Memo

Date	13 July 2017
To	Dan Clark, Craig Davison
cc	
From	Shirley Hayward and Adrian Meredith

Opihi River catchment – Ecological flow review

1 Introduction

The Opihi River Regional Plan (ORRP) was developed during the 1990s and has been the operative flow and allocation plan for the Opihi catchment since 2000. The ORRP set out minimum flow and allocation volumes for the two main subcatchments of the Opihi River system (Opihi River and Temuka River) and included provisions for the newly created Opuha Dam. Subsequent consenting processes have further established minimum flows on several tributaries of the Opihi and Temuka rivers (Scarf 2002).

Through the Healthy Catchments project, the Orari-Temuka-Opihi-Pareora (OTOP) zone committee will develop a series of recommendations for managing water resources that better achieve the community outcomes set out for the zone. As part of this process reviews of the surface water minimum flows and surface water and groundwater allocations of the Opihi catchment are being undertaken to assist the zone committee in developing recommendations. The purpose of this memo is to contribute to these deliberations and identify any further information needs.

2 Ecologically important flow indicators

2.1 Low flows

Low flows determine the physical limitations of habitat availability for many fish species, in particular salmonids. The mean annual low flow (MALF) is a commonly used metric to describe low flow conditions. Jowett et al., demonstrated that adult brown trout density were controlled by summertime flows (e.g. MALF).

The MALF is also relevant to native fish species with generation cycles longer than one year, at least in small rivers where the amount of suitable habitat declines at flows less than MALF. Research in the Waipara River for example, where native fish habitat is limited at low flow, showed that the detrimental effect on fish abundance increased with the duration and declining magnitude of low flow (Jowett et al. 2008).

Not only the magnitude of low flows is important for fish habitat availability, but the duration of low flows has compounding effects on community resilience through flow related effects on water temperature, dissolved oxygen, pH and substrate quality (smothering by periphyton and macrophytes).

Low flows also potentially constrain fish passage and migrations to and from sea (for diadromous species).

2.2 Median flows

Low flows determine the physical limitations of habitat availability, particularly for fish. For benthic invertebrates, many of which have shorter lifecycles and more than one cohort per year, they are able to rapidly recolonise waterways following disturbances (e.g., freshes) (Jowett et al 2008). Because of

File reference:

their ability to rapidly respond to available habitat conditions, median flows provides a relevant indicator of their overall habitat availability.

The two flow metrics, MALF and median, can be considered as surrogate measures of space and food availability (Hayes and Kitson, 2013)

2.3 Floods and freshes

Flow variability has a range of effects on stream biota. Floods can reduce fish and invertebrate abundance but the effect of flood disturbance differs among species. Native fish are generally well adapted to surviving large floods, and many invertebrates are able to rapidly recolonise habitats following flood disturbance (Jowett et al., 2008). Floods and freshes also reduce periphyton biomass, and in particular, are the primary mechanisms for removal of nuisance periphyton growths (Biggs 2000). Conversely, long periods of stable low flows can give rise to a build-up of fine sediment and increase the likelihood of nuisance periphyton (algae and other microbes on the river bed) and macrophyte (aquatic plant) growth

Clausen and Biggs (1997) studied the relationships between benthic biota and hydrological indices in New Zealand rivers. They found that the flood frequency statistic FRE3 (the annual number of flood peaks greater than three times the median flow), was the most useful overall ecologically relevant flow index for benthic biota in New Zealand streams. Periphyton biomass decreased with increasing FRE3, whereas invertebrate density peaked at values of FRE3 of 10–15 floods per year.

While the FRE3 metric provides a useful rule of thumb for ecologically relevant flow disturbance, it was never claimed to be a flow threshold for periphyton removal in all rivers (Kilroy and Wech, 2017). In a recent Canterbury three-year study of periphyton growth and environmental factors (flows, nutrients, invertebrates) Kilroy and Wech (2017) examined flow/periphyton relationships to determine on a site by site basis the effective flow at which periphyton was reduced to low levels. This ‘effective flow’ ranged from 1.5 to 10 times median flow for different rivers.

In addition to cleansing rivers of periphyton and macrophyte accumulations, floods have an important function in maintaining the channel’s morphology and substrate. High flow events keep the coarse sediment load moving downstream, flush fine sediment from pools, the stream margins, and from within the substrate, and can help control the encroachment of riparian vegetation (Hayes and Kitson, 2013).

2.4 Frequency, extent and duration of dry reaches

Dry reaches of hill-fed rivers and small tributary streams are a natural occurrence in some Canterbury streams. Flow permanence can vary greatly along a river channel and can be broadly characterised as:

- perennial - permanently flowing year round
- intermittent - reaches that receive groundwater when the water table intersects the channel, and may also receive runoff
- ephemeral - reaches that receive runoff only (usually after rainfall) as the channel is always above the water table (Larned et al. 2008).

Many of the hill-fed rivers that flow across the alluvial plains have some flow intermittency in their mid reaches; typically flow is lost to the groundwater as they exit the hills and flow gains occur from emerging groundwater near the coast. The duration and extent of the dry reaches, as well as the frequency that they occur, can be exacerbated by water abstractions connected to the stream (Martin and Leftley, 2012; Lessard and Norton, 2011)). There are obvious negative consequences for aquatic communities and other instream values when the stream is completely dewatered. These include loss of aquatic habitat, loss of migration opportunities for fish, and loss of downstream drift and colonisation opportunities for invertebrates. A suite of work completed in the Selwyn River in recent years indicates that the longer a river reach remains dry, the less diverse the invertebrate and fish species are when flows return (Datry et al., 2007; Larned et al., 2007; Arscott et al., 2010). Cultural, recreational, and amenity values are also diminished with increasing frequency, duration and extent of dry reaches.

2.5 Minimum flows and allocation

A minimum flow defines a flow below which consented water abstraction must cease, and is generally designed to maintain a certain level of environmental protection for instream values including aquatic ecosystem health, cultural and recreational values. Minimum flows may vary seasonally to reflect different abstractive needs and provide for seasonal variations in ecological, cultural and recreational flow related requirements (e.g, spawning of fish, whitebait migration). Multiple minimum flows may be set for the same site/waterway providing for varying levels of reliability of supply (e.g., direct abstraction for summertime irrigation, or high flow abstraction for storage). The way in which abstractions are managed above these minimum flows and in relation to minimum flow sites is also important and can affect the spatial variation and duration of low flows.

Water allocation defines the total quantum of water permitted for abstraction and can be in the form of annual/weekly/daily volumes of water (e.g., Mm^3/year) and/or instantaneous flows (e.g., L/s). The total volume of water permitted for abstraction can have significant effects on key ecologically relevant aspects of natural flow regimes. For example as the total abstracted volume increases, increased duration of low flow and reduced flow variability occurs.

