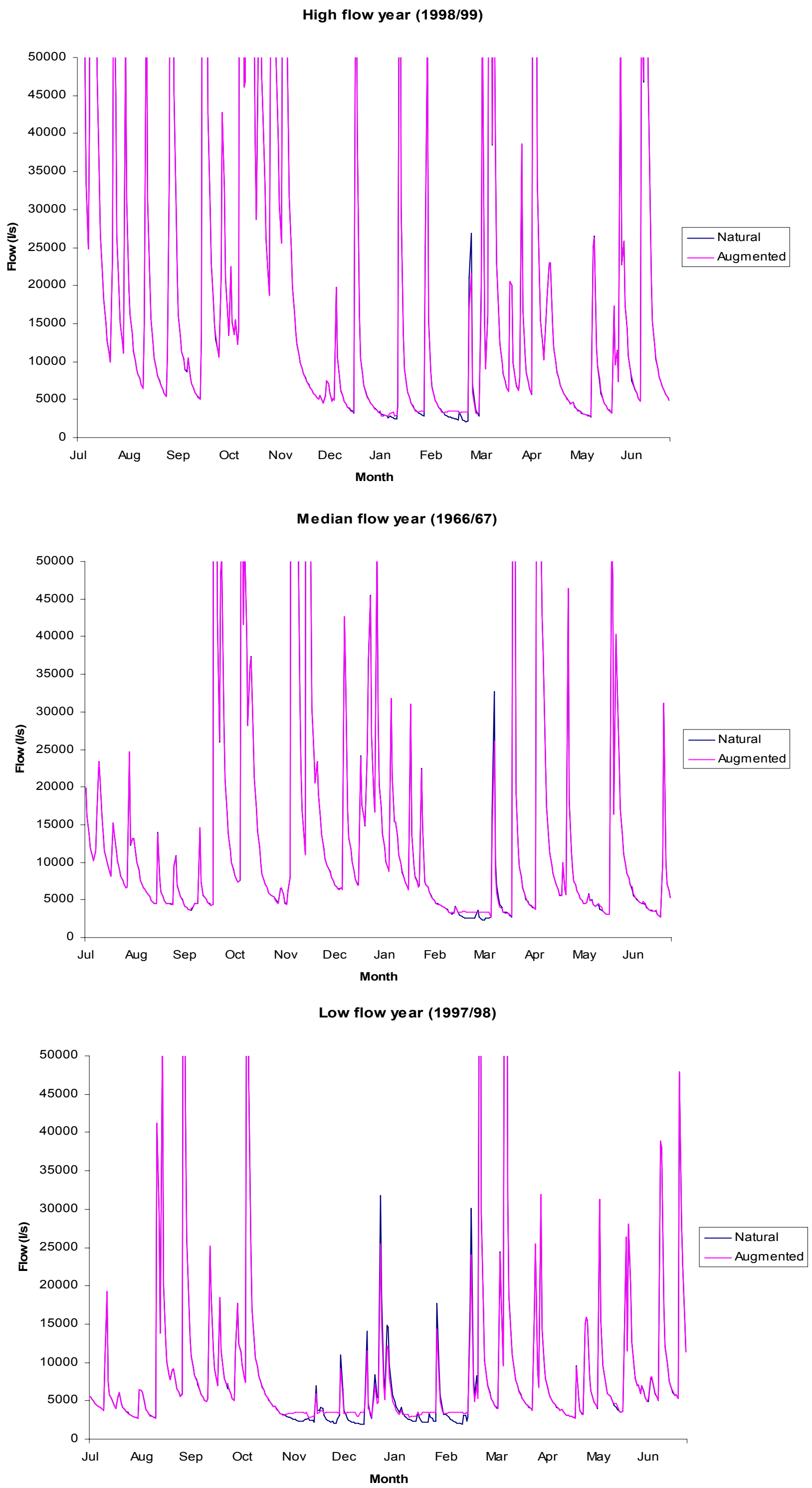


Figure 1. Hydrographs for (a) the highest, (b) the median, and (c) the lowest flow years between 1958 and 2005 for the Wairoa at Irvine's flow recorder site, comparing the naturally occurring flow and the predicted flow under the proposed augmentation scheme.