3 Current minimum flow and allocation regime for the Opihi River

The Opihi River Regional Plan (ORRP) is the currently operative plan for managing surface and groundwater abstractions and discharges to water in the Opihi catchment (including Temuka). The ORRP became operative on 16 October 2000, with the exception of Policy 5 and Method 5.3.4 which relate to the opening of the Opihi River mouth. These were made operative as part of the Regional Coastal Environment Plan on 26 November 2001 (Crossman et al. 2014).

The purpose of the ORRP is "to promote the sustainable management of the natural and physical resources of the Opihi River, its tributaries including the Temuka River, and hydraulically connected groundwater and to achieve the integrated management of those resources". The Plan applies to the Opihi River and its tributaries, including but not limited to, the Opuha (North and South Branches), Te Ana a Wai (Tengawai), Waihi, Hae Hae Te Moana, Kakahu and Temuka rivers and their tributaries.

The ORRP specified minimum flows and allocation volumes for the Opihi River and the Temuka River. For the Temuka River (at the Manse Bridge), the minimum flow for A block takes was set at 700 L/s (October to March) and 1,000 L/s (April to September), with varying partial restrictions above these minimum flows depending on flow sharing arrangements. The A allocation block for the Temuka River was set at 1,600 L/s and a B block allocation of 400 L/s.

For the Opihi River, minimum flow regimes differed for abstractors affiliated to the Opuha Dam Company and unaffiliated abstractors. For unaffiliated abstractors, minimum flows were set based on a calculation of 'unmodified flows' at SH1 (flow in the Opihi River as if the dam was not present) of 2,500 L/s for AN permits (permits not affiliated to the Dam Company and granted prior to 1994), and 15,000 L/s (actual flow) for BN permits. Minimum flows for the Opuha Dam Company (now Opuha Water Limited) and its affiliated abstractors varied seasonally and with varying lake levels (see section 7.5).

4 Ecological flow assessment methods and tools

There are a range of methods for assessing ecological (and other environmental) flow requirements. Quantitative methods for determining reasonable instream flows are generally grouped into three broad categories (Jowett et al. 2008). These are (1) historic flow regime, (2) hydraulic and (3) habitat based methods.

Historic flow methods rely on the historic flow of the waterway, and generally recommend a proportion of a certain flow statistics (mean, median, annual low flow etc) as a minimum flow. Proponents of these methods assert that they maintain a proportion of the flow that the communities present have adjusted to, and that they eliminate the uncertainties associated with habitat and hydraulic based methods.

Hydraulic flow methods rely on information from stream surveys to gain information on width, depth and velocity at different flows. This information can be used to identify a flow range where a parameter (e.g. wetted perimeter) declines sharply, or perhaps allows a particular stream width or depth to be maintained.

Habitat methods allow information regarding a particular aquatic species' hydraulic preferences to be used to determine flow options that provide optimum or acceptable proportion of habitat availability for a given river/reach (Becca 2008).

Other emerging methodologies includes bioenergetics and drift food intake-flow modelling. The application of these methodologies in New Zealand has been largely for rivers with significant trout fisheries (Hayes et al 2016).

An important step in assessing ecological flow needs is to determine current and/or desired critical ecological values (Becca 2008). This includes consideration of the diversity, conservation status and recreational value (salmonids) of the fish and invertebrate community. The selection of appropriate method for assessing ecological flows combines knowledge of the ecological values and the degree of hydrological alteration (Becca 2008). The higher the significance of ecological values and the degree of hydrological modification, the more detailed and specific methodologies are needed.

In 2008, the New Zealand government proposed a National Environmental Standard (NES) on ecological flows and water levels (MFE, 2008). The NES proposed a set of interim limits (e.g., minimum flows and allocation volumes for rivers) where no limits had been set, and provided a process for selecting the appropriate technical methods for evaluating the ecological component of environmental flows and water levels. While the proposed NES has not progressed to legislation, the advice within it is the result of deliberations by a consortium of New Zealand experts and is therefore considered to be an important guide.

The proposed NES interim limits are a minimum flow in rivers of 80 to 90% of MALF (for large rivers >5 m^3/s mean flow and small rivers < $5m^3/s$ mean flow respectively), and an allocation limit of 30 to 50% of MALF or the current allocation, whichever is the greater. These flow and allocation limits are designed to protect against deleterious effects from low flow conditions, and provide for maintenance of flow variability. In many situations, this recommendation closely matches minimum flow recommendations derived through habitat methods (eg. Rhyhabsim), and minimum flows derived through an expert panel type approach (Golder, 2013; MfE, 2008b). While it may be considered that the NES limits are conservative because of their assumed temporary nature, Snelder et al. (2011) found that they were less protective of habitat in smaller rivers than larger rivers.

5 Previous reviews and studies of environmental flows

The ORRP identified further work needed in relation to flow and allocation provisions for the major tributaries. In response, Scarf (2002) undertook a review of existing minimum flows established through consenting processes, and provided recommendations on changes to minimum flows. In undertaking this review, Scarf (2002) identified amenity values such as swimming and canoeing, primarily in the main stem of Opihi and Temuka rivers in the reaches below State Highway 1, owing to their close proximity to Timaru, Geraldine and Temuka townships. He identified other smaller tributaries such as the Hae Hae Te Moana, Waihi and Te Ana a Wai (Te Ngawai) as offering safe recreational environment for young children (from a flow perspective), while the deeper and faster flows of the Opihi were preferred by teenagers and adults. He did not offer preferred flow regimes for the smaller tributaries, but indicated that for recreational swimming of the Opihi flows in the range of 2,000 to 8,000 l/s were optimal.

Scarf (2002) asserts the most popular recreational use of the Opihi River is angling (trout and salmon). While angling flow preferences appear to vary, Scarf (2002) indicated flows of 8,000 to 14,000 L/s were preferred by experience anglers, and others prefer flows in the range of 6,000 to 10,000 L/s.

In the absence of hydraulic/habitat type analysis, Scarf (2002) recommended setting minimum flows based on a 1 in 5 year low flow, or 1 in 10 year low flows where over allocation was already established. Hayes (1999) provided support for this approach on the basis of trout population dynamics. For brown trout, the greatest reproductive contribution to their population occurs within their first five years of life during which, theoretically and on average, low flows including up to a 1 in 5 year low flow would be a limiting factor to the total adult trout abundance.

Some instream habitat assessment work has been carried out on the upper Opihi River near Fairlie and Rockwood in the 1980s and 1990s (Jowett, 1996, Jowett, 1999). Fish passage survey of the Te Ana a Wai River and Opihi River as Grassy Banks also appears to have been carried out (Scarf 2002). The findings of these studies have been drawn on in this review of ecological flow requirements.

6 Approach to reviews of ecological minimum flows for the Opihi catchment

The approach taken in this review is largely based on analysis of historic (naturalised) flow statistics, and draws on Scarf (2002) and proposed National Environmental Standards for ecological flows interim guidelines (MfE 2008). Where available, previous instream habitat assessments were also considered.

Available information on the fish species present, invertebrate communities (QMCI – Quantitative macroinvertebrate community index), periphyton issues and recent water temperature data has also been included to describe the current ecological values and stresses.

We also trialled the NZ River Maps tool recently developed by NIWA that provides generalised flow and habitat data (amongst other data) for all mapped NZ river reaches based on national hydrological and habitat models (Booker and Woods, 2014; Booker 2016). These generalised models can provide valuable habitat and flow information in areas where data are absent. However, at this stage the tool had limited use in rivers with significant surface water/groundwater interactions, as is the case in much of Canterbury's lower hill-fed and spring-fed rivers. Furthermore, problems with access to the tool at times limited its current usability.

7 Minimum flow assessments by surface water allocation zones

7.1 North and South branches of Opuha River

The upper branches of the Opuha River collectively support a highly diverse range of fish species. Canterbury galaxiids (*Galaxias vulgaris*) and alpine galaxiids (*G. paucispondylus*) are found in the North Branch Opuha River. Longfin (*Anguilla dieffenbachii*) and shortfin (*A. australis*) eels have been identified in the South Branch Opuha River and are also expected to occur in the North Opuha River and the many tributaries above Lake Opuha. Upland bullies (*Gobiomorphus breviceps*) and common bullies (*G. cotidianus*) have also been identified in the North and South branches of the Opuha River (Hayward et al. 2016). Both the north and south branches have potential habitat for spawning of land locked chinook salmon (*Oncorhynchus tshawytscha*) that were released into Lake Opuha as well as brown trout (*Salmo trutta*) (Unwin 2006).

Macroinvertebrate sampling of the South Branch Opuha River (at Claytons Rd bridge) over the past decade indicates generally good to excellent water/habitat quality. However, the lowest QMCI score recorded occurred in December 2015, indicating poor water/habitat quality. During this summer, a number of sites in the Opihi catchment had their lowest QMCI scores. This was at least partly attributed to successive low flow periods (Hayward et al 2016) and indicates a sensitivity of the macrophytes to prolonged low flows.

Table 1 provides the flow statistics and current minimum flows for the North and South branches of the Opuha River.

On the basis of an estimated 7D MALF of 770 l/s (limited dataset obtained during 1997), Scarf (2002) suggested that the minimum flow for the North Branch Opuha River could be relaxed to a minimum flow (total cessation of takes) of 560 l/s. (1 in 5 year 7D MALF). It is important it note that more recent analyses of flow statistics for the North Branch Opuha River indicate a naturalised 7D MALF at Clayton Rd of 847 L/s (Dodson & Steel, 2016).

In contrast, based on Scarf's (2002) estimates of MALF, 1:5yr and 1:10yr for the South Branch at Clayton Rd, he recommended raising the minimum flow to 650 L/s (1:10yr low flow) and commented that the existing regime is an 'inordinately high level of abstraction'. Dodson and Steel (2016) only provided naturalised flow statistics for the South Branch at Stoneleigh flow recorder site but indicated that there is loss of flow between the Stoneleigh and Clayton Road sites. At the Stoneleigh site Dodson and Steel (2016) estimated the naturalised MALF of 1,026 L/s, which is similar to Scarf's MALF estimate for Clayton Rd site.

Given the high ecological values found in the North and South Branches of the Opuha River, and given some observations of impact of low flows on aquatic invertebrate indicators, maintaining minimum flows within 90 to 100 % of MALF is recommended. Additional consideration of impact of abstractions (or any increased abstraction) on water levels of Lake Opuha is also relevant.

Table 1 Summary of low flow and minimum flow indicators for the North and South Branches of the Opuha River.

Surface water allocation zone	Minimum flow site location and site No.	Naturalised 7dMALF (L/s)	Naturalised Median flow (L/s)	Common consent min. flows (L/s)	NES min. flow (L/s)	Scarf (2002) recommended minimum flows	Recommended minimum ecological flow (L/s)
North Opuha	Clayton Rd 69615	847	1,920	850 Oct - Apr	762	560 (based on MALF of 770 L/s)	760 – 850 (Oct – Apr)
				1,000 Apr - Sep			1,000 (Apr – Sep)
South Opuha	Stoneleigh 61619	1,026	2,230		923	650 (based on MALF of 1,025 L/s)	900 L/s (at Stoneleigh) (Oct – Apr)
	Monument bridge 69616	?	?	Sep - Apr 500			
				Apr - Aug 800			

7.2 Upper Opihi (above Rockwood)

The upper Opihi at Rockwood surface water allocation zone includes all of the Opihi catchment above the Rockwood flow recorder site. This part of the Opihi catchment supports a diverse native fishery, with alpine and Canterbury galaxiids, upland bullies and longfin eels found up to higher elevation reaches. Torrentfish (*Cheimarrichthys fosteri*) have been found above the gorge, as far up as Fairlie. The Opihi River mainstream provides important salmon habitat, both above and below the gorge, and is listed in Schedule 17 of the Land and Water Regional Plan as a significant salmon spawning area. Adult brown trout are widely distributed throughout the Opihi River system, with higher densities found between Raincliff and the mouth (Scarf 2002).

The macroinvertebrate communities found in the upper Opihi reaches generally indicate good to excellent water/habitat quality, although some variation occurs. However, the Opihi River at Fairlie and Stony Stream at Monument road are both showing a long-term decline in QMCI scores (Hayward et al 2016). Additionally, the effects of prolonged low flows, including lack of winter freshes/floods culminated in a sharp drop in QMCI scores in 2015 for 3 sites on the Opihi River (at Rockwood, Tondros Rd, and Fairlie). It is assumed that these will recover once normal flows (and floods) have returned but this effect of low flows (direct or indirect) on macroinvertebrate communities is noteworthy. It can be expected this may also have some detrimental (but hopefully short lived) effect on fish communities.

Continuous temperature recording data is available for the past five years at the Rockwood flow recorder site. Given the site is located immediately downstream of the gorge, which is narrow and deep sided, it is likely that summertime water temperatures recorded at this site are lower than we would expect to see in the open reaches above the gorge. Regardless, the temperature data show that daily maximum summertime temperature exceeded the LWRP water quality objective of a maximum water temperature of 20°C from between 4 to 20 days during each summer. This occurred consistently between the months of December to February, during which time the flows were at their annual lowest (Figure 2). The most frequent exceedance of 20°C temperatures occurred in 2014/15 summer, in which flows also declined to below the current minimum flow for several days. Increased duration and extent of elevated temperatures can have deleterious effects on macroinvertebrates and fish.

Another consideration for this reach of the river is the frequency and extent of blooms of the benthic cyanobacteria, Phormidium sp. During the past summer, up to 90% cover of Phormidium was observed in the reach above the gorge, 64% below the gorge above Raincliff, and up to 29% at Fairlie (Allandale Bridge). Stable flows and summertime light and temperature regimes play a role in promoting Phormidium blooms (Heath et al., 2011). Reduction of low flows and increase flow stability is undesirable in rivers that have known or potential Phormidium issues.