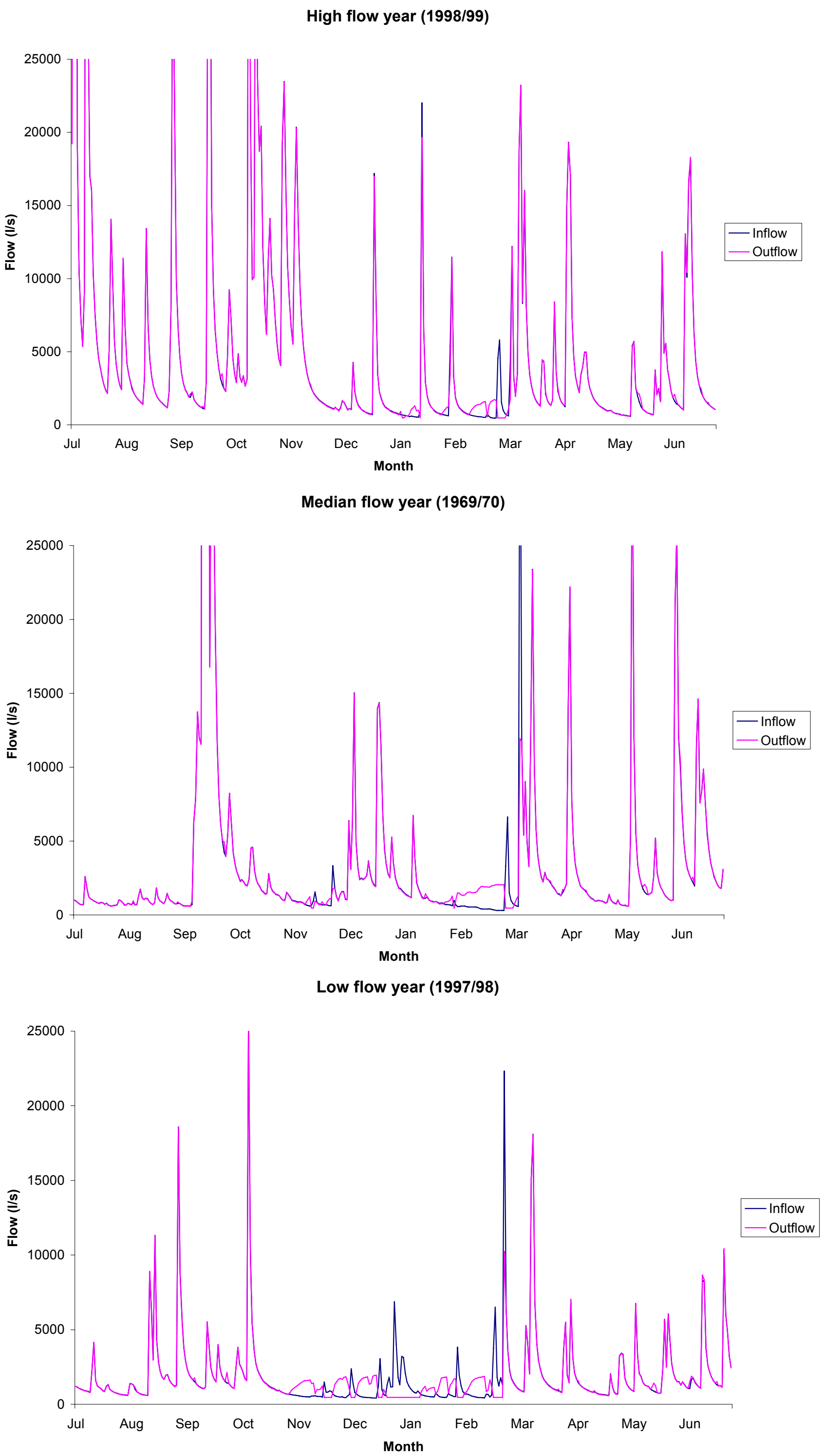
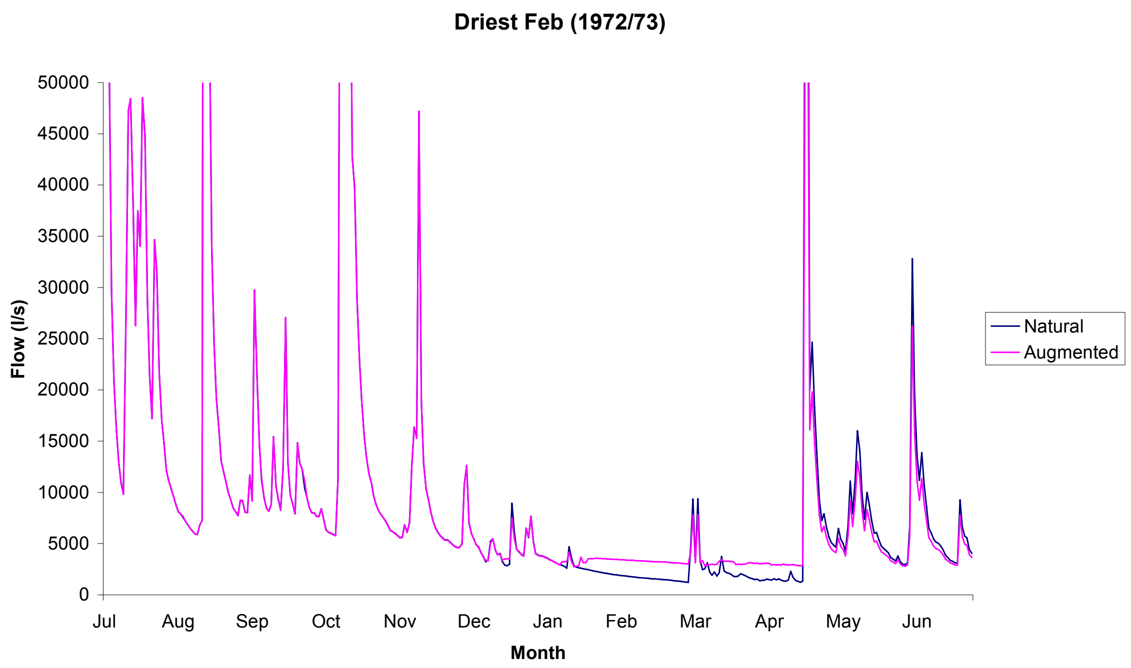


Figure 2. Hydrographs for (a) the highest, (b) the median, and (c) the lowest flow years between 1958 and 2005 for the proposed the Lee River dam site, comparing the naturally occurring flow (inflow) and the predicted flow under the proposed augmentation scheme (outflow).