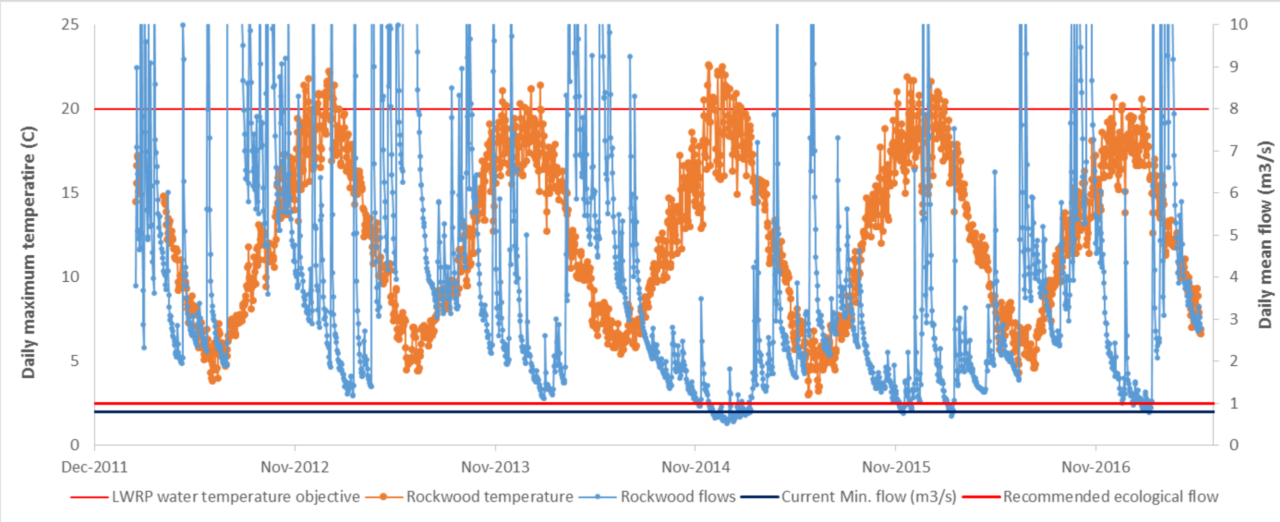

Figure 1 Maximum daily water temperature and mean daily flow for Opihi at Rockwood site

Scarf (2002) supported retaining the minimum flow at 790 L/s (1:10 year low flow). This flow is about 61% of the 7D naturalised MALF, compared to the default NES minimum flow guideline of 80% of MALF (for a mean flow > 5m3/s). Wintertime minimum flows of over 1,250 L/s were deemed by Jowett (1999) and Hayes (1999) to be sufficient for salmon spawning and migration. However, Hayes (1999) indicated that a summertime minimum flow of somewhere between the 1:5 year low flow and MALF would provide for protection of adult brown trout. Therefore, summertime minimum flow of 790 L/s for the Opihi River at Rockwood appears lower than desirable from an ecological perspective for this reach of river with high fishery values (particularly sports fishery). A summertime minimum flow in the range of 1,000 L/s is recommended in recognition of the high sports fishery value as well as known issues with Phormidium blooms. Wintertime flows in the range of 1,200 to 1,500 L/s appear more appropriate for salmon spawning and migration.

Table 2 Flow statistics and minimum flows for Opihi at Rockwood surface water allocation zone

Surface water allocation zone	Minimum flow site location and site No.	Naturalised 7dMALF (L/s)	Naturalised median flows L/s	Common consent min. flows (L/s)	NES min. flow (L/s)	Scarf (2002) recommended minimum flows (L/s)	Recommended minimum ecological flow (L/s)
Opihi at Rockwood	Rockwood 69618	1,296	3,242	790 Nov - Mar 1,280 Apr - Oct	1,037	790	1,000 Nov - Mar 1,200 - 1,500 Apr - Oct

7.3 Te Ana a Wai (Tengawai River)

The Freshwater Fish database records for the Te Ana a Wai indicate the rivers supports a diverse range of native fish including Canterbury galaxiids, upland and common bullies, koaro (*G. brevipinnis*), longfin and shortfin eels and the only record in the OTOP zone of banded kōkopu (*Galaxias fasciatus*). The river also supports a small brown trout fishery and provides salmon spawning habitat in its mid to lower reaches (listed in Schedule 17 of the LWRP) (Hayward et al. 2016).

Macroinvertebrate community data for the Te Ana a Wai at Tengawai bridge (lower reach close to its confluence with Opihi) generally indicated good to excellent water quality/habitat quality. However, the invertebrate community showed a substantial loss of sensitive species (low QMCI scores) in data collected in December 2015. This pattern of low QMCI scores was noted among many rivers in the Opihi catchment by Hayward et al (2016) and is linked to prolonged low flows and lack of winter freshes.

The estimated naturalised MALF for Te Ana a Wai River at the Cave picnic grounds is 634 L/s. There is substantial flow loss below this reach in the order of 300 L/s (Scarf 2002). At low flows, the river may become discontinuous pools of water in this reach. Scarf (2002) indicated flows of 400 L/s were about a 1:10 year low flow, that Central South Island Fish and Game aimed to retain flows of 50 L/s in this losing reach to maintain fresh pools and allow juvenile fish to migrate through this section. For this reason, Scarf (2002) recommended a minimum of 400 L/s at Cave with staged restrictions between 620 L/s and 400 L/s. However, it is uncertain whether this assumption about flows at the minimum flow site and the downstream losing reach still hold, particularly given the impact of increased groundwater abstraction in recent year may have on groundwater inflows to the lower river.

Continuous temperature data is available for the Te Ana a Wai River flow recorder site at Cave (Figure 2). Summertime daily maximum temperatures over the past 3 summers have routinely exceeded the LWRP objective of 20°C. This can occur from November to March over more than 50% of the days. These elevated summertime temperatures are likely to stress some invertebrates and fish, particularly salmonids, especially when temperatures exceeded 25°C on occasions. Flow abstraction can exacerbate the naturally high summertime temperatures and reduce the availability of cool refugia such a pools. Impacts of abstractions on water temperatures in a small river like the Te Ana a Wai is an important consideration.

Development of blooms of benthic cyanobacteria Phormidium have occurred in recent summers in the lower Te Ana a Wai River prompting warnings against swimming in the river (Hayward et al. 2016). Stable low flows and warm temperatures are likely contributors to these blooms but it is the frequency of floods and freshes that exert the greatest control of blooms. Flushing flows of around 17 m3/s are necessary to remove periphyton accumulations including Phormidium in the Te Ana a Wai River (Kilroy and Wech 2017). Ensuring water abstractions do not reduce the frequency of this size flushing flow is an important consideration in setting flow and allocation regimes.

The existing minimum flow on the Te Ana a Wai River of 400 L/s is 63% of the estimated naturalised MALF, which is considerably lower than the proposed NES guideline of 90% of MALF (for rivers with mean flow <5m^3/s), but is about a 1:5 year low flow, which could be considered adequate for the protection of adult brown trout and native fish (Hayes 1999). However, elevated summertime temperatures may be a constraint on trout populations and salmon rearing. Given the high ecological values of this river, and indications of stresses occurring during low flows (elevated temperature, loss of sensitive invertebrate taxa, Phormidium blooms) minimum flows close or at the MALF are considered more appropriate.

The wintertime minimum flow of 600 L/s is half the flow indicated necessary to allow adult trout movement through the flow losing reach (near Hammonds Rd) and would definitely inhibit salmon passage (Scarf 2002). Ideally, a higher wintertime minimum flow of around 1,200 L/s would provide improved fish passage through the flow losing reaches.

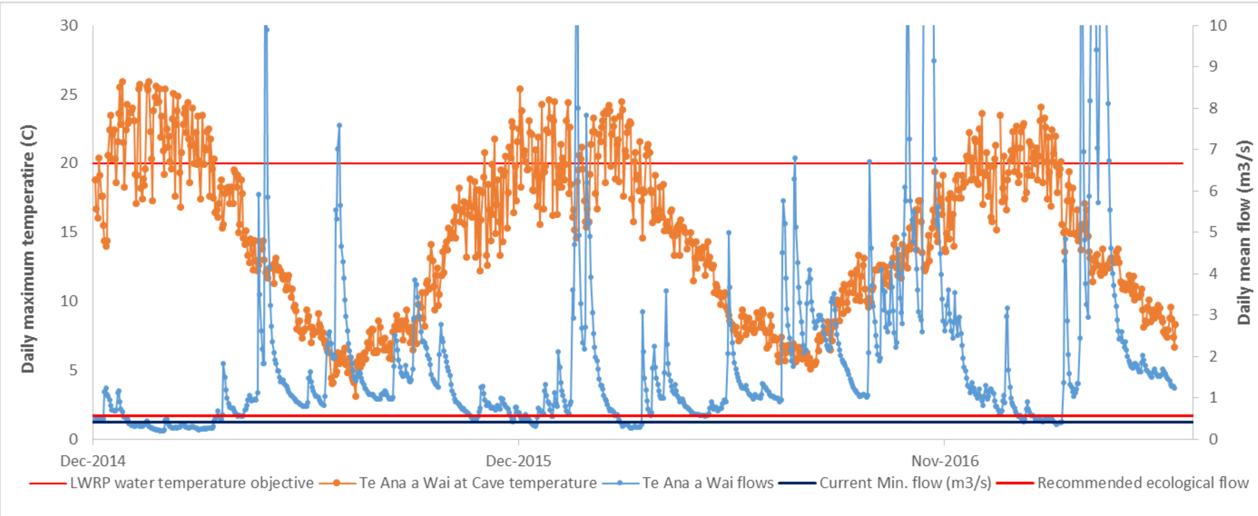

Figure 2 Daily maximum temperatures recorded in the Te Ana a Wai River at the Cave flow recorder site.

Table 3 Flow statistics and minimum flows for the Te Ana a Wai (Tengawai) surface water allocation zone

Surface water allocation zone	Minimum flow site location and site No.	Naturalised 7dMALF (L/s)	Naturalised median flow (L/s)	Common consent min. flows (L/s)	NES min. flow (L/s)	Scarf (2002) recommended minimum flows (L/s)	Recommended minimum ecological flow (L/s)
Te Ana a Wai (Tengawai River)	at Picnic grounds 69635	611	1,808	400 Oct-Apr (50% restriction at 500_ 600 May-Aug 500 Sep one consent has 600 all year	550	400	550 (Oct - Apr) 1,200 (May - Sept)

7.4 Temuka (including Waihi, Hae Hae Te Moana, and Kakahu tributaries)

Eight native fish species are recorded from the Temuka Catchment including one species of galaxiid and Canterbury mudfish (*Neochanna burrowsius*). Rangatira Creek in particular serves as important habitat for the nationally declining longfin eel and critically endangered Canterbury mudfish. The Temuka catchment consists of a reasonable brown trout fishery with a moderate number of recreational anglers accessing its major rivers each year. NZFFD records for other salmonids are rare, however the Waihi and Temuka Rivers are known to be spawning grounds for salmon (Hayward et al 2016).

Invertebrate communities indicate generally better water and habitat quality in the upper reaches of the hill fed tributaries (e.g., Waihi and Hae Hae Te Moana gorges) compared to sites further downstream on the plains. QMCI values for the Temuka River at SH1 generally indicate fair to good water and habitat quality, but fail to meet the LWRP objective of 'excellent' (QMCI score >6) (Hayward et al 2016).

The Temuka surface water allocation zone has one main minimum flow site (at the Manse bridge flow recorder sites) for most abstractions including from the main tributaries Kakahu, Hae Hae Te Moana and Waihi rivers. Abstractions from Dobies Stream and Stony Creek have minimum flow requirements set for these streams in addition to the Manse Bridge site (Dodson and Steel 2016).

The existing minimum flow on the Temuka River of 700 L/s only 39% of the estimated naturalised MALF, which is considerably lower than the proposed NES guideline of 1,440 L/s based on 80% of MALF (for rivers with mean flow > 5m3/s). The current minimum flow is also less than a 1:10 year low flow (Scarf 2002). Comparison of naturalised and recorded flow for the Manse Bridge flow recorder site by Dodson and Steel (2016) indicate substantial reductions in summertime flows from current levels of abstraction, although there is considerable year to year variations in low flows. The impact of abstractions during winter months have far less impact compared to naturalised flows (Dodson and Steel, 2016).

Water temperatures in the Temuka River exceeded the LWRP objective in most summers, regardless of the severity of low flows (Figure 3). Temperatures above 25°C were not recorded at this site, even during the particularly low flows of 2014/15. This probably reflects the relatively high contribution of groundwater fed streams that typically maintain lower (steady) water temperatures throughout the year.

Periphyton accumulations have long been recognised as an issue in the Temuka catchment Scarf (2002). This was initially owing to municipal and industrial waste discharges, which have largely ceased now. More recently, Phormidium blooms have been observed that result in public health warnings to avoid swimming in the affected reaches (Hayward et al. 2016). Kilroy and Wech (2016) determined that freshes of around 33 m3/s were needed to effectively remove periphyton from the Temuka River. It is important that flow allocation limits do not reduce the frequency of these high flow events.