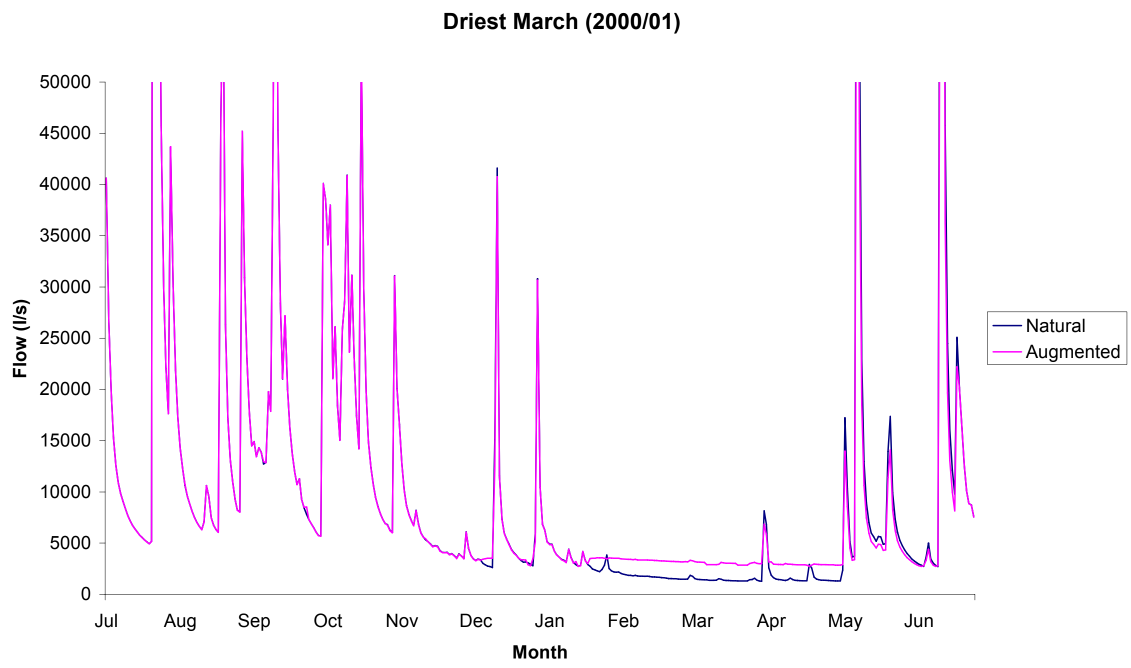
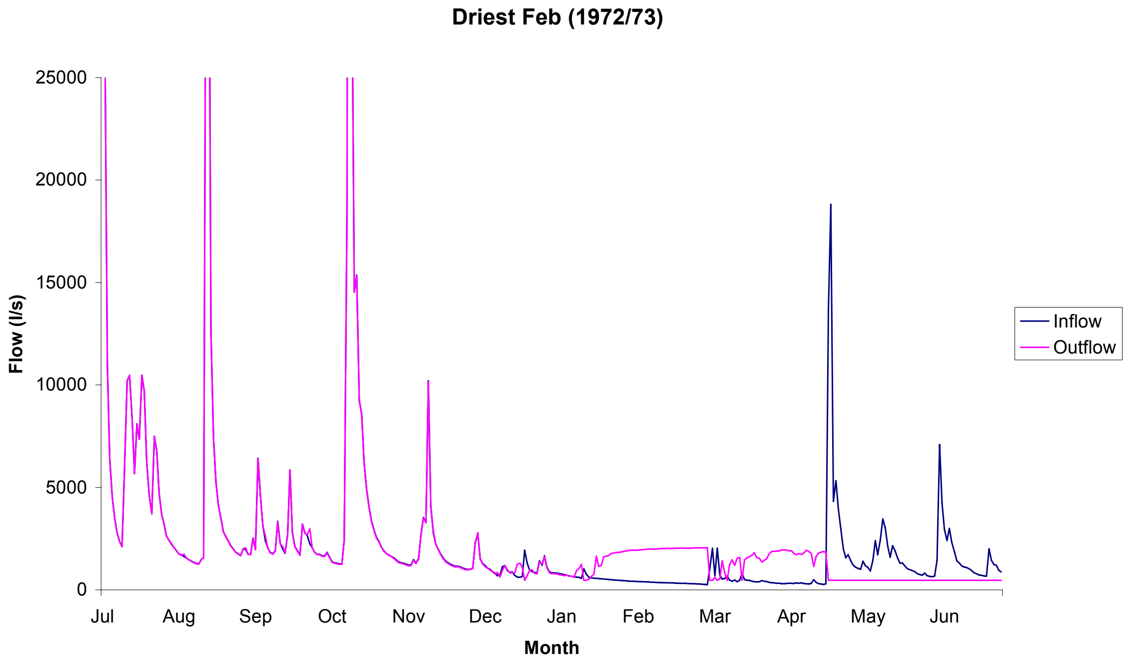


Figure 3. Hydrographs for water years with (a) the driest February, and (b) the driest March between 1958 and 2005 at the Wairoa River at the Irvine's flow recorder site, comparing the naturally occurring flow and the predicted flow under the proposed augmentation scheme.



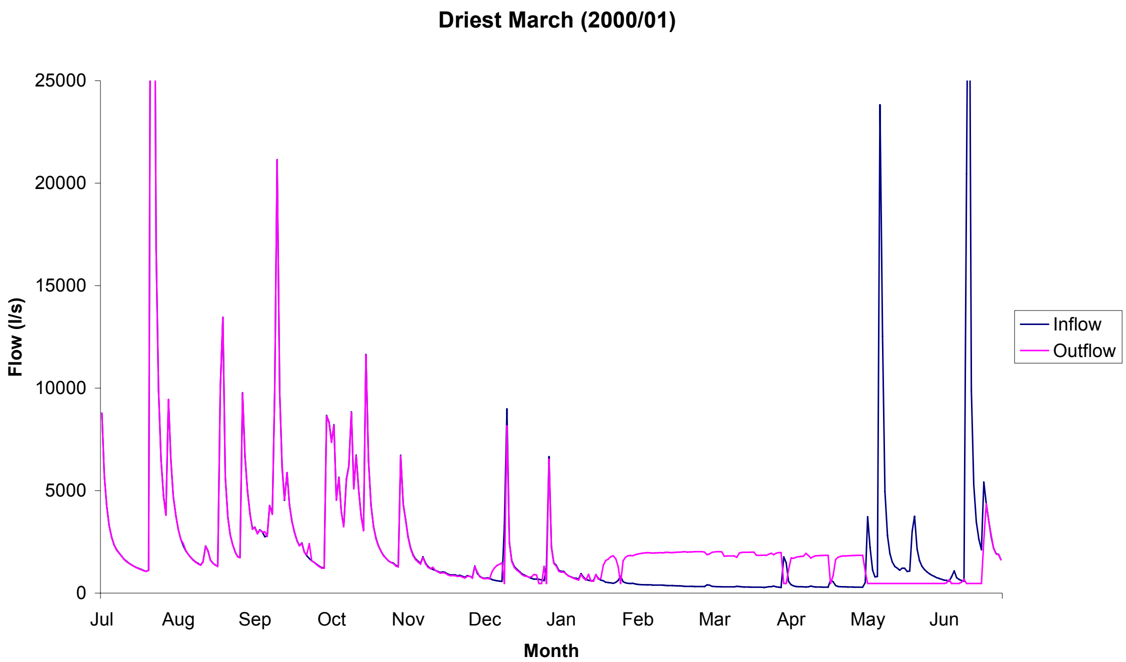


Figure 4. Hydrographs for water years with (a) the driest February, and (b) the driest March between 1958 and 2005 for the proposed the Lee River dam site, comparing the naturally occurring flow (inflow) and the predicted flow under the proposed augmentation scheme (outflow).

2.1. Wairoa River at Irvine's flow recorder site

The effects of the proposed augmentation scheme on the Wairoa River below the confluence with the Lee (and hence the Waimea River) are likely to be largely positive. The most obvious effect of augmentation in this reach is higher minimum flows. This mainly affects the summer months (January–early March), when minimum flows are generally predicted to be in the order of 3.3 m^3/s under augmentation, compared with 1.2 m^3/s under the natural flow regime. Higher flows during this period could have either positive or negative effects on habitat availability for freshwater species, depending on their habitat preference (i.e. whether they prefer deeper, faster water or shallower, slower habitat). However, overall it is likely that the increased flow would have beneficial effects on productivity, by increasing the overall area of wetted habitat during periods of naturally low flow. This is especially the case since some shallow, slow water habitat will still be provided in the stream margins even at higher flows. Habitat modelling focused on this reach could shed light on this, but is arguably unnecessary considering the short distance between the Lee confluence and the section of the Wairoa/Waimea river where habitat modelling has already been undertaken (Hay & Young 2005a).