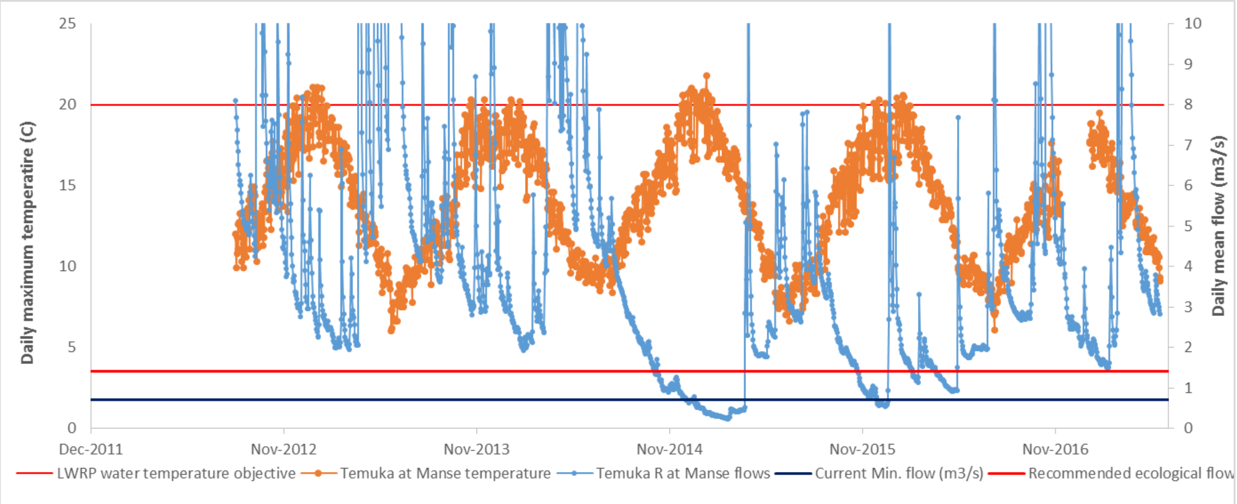

Figure 3 Daily maximum temperatures recorded in the Temuka River at the Manse Bridge flow recorder site.

While a minimum flow set at the Manse Bridge attempts to address flow needs in the Temuka River and downstream, it is uncertain whether it will adequately provide for specific instream flow requirements of the main tributaries; Hae Hae Te Moana and Waihi. These tributaries have substantial flow losing reaches in their mid reaches and it is uncertain what the effect the current level of abstractions and minimum flow at Manse Bridge have in these reaches.

Scarf (2002) recognised the highly allocated nature of the Temuka catchment, and it is apparent that this tributary catchment remains the most highly allocated zone within the greater Opihi catchment. The current minimum flow set for the Temuka River is unlikely to provide adequate protection for instream ecological values, particularly based on the current relationship with naturalised MALF (39% of MALF). Ideally a minimum flow would be set based on a 1:5 year low flow or 70-80% of MALF (1,300 to 1,400 L/s).

Table 4 Flow statistics and minimum flows for the Temuka River surface water allocation zone

Surface water allocation zone	Minimum flow site location	Median flow L/s	Naturalised 7dMALF (L/s)	ORRP minimum flow (L/s)	NES min. flow (L/s)	Scarf (2002) recommended minimum flows (L/s)	Recommended minimum ecological flow (L/s)
Temuka	Temuka R at Manse Bridge	4,142	1,800	700 Oct - Mar 1,000 Apr - Sep	1,440	870	1,400 Oct - Apr

7.5 Opihi River mainstem

Prior to the construction and operation of the Opuha Dam, the lower Opihi River experienced periodic low flows including drying reaches between the Saleyards Bridge and the Temuka River confluence. Proposals to augment and/or dam flows in the catchment have been put forward since the 1980s.

Modification of natural flow regimes through on-river dams can have a profound effect of the ecosystem functioning of the waterway. There are many books and reviews published around the world on the effects of "Regulated Rivers". In addition to consideration of run-of-river abstraction issues (eg impacts of lowering base flows), on-river dams affect a number of other elements of the physical and biological river environment.

The Opuha Dam has had a significant effect on the downstream flow regime. The greatest influence is in the Opuha River itself downstream of the dam to its the confluence with the Opihi River at Raincliff, and with continued but diminishing flow regime influences along the length of the Opihi River to its mouth.

The elements that need to be (and were) considered when developing a flow regime for the lower Opihi River as a result of the dam can be broadly grouped as follows:

- effects on the Opihi lagoon opening in relation to fish migrations, lagoon water quality and impacts on inundation of surrounding land
- flows to support cultural values including mahinga kai
- flow connectivity and variation to allow for fish passage along the mainstem
- periphyton and fine sediment accumulations and flushing flows to aid removal
- impacts of flows on fish and invertebrate habitat availability, and water quality
- flows for recreational and amenity values
- loss of flood and fresh size and frequency
- loss of bed scouring sediment sources.

The ORRP was developed during the consenting and construction of the Opuha Dam, and therefore, provides seasonal minimum flows taking into consideration the effects and opportunities of the newly created dam. We are not aware of any specific documented rationale for the ORRP monthly minimum flows (Table 5). However, we understand the monthly minimum flows were primarily chosen to represent suitable flows for different features of the important salmonid fishery. We surmise that:

- Lowest flows in January/February (3.5 m^3/s) is a period with lowest flow requirements, following the peak fishing months and prior to spawning migrations. As such it maintains river connectiveness and suitable instream habitat.
- High flows in March and April (7.5 and 8 m^3/s) produce high flows that will stimulate both salmon in-migration from the sea and upstream spawning migrations to optimise fish passage to spawning sites, as well as stimulate salmon autumn smolt out-migration.
- Low to Moderate flows in May to August (4-4.5 m^3/s) to optimise low stable flows for spawning, and security of redds (egg development, hatching and alevin development in the gravels), and minimises the deleterious effects of winter freshes and floods.
- Higher flows in September to December (6-8.5 m^3/s) facilitates spring salmon and trout parr dispersal; stimulates sea-run trout entry into the river; and optimises season opening (1 October) and early season angling opportunity.

These seasonal flow regime rationales are also relevant for life cycle requirements of key native fish species, such as spring high flow periods facilitating and stimulating entry of whitebait species, and entry of juvenile eels (glass eels and elvers), while the autumn high flow periods would stimulate mature eel outmigration to the sea and downstream torrentfish breeding migrations.

In addition to the instream flow considerations, the volume of water that enters the Opihi Lagoon has a significant effect on a number of aspects of lagoon functioning. The ORRP included provisions for the artificial opening of the lagoon for the purposes of flood mitigations or to provide for fish passage, cultural purposes and for managing adverse water quality conditions. At any time of year, when lagoon levels rise because of mouth closure, inundation of surrounding land is problematic, and at times can result in the need for artificial openings of the lagoon.

During summer months when the lagoon is closed to the sea, water quality problems can arise such increased water temperatures, low overnight dissolved oxygen levels, elevated pH, ammonification during anoxic conditions, and excess plant growth and die back.

Prior to the construction and operation of the Opuha Dam, the Opihi River mouth was frequently closed and experienced water quality issues. The development of the minimum flows in the ORRP for the lower Opihi River included recognition of the need to maintain mouth openings. Consequently, the frequency and duration of mouth closures has reduced since the Opuha Dam has been operating. (McSweeney et al. 2016), although closures still occur, particularly during January and February.

In August 2008, after some extensive review work based on the experience to date of the operation of the lake and river since the dam was commissioned, the Opuha Environmental Flow Release Advisory Group (OEFRAG) proposed some significant changes to the flow regime during water shortages. While these proposed changes were not formally pursued, they have provided the platform from which OEFRAG has dealt with the low flow situations since 2008, and in particular the period from November 2014 until January 2016 (AMWG 2017). More recently, the Opuha adaptive management group have further reviewed the flow regime for the Opihi River, and drawing on the experience of very low flows in recent years, have developed a proposed alternative flow regime (Table 5). This alternative proposal has taken into consideration many of the aspects listed above (e.g., Table 4 AMWG 2017).

Table 5 provides an estimate of naturalised monthly mean low flows at the Saleyards Bridge pre dam. The pre-dam flow record was generated from the relationship between flow gauging records for the Opihi River at Rockwood and at Saleyards Bridge, and subsequent generation of synthetic flow record for Saleyards Bridge for the period 1964 to 1996. The Saleyards Bridge flow site is above Levels Plains irrigation diversion race, which was constructed in the 1930s.

Comparison of the estimated naturalised low flows with the current and proposed minimum flows indicate a substantial decrease in low flows for most months, and some deviations from natural seasonal flow variations.

While the proposed regime is a significant deviation from naturalised flow regime, it does appear to largely provide for key elements identified above (flow connectivity, recreation, mouth openings, fish movements). The implied advantage of this regime is the ability to store and utilise water in a more effective manner for the benefit of both the down river environment and irrigators/shareholders. The key to the successful outcome of this regime will depend on how the different regimes are implemented.

Table 5 Current and AMWG proposed minimum flow regimes for the Opihi River (at Saleyards Bridge) compared to estimated naturalised pre-dam flows

	Opihi Saleyards bridge (69650) estimated flows pre-dam 1964 - 1996	ORRP min. flows at Saleyards Bridge		Opuha Adaptive Management Group - proposed Opihi River (Saleyards Bdge) flow regime				
				Minimum flow (normal regime)		Minimum flows (conservative regime)		Minimum flows (extreme regime)
Month	Average monthly min. flows (m3/s)	Water level >375 (masl)	Water level 375 - 370 (masl)	Instantaneous flow (m^3/s)	Average monthly flow (m3/s)	Instantaneous flow (m3/s)	Average monthly flow (m3/s)	Instantaneous flow (m3/s)
January	6.0	3.5	3.35	3.5	4.5	3	3.5	2
February	4.7	3.5	3.35	3.5	4.5	3	3.5	2
March	5.6	7.5	5.35	6	7	5	5.5	2
April	7.3	8.0	5.60	6	7	5	5.5	2
May	7.8	4.5	3.85	4	4.5	3.5	4	2
June	8.5	4.0	3.60	3.5	4	3	3.5	2
July	8.4	4.0	3.60	3.5	4	3	3.5	2
August	10.3	4.5	3.85	4	4.5	3.5	4	2
September	12.7	6.0	4.60	5	6	4	5	2
October	13.3	8.5	5.85	6	8	5	6	2
November	10.2	7.0	5.20	5	7	4	4.5	2
December	8.5	6.0	4.60	5	6	4	4.5	2

It is worth noting the current and proposed regime is a considerable improvement for the lower Opihi River compared to minimum flows pre ORRP, whereby, minimum flows for the Levels Plains irrigation take at Saleyards Bridge was 2,000 L/s, with partial restrictions below 7,000 L/s (Scarf 2002). During this regime, the Opihi River reportedly went dry in reaches below SH1 in some summers (AMWG 2017). The minimum flow proposed for the extreme regime of 2,000 L/s is intended to ensure that at a minimum the river flows remain continuous below SH1 bridge (AMWG, 2017). While this is a sensible approach in extreme conditions, considerable care would be needed before making a decision to implement that extreme regime. Prolonged periods flows this low will inevitably carry risks of deterioration of instream ecological health, particularly during summer months, with increased nuisance periphyton accumulations likely and elevated water temperatures. Figure 6 shows the daily maximum temperatures at the Opihi River SH1 flow monitoring site. While daily maximum temperature exceeds the LWRP objective of 20°C in most summers, there were more frequent exceedances during periods of when flows reached or went below 2,000 L/s.

Flushing flows is a key element that is not controlled by base flows, but rather by ensuring sufficient water storage to allow flushing flows to be released as needed. The proposed AMWG flow regime claims to be able to store more water, with the ability to provide more frequent effective flushing flows. If this is enabled, particularly given the recent upgrade to the dam that enables considerably higher peak flushing flows than originally designed, will have positive effect on stream health. This will be most pronounced in the Opuha River, with diminishing but not insignificant benefits in the lower Opihi River (Kilroy and Measures 2015).

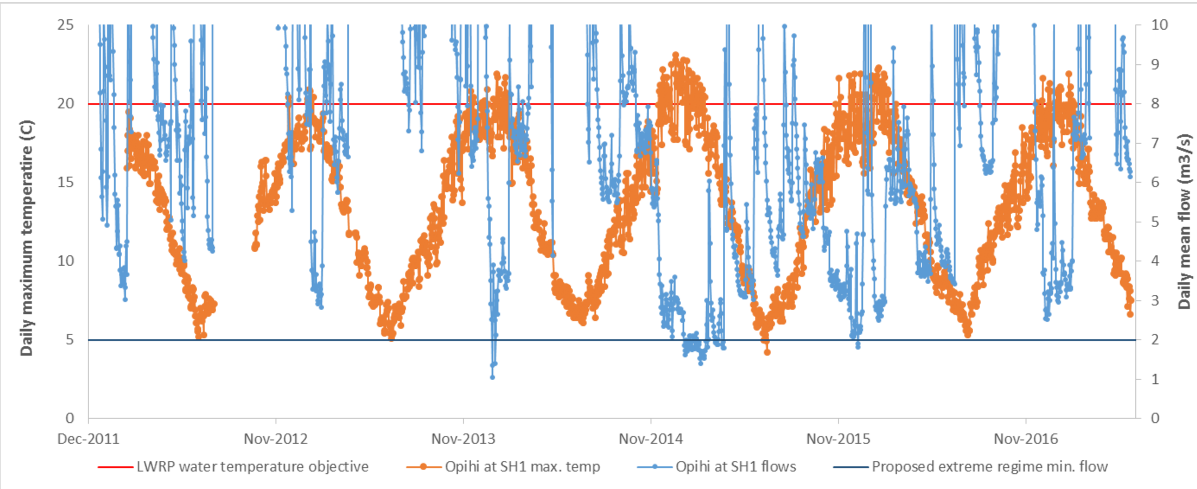

Figure 6 Daily maximum temperatures recorded in the Opihi River at SH1 Bridge flow recorder site.