There is a very slight reduction in flow relative to the natural flow in the periods immediately following augmentation, particularly prolonged episodes. This is mainly evident in the autumn and early winter (April–July). These flow reductions are so minor that they are unlikely to have any environmental effect.

Overall the proposed augmentation scheme is predicted to have very little effect on the flow regime experienced in the Wairoa River at Irvine's and areas below this, other than increasing minimum flows (Table 1). This is evident in the very minor differences in the median flow predicted during summer into early winter (January to March), when most flow augmentation is likely to take place, and during autumn to early winter (April to June), when refilling of the storage reservoir is most likely to reduce downstream.

Table 1. Comparison of flow statistics under the natural flow regime and proposed flow augmentation scheme for **t**he Wairoa River at the Irvine's flow recorder site.

	Wairoa Natural (l/s)	Wairoa Augmented (l/s)
Mean	16309	16305
Median	7336	7293
Minimum	1206	2740
Median Jan to March	4549	4470
Median April to June	6763	6740

2.2. Lee River below the proposed dam site

The effects of the scheme on the flow regime in the Lee River below the dam site are more pronounced than in the Wairoa. Consequently, the potential effects on aquatic ecosystems are likely to be greater. As expected the augmentation scheme is predicted to increase the minimum flow and the median flow, particularly during the summer (January to March; Table 2). These changes should have largely beneficial effects on productivity due to the increased wetted area most of the time, although habitat modelling would need to be conducted in this reach to confirm this. Any negative effects of the augmentation scheme will also be more pronounced in the Lee River than further downstream.

Table 2. Comparison of flow statistics under the natural flow regime and proposed flow augmentation scheme at the proposed Lee River dam site.

	Inflow (l/s)	Outflow (l/s)
Mean	3524	3520
Median	1585	1670
Minimum	261	470
Median Jan to March	983	1366
Median April to June	1461	1498

2.2.1. 'Flat-lining' of flows

One of the most obvious effects of the dam and augmentation scheme on flows in this reach are the prolonged periods of 'flat-lining' at the minimum flow (470 L/s) experienced below the dam, as the reservoir is refilled, following long periods of augmentation. An extreme example of this is evident in Figure 4a. Following the driest February on record in 1973 and assuming the augmentation scheme had been in place, flow would have 'flat-lined' for almost three months (from late April until early July). In this case the first flood following a long period of low stable augmented flows would have been almost 19 m^3/s under the natural flow regime. However, it would have been entirely captured by the reservoir, as were subsequent smaller floods. This would have removed the potential for these floods to scour and flush excessive periphyton growths, as well as other detritus, that may have accumulated in the downstream river during the preceding stable low flows. However, this may be a reasonably rare occurrence given the similarity of median flows for April to June under the natural and altered flow regimes (i.e. inflow to the dam versus outflow below the dam, Table 2).

These prolonged (albeit infrequent) periods of 'flat-lining' may lead to development of nuisance growths of periphyton, or exacerbate existing proliferations. Excessive periphyton growths are associated with a reduction in the diversity of invertebrate community, as well as the diversity of the periphyton community itself. Invertebrate communities generally tend to become dominated by smaller invertebrates and taxa that are less available, or of lower value, as food for fish (particularly drift feeding fish, such as trout).

The timing of these low flows (over autumn and winter) is likely to minimise any increase in water temperature caused by reduced flow, and consequently rates of periphyton growth are likely to be slower than if these periods of low flow occurred earlier in the year. Water temperatures downstream of the dam may be further reduced if cooler water from the bottom of the dam is released during these periods (see discussion of water temperature in Water Quality Issues section). Conversely, the water stored behind the dam may have been warmed through the full depth of the water column if it had been held at sufficiently shallow levels, in which case the flow release may increase water temperatures downstream of the dam.

The potential for periphyton proliferations in the Lee River is reduced by its relatively low natural concentration of dissolved nutrients (Hay & Young 2005b), which mean that periphyton growth may be nutrient limited in this river. However, there is potential for the increased head, caused by water storage behind the dam, to increase the contribution of seepage from groundwater into the channel; this is often associated with higher nutrient concentrations (Biggs 2000). Nutrients may also be released into the reservoir water from submerged vegetation, soil and incoming debris that is trapped within the reservoir.

Releasing additional water over a short duration to coincide with naturally high inflow to the dam could provide for flushing of excessive periphyton growths. A flushing flow of approximately 6-8 times the preceding baseflow is generally sufficient to reduce periphyton biomass (Biggs & Close 1989; Biggs 2000). Given a preceding base flow of 470 L/s (equivalent to the minimum flow) a release of 2.8–3.75 m^3/s as a flushing flow would be required. This could be released whenever inflow to the dam naturally exceeded this level and stable low flows have predominated for the preceding month. The duration of flushing flow required to remove excessive algal biomass may be relatively short, perhaps in the order of a few hours. However, extending the release for a longer period may also help stimulate fish migration, as discussed below. Provision would need to be made in the design specification for the dam for release of such large volume through the dam outflow, since these releases would be necessary when the water storage behind the dam is below spilling level.

'Flat-lining' low flow during autumn and early winter has the potential to impact on fish migration. The timing of these low flows make them particularly relevant to brown trout, whose upstream spawning migrations occur at this time of year and are often associated with high flow events. It is not known how important the Lee River and it tributaries downstream of the proposed dam site are as spawning streams for trout. Some additional investigation into this may be warranted. However, downstream migration of mature eels and juvenile koaro are also associated with high flow events at this time of year (see discussion on fish passage below). If the duration of the flushing flows suggested to reduce algal proliferation were extended, say to 24 hours, this may provide an opportunity and stimulus for migrating fish to move.

2.2.2. Rapid Flow fluctuations

The slow ramping up of outflow from the dam during periods of augmentation, interspersed with rapid reductions to the minimum flow, result in an inversion of the natural hydrograph for this section of the Lee River (Figures 2 and 4). This flow regime results from the need to balance changes in the contribution of flow from other tributaries to maintaining the minimum flow plus abstraction volume in the lower Wairoa and Waimea Rivers. As inflow from other tributaries decreases during natural flow recession, the augmentation flow from the dam must be increased accordingly. Conversely, whenever there is adequate flow from the other tributaries to maintain the flow requirements downstream, as occurs during small freshes there is an opportunity to capture water in the reservoir, and outflow from the dam is reduced accordingly. One potential impact of this inverted hydrograph is if there is a sudden reduction in flow at the end of periods of augmentation this may lead to stranding of fish and invertebrates. An example of one of these flow reductions is the simulated drop from 1825 L/s to 470 L/s between 20 and 21 April 1973). The effect of these flow reductions depends on how suddenly they occur. There is the potential to minimise these effects by "ramping" flow down gradually over several hours.

2.3. Sediment regime

One other issue is that sediment supply below the dam may be reduced, as sediment from upstream is impounded behind the dam (Young et al. 2004). This may lead to armouring of the bed downstream and/or possibly incising/deepening of the channel. Bed armouring may encourage periphyton proliferation, by offering more stable substrate and reduced abrasion by fine sediments during flood events. Armouring can also reduce the availability of gravels suitable for trout spawning. However, the coarser substrate size and greater substrate stability may be beneficial for benthic invertebrate production, as long as they are not smothered by excessive periphyton growth. The build up of sediment behind the dam will also reduce its storage capacity over time, although this has been considered in the dam design.

One potential remedy to the effects on downstream habitat would be to periodically dredge out sediment built up behind the dam and place it on downstream side of the dam, on or around the spillway so it would be carried downstream during subsequent spilling events. Alternatively, if the dam has the facility to bottom release and the gauge of the release pipe is large enough, then releasing water from the bottom of the dam during natural flood events (rather than letting it spill over the top) may allow some of this sediment to be carried downstream. However, the practicality and costs/benefits of such an initiative would need to be considered carefully before proceeding.

3. WATER QUALITY ISSUES

Currently, water quality in the Waimea Catchment is generally high. Maintenance of high quality water is important for three purposes:

- Instream ecological and recreational requirements downstream of the dam.
- In-reservoir requirements for ecological and recreational purposes.
- Consumptive uses, such as irrigation, downstream.

3.1. Current water quality

Historically, water quality in the Lee River has generally been good. Data from Tasman District Council's (TDC) regular State of the Environment (SoE) monitoring indicates that water quality in the Lee consistently complies with guidelines for nutrient concentrations, pH, dissolved oxygen, water clarity, and faecal indicator bacteria (Hay & Young 2005b). The only guidelines exceeded from the Lee at Meads Bridge SoE monitoring site were turbidity and water clarity, and this occurred only occasionally (i.e. on <8 % of sampling occasions).

Tasman District Council's SoE monitoring also includes observations of periphyton using a visual assessment where the percentage cover of different algae types are weighted according to their pollution tolerance, and then combined to give an overall score for the site ranging between 1 and 10 (1 indicating a site with highly degraded water quality and a score of 10 indicating a healthy site with good water quality[1]) (Biggs & Kilroy 2000). The minimum score recorded from the Lee River at Meads Bridge site in 14 sampling occasions between April 2001 and November 2004 was 7.53. The maximum value recorded during this period was 10 and the median was 9.80, indicating that the periphyton community in this reach is generally indicative of good water quality. Even during an extremely low flow period in late summer in 2001, when some other sites in the Waimea Catchment recorded scores <5, the Lee at Meads Bridge site still scored relatively high (>9). This suggests that algal growth in the Lee River may be limited by low nutrient concentrations, rather than controlled by flow fluctuations.

3.2. Potential effects of the dam on downstream water quality

The construction and operation of the proposed water storage dam in the Lee has the potential to have some negative impacts on the water quality in the river. The most obvious effect is the likely increase in turbidity and sediment load during the construction phase. Storage of water in reservoirs also results in changes to the physical and chemical characteristics of the water released downstream. The changes depend on a wide variety of factors including the average length of time taken for water to pass through the reservoir (residence time), the position of the reservoir within the catchment, whether the water within the reservoir becomes stratified and anoxic, the quality of incoming water, and the level of the reservoir outlet (Young et al. 2004).

Generally, the longer the residence time, the greater the potential effects of water storage. Based on preliminary hydrological modelling, the average residence time for water stored in the proposed Lee impoundment will be in the order of six weeks. This represents the time required for the average storage volume in the impoundment (12,686,706 m^3 based on a synthetic record for November 1957 to April 2006) to be accumulated or drained by average inflows and outflows from the dam (approximately 3522 L/s). By way of comparison, the estimated residence time of water in the Maitai Dam is close to eight weeks, based on a mean

[1] The 'Rapid Assessment Method 2' protocol (Biggs & Kilroy 2000) is used. This involves visually estimating the percentage cover of all algae present, classified according to their appearance (e.g. growth-form and colour), at a number of regularly spaced points across five separate transects. The percentage cover values are weighted according to the pollution tolerance of the different algal classifications, and then combined to give an overall score for the site ranging between 1 and 10. The TDC's methodology varies from that outlined by Biggs & Kilroy (2000) in that clean substrate is given a score of 10 (along with pollution intolerant classes of algae), rather than scoring 0.

inflow from the Maitai North Branch of 610 L/s and a lake volume of 4 million m^3 (Stark 2000). A worst case scenario for residence time in the Lee reservoir can be estimated as the time required to drain the dam from full (13 million m^3) assuming the minimum outflow of 470 L/s, which would require approximately 46 weeks. However, this scenario would never actually occur under the proposed operation of the scheme. Nevertheless, the six week long average turnover time would provide plenty of opportunity for thermal stratification of the impounded water, deoxygenation of the lower strata to develop and for phytoplankton blooms to develop if nutrient levels are sufficient. Pridmore & McBride (1984) noted that residence times less than 14 days may limit phytoplankton growth in lakes, even when nutrients are not limiting.