7.6 Opuha River

The lower Opuha River (below the dam) has been heavily modified/affected by the Opuha Dam. Reduction of flow variability and armouring of the river bed sediments is an expected outcome from a change to an artificially regulated flow regime. Increased periphyton biomass is also an expected consequence from flow regulation because of the reduction in magnitude and frequency of flushing flows. Following the construction of Lake Opuha, an overall increase in periphyton biomass was noted, but in particular Phormidium blooms were frequently recorded between 1999 and 2008 (Lessard et al 2011). In 2008 the invasive algae *Didymosphenia geminata* (didymo) became established in the Opuha River and has dominated the periphyton community since this time. Several flushing flow trials by Opuha Water Limited has shown varying success at removal of periphyton blooms in the river and remain an important means of controlling nuisance growths (Kilroy and Measures 2015).

Opuha Water Limited are required in their consent to discharge 1,500 L/s from the weir below the Opuha Dam (AMWG, 2017). There does not appear to be a requirement to allow for up to 1,200 L/s abstraction by Kakahu Irrigation, thus potentially leaving a much reduced flow below the Kakahu intake. The AMWG have proposed a residual flow requirement of 1,500 L/s (after any affiliated abstractions). The naturalised MALF for the Opuha River at the weir is 1,766 L/s and is 2,300 L/s at Skiptons Bridge. At 90% of MALF, these flows would be around 1,600 L/s and 2,100 L/s respectively. Maintaining residuals flows of around 2,000 L/s is preferable.

7.7 Opihi unmodified flow regime

The ORRP distinguished between abstractors affiliated to the Opuha Dam Company and unaffiliated abstractors. Minimum flows for unaffiliated abstractors (set at the SH1 Bridge site) were 2,500 L/s based on a calculated 'unmodified flow' by Environment Canterbury (Dobson and Steel 2016). This is a low flow, given that the unmodified (and naturalised) MALF for SH1 is likely to be around 3,000 to 4,000 L/s, but will at least maintain connectivity of flow in the lower Opihi River. Retaining at least a minimum flow of 2,500 L/s is recommended.

For unaffiliated B permits, the minimum flow (measured) at SH1 is 15,000 L/s. The naturalised mean and median flow for the Opihi River at SH1 (based on data since 1998) is 16,919 L/s and 11,967 L/s respectively (Dodson and Steel, 2016). These mid range flows are important for food producing/invertebrate habitat flows, and substantial reductions in these flow metrics can reduce overall productivity of small to medium sized rivers. It is therefore appropriate that B block minimum flows are set around or above median flows.

8 Conclusions and recommendations

This review largely drew on previous studies of minimum flow requirements for the Opihi catchment and on the generalised guidance provided by the interim limits in the proposed NES for ecological flows. For some of the tributaries, the current minimum flows and abstractive pressures may warrant further refinement of instream flow and habitat needs. More detailed assessment of instream habitat/and or flow requirements of the main tributaries of the Temuka River (Waihi, and Hae Hae Te Moana rivers) is recommended, and to assess whether the minimum flow site at the Manse Bridge is an appropriate minimum flow site for these tributaries.

This review has not consider the impact of the size of the A block allocation on the duration of low flows. The ORRP set allocation block at a very coarse scale (Opihi and Temuka catchments). Examination of the impacts of allocation blocks (both groundwater and surface water) in the main the tributaries is recommended to assess any effects of extended low flows or drying reaches.

This review has not considered current B block minimum flows or allocation. High flow takes can have impacts on the mid ranges flows of rivers, affecting overall river productivity and flushing flows. Further analysis of flow requirements in tributaries with large B Block takes is recommended.

9 References

Adaptive Management Working Group, 2017: Proposed Opihi River adaptive management regime. Paper presented to the OTOP zone committee 3 June 2017.

Beca. 2008. Draft Guidelines for the Selection of Methods to Determine Ecological Flows and Water Levels. Report prepared by Beca Infrastructure Ltd for MfE. Wellington: Ministry for the Environment.

Crossman, J., Clarke, G., Hidajat, R., Hunt, S., Johnston, K., Ritson, J., Scott, M., Stevenson, M., Wilson, W.: Efficiency and effectiveness evaluation of the Opihi River Regional Plan. Environment Canterbury technical report R14/131.

Dodson, J., Steel, K. 2016: Current state of surface water hydrology in the Ophi and Temuka catchments. Environment Canterbury draft technical report R16/46

Hay, J. Kitson, J. 2013. Flow harvesting: a review of policy and potential effects. Prepared for Environment Southland, Cawthron report No. 2408

Hayes, J. W. 1999: Statement of evidence on behalf of Central South Island Fish and Game in the matter of applications by members of the Kimbell-Fairlie Water Users Group for water permits and discharge permits for the proposed irrigation of land in the Kimbell-Fairlie area.

Hayes, J.W. Goodwin, E. Shearer, K.A. Hay, J. Kelly, L, 2016. Can Weighted Useable Area Predict Flow Requirements of Drift-Feeding Salmonids? Comparison with a Net Rate of Energy Intake Model Incorporating Drift–Flow Processes. Transactions of the American Fisheries Society Vol. 145 , Iss. 3,2016

Heath, M.W., Wood, S.A., Ryan, K.G. (2011) Spatial and temporal variability in Phormidium mats and associated anatoxin-a and homoanatoxin-a in two New Zealand rivers. Aquatic Microbial Ecology, 64(1): 69-79.

Jellyman, D. 2012: Survey of tuna in customary areas of ANG 14. New Zealand Fisheries Assessment Report 2012/33

Jowett, I. G. 1996: Assessment of flow requirements for salmon spawning in the upper Opihi River. Report prepared for Opuha Dam Ltd. August 1996

Jowett, I. G. 1999: Effect of flow abstraction on the Opihi River above Rockwood Bridge. Report prepared for Opuha Dam Ltd. August 1996

Jowett, I.G., Hayes, J.W., Duncan, M.J. 2008: a guide to instream habitat survey methods and analysis NIWA science and technology series No. 54

McSweeney, Sarah L; Hart, Deirdre E; Todd, Derek J; Kennedy, David M. Journal of Coastal Research, suppl. Special Issue; Fort LauderdaleSI.75 (2016): 88-92.

Kilroy, C. Measures, R. 2015: Opuha and Opihi River periphyton investigations 2014-15. NIWA client report for Opuha Water Limited.

Scarf, F. 2002: Opihi River Regional Plan. Review of minimum flows – a discussion document. Environment Canterbury report U02/79

Snelder, T., Booker D., and Lamouroux N., 2011. A Method to Assess and Define Environmental Flow Rules for Large Jurisdictional Regions. *Journal of the American Water Resources Association (JAWRA)* 47(4):828-840.