3.2.1. Increased sediment load during construction

Excessive sediment loading in rivers can impact primary producers, benthic invertebrates and fish through direct physical effects (such as smothering and abrasion), and/or indirectly, through changes in the availability or quality of food resources or habitat (Crowe & Hay 2004). The most commonly described impact of fine sediments on algae and other aquatic plants is a reduction in photosynthetic activity and thus, primary productivity, due to reduced light penetration through the water column (e.g. Davies-Colley et al. 1992; Lloyd et al. 1987; Van Nieuwenhuyse & LaPerriere 1986). When transported in suspension, or as bedload via saltation, fine sediments can also damage or physically remove aquatic plants and algae through abrasion (Lewis 1973a, 1973b; Newcombe & MacDonald 1991). When fine sediments are deposited on the river bed, they can become incorporated in epilithic (stone-surface) biofilms, reducing organic content and thus the nutritional value of the biofilm as food for macroinvertebrates (Graham 1990). Deposition of fine sediments can also reduce biomass of periphyton and aquatic macrophytes through direct smothering of existing plants (Yamada & Nakamura 2002), and via a reduction in stable attachment surfaces for attached algae, such as periphytic diatoms and filamentous taxa (Wood & Armitage 1997).

Waters (1995) commented that ‘by definition, benthic invertebrates inhabit the stream bottom; therefore, any modification of the streambed by deposited sediment will most likely have a profound effect upon the benthic invertebrate community’. The effects of fine sediments on benthic invertebrates are wide-ranging and can include a reduction in feeding ability, alteration of habitat, increased drift and increased scouring and abrasion. Ultimately, these changes result in a change in community composition, with taxa that are intolerant to the impacts of fine sediment being replaced by those more adapted to these conditions.

High loads of fine sediment in rivers are known to impact fish, both through direct physical effects, and less directly as a result of effects on habitat and food availability. Suspended sediments can scour and abrade fish, particularly the gill-rakers and gill filaments, making fish in turbid waters more susceptible to disease and even causing mortality in extreme cases (Wood & Armitage 1997). Deposited fine sediments can cause a reduction in suitable spawning habitat, reducing survival or hindering development of eggs and fry, and can reduce habitat and cover for juvenile and adult fish. Growth rates of fish are also commonly decreased in rivers with high fine sediment loads, due to a reduction in the feeding efficiency of visual-feeders (such as trout) in low clarity waters, as well as reductions in the invertebrate food-supply for drift-feeders.

The effects of elevated sediment load are likely to be relatively short lived in the Lee River, being largely confined to the construction phase, although this could take up to two years. Given the reasonably frequent high flood flows generated in the catchment, deposited sediment should be flushed out of the system reasonably rapidly once the construction disturbance is finished and the reservoir filled. Effects can be minimised by good construction techniques and sediment control.

3.2.2. Water temperature

The main water quality concern during the operation of the augmentation scheme is likely to relate to water temperature. Using reservoir water to augment flow in a river presents problems because the temperature regimes of lakes and rivers are quite different. Lakes, being larger in volume, tend to respond far more slowly to climatic influences and tend to remain warmer in winter and cooler in summer than rivers. However, water held in relatively shallow lakes or impoundments during summer has the potential to become significantly warmer than the inflowing water. For, example water temperatures in the Cobb Reservoir were consistently higher than those recorded in the river upstream between December 1999 and July 2000 (Young et al. 2000). On average the reservoir water was 3°C warmer, with a maximum difference of 8.5°C.

The main concerns with water temperature are the effects of high temperatures on aquatic life. Some species prefer relatively cool water and may become stressed or die if temperatures become too high. For example, laboratory studies indicate that brown trout growth is optimal at 13°C (Elliott 1994). Trout will cease feeding once temperatures climb above 19°C and begin to die once temperatures exceed 25°C for a sustained period (Elliott 1994; Jowett 1997). Trout cannot tolerate temperatures above 30°C for even a short period. Similarly, Quinn et al. (1994) examined the temperature tolerances of 12 types of freshwater invertebrates and found that LT50 values (i.e. the temperature at which 50% of animals died after 96 hours) ranged from 22.6°C to 32.4°C. One of the most common types of invertebrates (the mayfly *Deleatidium*) was the most sensitive (Quinn et al. 1994).

The above information on lethal and sub-lethal temperatures is for relatively short term exposure. From these data, one might get the impression that a trout population could "cope" with short to longer periods of high water temperature, providing they did not exceed the short term lethal tolerances. This is an incorrect assumption. In fact the impacts of "sub-lethal" high water temperatures are expressed not only in fish behaviour and growth rate but also in survival rates and population production. Trout deaths have been reported in New Zealand rivers when water temperatures have equalled or exceeded 26°C (Jowett 1997).

Trout eggs are highly sensitive to temperature changes, especially during the first half of their incubation period (Bell 1986). Brown trout appear to require water temperatures less than about 11°C for successful incubation (Hay et al. 2006). Winter water temperature was one of the main predictive factors in Jowett's (1992) "100 rivers models" predicting brown trout abundance in New Zealand rivers. Jowett's study indicated that rivers with winter water temperatures >10°C contained very few, or no, brown trout. Winter temperatures exceeded 10°C in only eight of the 89 sites in 82 rivers used to construct his models. When these sites where excluded, no significant correlations remained between any temperature variable and brown trout abundance. It appears from this that high water temperatures in winter (the spawning and incubation period) may limit brown trout recruitment in New Zealand rivers. This is supported by Scott & Poynter (1991), who showed that temperature increases, predicted under climate change scenarios, had the potential to reduce the northern range of both brown and rainbow trout in New Zealand. Increased winter temperatures, affecting spawning and incubation, appeared likely to have the greatest impact.

Increased water temperature can also promote algal growth, increasing the risk of algae developing to nuisance levels. However, other factors such as flow variability and the availability of light and nutrients are expected to have a larger effect on algal growth rates.

The temperature of water released from the dam may be able to be controlled to some extent by manipulating the level from which the released water is sourced. This relies on having the ability to select the level in the water column in the impoundment from which the water released downstream is sourced. If the water in the impoundment is stratified during summer, then cooler water from lower in the water column could be released to minimise the change in temperature between inflow and outflow.

3.2.3. Deoxygenation of bottom water

Another concern, particularly for a newly formed impoundment, is possible deoxygenation of lake-bottom waters due to decomposition of submerged terrestrial vegetation and other organic matter that sinks down to the bottom of the reservoir. As the concentration of dissolved oxygen near the lake bed declines, the release of phosphorus, iron and manganese increases sharply (Young et al. 2004). Discharge of this water and the high levels of manganese and iron contained within it, can have consequences for aquatic life downstream (Stark & Hayes 1996; Young 2001). This has been recorded below the Maitai Dam, following its commissioning in 1987, and iron levels have occasionally exceeded the Canadian guideline level of 0.3 g/m^3 (Crowe et al. 2004). However, manganese is rarely found at concentrations above 1 g/m^3 in fresh waters, while tolerance values reported for aquatic life range from 1.5 g/m^3 to over 1000 g/m^3 (USEPA 1986). For this reason manganese is not generally considered to be a problem in fresh waters (Stark & Hayes 1996). Nevertheless, the operation of the discharge from the Maitai Dam into the Maitai South Branch has also been associated with a decrease in water clarity for a relatively short distance downstream (Stark & Hayes 1997). Reductions in water clarity of up to 10 m have been linked with the discharge from the Maitai

Dam and high concentration of manganese and iron precipitate may be responsible for this reduction in clarity.

Removal of terrestrial vegetation and top soil from the dam footprint prior to filling would help reduce the chances of deoxygenation within the reservoir. There may also be some ability to restrict the amount of iron- and manganese-rich water released from the reservoir by manipulating the level from which the released water is sourced. However, the critical periods when iron and manganese concentrations in bottom waters are high are likely to correspond with warm water temperatures in the upper layers of the reservoir. Therefore a trade-off would need to be considered between the release of warm water with low iron and manganese concentrations versus cooler water with potentially higher concentrations. In addition, if surface water is preferentially discharged from the reservoir the bottom waters will have a longer residence time within the reservoir and potentially accumulate even higher concentrations of iron and manganese.

3.2.4. Release of nutrients

The retention of water in the reservoir may result in an increase in nutrient concentrations in the water released from the reservoir (Young et al. 2004). This could be particularly problematic if deoxygenation occurs in the bottom waters of the reservoir, which may facilitate the release of available phosphorus from the sediments. Decomposition of organic matter deposited on the lake bed will also release other nutrients. For example, concentrations of ammonium nitrogen were elevated in the Cobb Reservoir during a period of low lake levels and may have been responsible for stimulating an abundant growth of filamentous green algae downstream of the power station (Young 2001). Once again, removal of terrestrial vegetation and top soil from the dam footprint prior to filling would help reduce the chances of this occurring.

3.3. Potential water quality issues within the reservoir

3.3.1. Fluctuating water levels behind the proposed dam

The operation of the augmentation scheme will see some fluctuations in the water level behind the dam. Although (based on preliminary hydrological modelling) the dam will be full and potentially spilling approximately 83% of the time, there will be periods during most years when augmentation will draw the water level below full. The median annual maximum draw down that would have occurred for the synthetic record for November 1957 to April 2006 (i.e. the median over this period of the maximum reduction in water level behind the dam in each year) is approximately 1.8 m, and the maximum is approximately 46 m (i.e. the full height of the dam), which would have occurred in May 2001 if the scheme were in place. These drawdown levels are based on unrestricted supply to irrigators and a high level of demand (exceeded only in 10% of years) and thus are not necessarily a good indication of what would occur in practice. A drought management plan will be prepared as part of the Stage II investigations for the scheme, and is likely to include rationing and supply restrictions once the reservoir drops to certain trigger levels (yet to be determined).

Variations in lake levels occur in most lakes. In New Zealand, these fluctuations are usually less than 4 m, but may exceed 20 m in extreme examples, such as Lake Hawea (Mark 1987). In natural lakes, the frequency and magnitude of these fluctuations may depend on a range of factors including; catchment and lake size, lake morphology, climatic conditions, and the nature of inlet and outlet rivers. However, the fluctuations usually are relatively constant daily and seasonally and the lake flora and fauna have adapted to these changes (Mark 1987). However, in hydroelectric lakes, irregular and artificial changes in water levels may severely disturb the biota, and it may take years for plant and animal communities to develop (Mark 1987).

The most direct effect of receding water levels on aquatic communities is exposure resulting in desiccation in summer and freezing in winter. This is used as a control measure in some lakes to kill nuisance aquatic plants. Even short periods of exposure can have a significant impact on macroinvertebrates, although logs, roots and moist vegetation on the exposed bed may provide some protection against desiccation (Winterbourn 1987). According to Greig (1973) some macroinvertebrates, such as snails and worms, inhabiting the upper littoral regions of Lake Waitaki were able to tolerate severe exposure, at least over the short-term. Furthermore, Fillion (1967) observed chironomid larvae surviving up to 85 days on an exposed lake shore. However, Greig (1973) noted that some animals, particularly caddisflies, did not appear in the littoral zone except at the bottom of the drawdown zone where water cover was more permanent and the finest sediment and organic matter was deposited.

Fluctuating water levels in the proposed Lee River impoundment are likely to retard the establishment of macrophyte communities and their associated macroinvertebrate communities around the shallow margins, which are generally recognised to be the most diverse and productive component of the lake fauna (Kelly & McDowall 2004). Those plants that do establish around the shallow margins of the reservoir will periodically be exposed and killed during periods of draw down. Without the stabilising influence of vegetation cover the reservoir margins are likely to be more prone to erosion. Given that the aim of the reservoir is to store and release water, water level variations are inevitable. However, a drought management plan will help to mitigate the effects of lake level fluctuations.

3.3.2. *Sediment*

The sediment load in the Wairoa River (downstream of the Lee River) is relatively low to moderate and the design of the dam has considered the amount of sediment that will be trapped within the reservoir (Tonkin & Taylor 2006). During investigations for an alternative potential dam site in the upper Wairoa concerns were raised about the toxicity of metal-rich sediments sourced from ultramafic rocks in the catchment (Tonkin & Taylor 2006). However, there is no ultramafic material in the catchment of the proposed Lee reservoir and so no adverse effects of toxic sediments are expected.

3.3.3. *Algal blooms*

Prolific blooms of algae (phytoplankton) can occur in some lakes (Schallenberg 2004). Such blooms can result in unsightly accumulations of algal material and water quality problems such as reduced water clarity and deoxygenation of the bottom waters. One group of phytoplankton (called cyanobacteria) are a particular concern because they produce toxins that can cause sickness, and sometimes death, of people and animals that drink the water or ingest algal material. In drinking water reservoirs, cyanobacteria are also linked with taste and odour problems.

Algal blooms are primarily controlled by nutrient concentrations and are most common in nutrient-rich lakes (Schallenberg 2004). Light availability and the abundance of algal 'grazers' can also have a profound effect on algal bloom formation. Algal blooms have not been a significant problem in the neighbouring Maitai Reservoir (Stark 2000). The low nutrient concentrations of water in the Lee River would also suggest that algal blooms are unlikely to occur in the proposed reservoir.

4. FISH PASSAGE ISSUES

4.1. Existing fish community in the vicinity of the proposed scheme

Fifteen species of fish and one crustacean have been recorded from the Waimea catchment (Hay & Young 2005b). Fish distributions ascertained from these records indicate that seven species of fish and a crustacean (freshwater crayfish) were from the near vicinity of the proposed storage reservoir in the Lee River (Table 3). Both eel species, koaro, redfin and bluegill bullies have life cycle requirements that require access to and from the sea (Table 3).

Table 3 Fish species recorded from the near vicinity of the proposed storage reservoir in the Lee River

Common name	Scientific name	Life cycle
Longfin eel	*Anguilla dieffenbachii*	Migratory
Shortfin eel	*Anguilla australis*	Migratory
Koaro	*Galaxias brevipinnis*	Migratory
Brown trout	*Salmo trutta*	Freshwater
Redfin bully	*Gobiomorphus huttoni*	Migratory
Bluegill bully	*Gobiomorphus hubbsi*	Migratory
Upland bully	*Gobiomorphus breviceps*	Freshwater
Freshwater crayfish	*Paranephrops planifrons*	Freshwater

4.2. Changes to fish community post scheme commissioning

A dam has the potential to restrict access upstream of this point for all migratory fish. In a sense all fish migrate or move about a river system to some extent. In a detailed study of a trout stream, which included the interaction of trout with native species, Hopkins (1970) reported the possibility of some upland bully fry being displaced downstream with a reverse movement of yearling bullies upstream a year later. Therefore, the presence and resilience of all fish species above a dam is at risk if their population is depleted through natural events and recruitment from downstream is cut off.

In the absence of migratory species gaining access above the proposed dam on the Lee River, the most likely fish community that would establish in the storage reservoir and upstream would consist of brown trout, upland bullies and freshwater crayfish. It is possible that a 'land-locked' population of koaro may also establish if the reservoir provides the right conditions for larval koaro development. The brown trout in the reservoir could support a relatively small lake fishery. Any of the remaining species listed in Table 3 would remain as a remnant population until either dying out or migrating downstream. Those remnant species remaining the longest would be eels, a few of which could persist for up to 100 years.

Below the dam, all species listed in Table 3 can be expected to continue being present. For the stronger migrants, such as eels and koaro, the release of augmentation flows will act as an attractant for their juveniles to search for access above the dam and they will attempt to negotiate any sources of outflow from the dam. In turn, the accumulation of juvenile fish at the dam face searching for access will attract both aquatic and terrestrial predators.

4.3. Fish passage mitigation options

Placement of a dam on a river causes both upstream and downstream issues for migratory fish.

At a structure as high as the proposed dam on the Lee River (>48 m), it is only practical to provide upstream access for the strongest of migrants such as elvers and young koaro (WWAC has endorsed the decision that provision for other species is not expected). Both these species will attempt to scale structures such as the proposed dam provided they have an uninterrupted wet surface that leads from the downstream base of the dam to permanent water in the reservoir. Most upstream migratory attempts could be expected to occur from November to February. If an uninterrupted wet surface were to be incorporated in the spillway design, sporadic access for these stronger migrants would occur when freshes top the spillway. However, when the reservoir is below full a small flow of about 0.5 litres per second would need to be pumped across the weir crest to form a continuous wetted surface from the weir crest down to a ponding area at the bottom of the spillway. By ensuring augmentation flows and the ponding area at the base of the spillway coincide, migratory fish will naturally accumulate directly below the wetted surface provided for them on the spillway face. Design details would need to be arranged with an engineer and a biologist experienced with fish passage issues, but may include a 'dished' section from the weir crest to the bottom to keep the flows concentrated in one part of the spillway.

Alternatively, an attraction flow leading from a trap could be installed so that migratory species could be caught and manually transferred upstream. Of the two options, a functioning pass is preferred since it is less expensive to maintain and would be permanently in place to provide access at any time fish attempt to migrate. A trap, on the other hand, requires maintenance and unless operated continually could miss some migrations. However, traps do have the benefit of "feel good" about them in that people are able to see and count what is transferred regardless of the biological significance of the transfer.

Having provided access above the dam for koaro and eels, some consideration then needs to be given to providing their return access downstream. Koaro require downstream access after spawning in autumn when their larvae passively migrate downstream during a fresh. Consequently they will be naturally entrained, either via augmentation releases or spilling. Natural mortality of koaro larvae as they are shunted downstream is unknown. However, survival through extreme conditions provided by artificial structures such as intakes and turbines are some indication. Coutant &Whitney (2000) report that survival of planktonic fish through turbines is high. Therefore, a downstream pathway that is free of obstructions such as turbines is unlikely to improve koaro larvae survival and therefore not necessary.

Eels present a slightly different problem because they migrate downstream as mature (and often very large) adults. Depending on how they exit the dam, they can suffer some damage, though in the absence of turbines or screens, this is likely to be less of an issue. Eel downstream migration occurs during autumn freshes.

There are likely to be few options for enhancing out migration of koaro larvae or adult eels other than releasing some flow from the reservoir during autumn freshes when the strongest likelihood of these fish seeking downstream access will occur. With the intake tower set back from the dam wall, allowing release of water through the spillway rather than the intake may allow fish, particularly eels, a better chance of locating the exit. However, many natural autumn freshes may be 'captured' within the reservoir as water levels recover following flow augmentation over the summer. Therefore, spilling is only likely to occur during wet years. Lake and reservoir populations of eels are often restricted to out migration during years when there are a sufficient number of freshes to allow access out. As a contingency for successive dry years that produce no spilling during autumn, the only feasible option to facilitate downstream migration would be to trap migrants and manually transfer them downstream over the dam wall.

5. RECOMMENDATIONS FOR FURTHER WORK

In order to support an application for resource consents for the construction of the dam some further ecological investigations would be desirable. These would include:

1) A habitat survey and modelling exercise on the Lee River to determine the effects of the proposed flow on habitat availability for key species found in that part of the catchment. This would enable a more detailed assessment of an appropriate minimum flow for this reach of the river and also help determine the flows required to effectively flush sediment and algae from this reach of the river.

2) Sampling stream invertebrate communities in the vicinity of the dam to ensure that the results from further downstream can be extrapolated to this section of the river.

3) Collection of pre-dam water quality and temperature data to compare with results from any future monitoring efforts.

4) An assessment of the importance of the lower Lee River and tributaries as spawning areas for brown trout.

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