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Impact of the Opuha dam on the turbidity and health of the Opuha and Ōpihi Rivers

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Abstract

Since the completion and commissioning of the Opuha dam in South Canterbury, New Zealand, in December 1998, a notable decline in the health of the Opuha River below the dam, and Ōpihi River further downstream, has been observed by expert fishers and local river users. The rivers have become visibly more turbid and ecological assessments confirm their poor health. However, the reasons for these changes remain unclear.

Analysis of black disc clarity, turbidity and macroinvertebrate data from the National River Water Quality Network 30-year monitoring record suggests that the installation of the Opuha dam has resulted in significant increases in suspended fine sediment being discharged routinely down the Opuha River in lower flows. Prolonged releases of sediment-laden water and increased fine sediment deposition are most likely responsible for declines in the health of the Opuha and Ōpihi Rivers. The increase in fine sediment is due to a combination of factors including the Lake Opuha infrastructure design, the fixed water offtake behind the dam intersecting turbid water, and the dam altering the hydrology and continuity of sediment transport through the Opuha River system. The declines in ecological health reflect a hitherto unrecognised consequence of this water storage scheme. If other schemes are constructed in a similar fashion, then there will be a real risk that they too will release turbid water that could degrade the ecological health of rivers downstream. The impacts may be prevented by not using rivers as conduits for turbid irrigation water and instead piping water directly to irrigation schemes. In addition, allowing only settled sediment-free water to be discharged from storage lakes, ensuring storage lakes are of the right design to provide for sufficient sediment removal, and taking water only from zones free of suspended sediment, may help alleviate this issue.

Keywords

Opuha River, Ōpihi River, Kakahu River, Opuha dam, turbidity, suspended sediment, ecological health, water storage schemes

Introduction

The Opuha dam in South Canterbury, New Zealand, was built to provide for storage of water for irrigation, electricity generation, urban water supply and augmentation of low summer flows (Gibbs and Hickey, 2012). The Opuha River has a catchment area of about 64 km^2 and is a major hill-fed tributary of the Ōpihi River, a gravel-bed braided river on the dry eastern side of the Southern Alps (Fig. 1). The Ōpihi River has a total catchment area, including that of the Opuha River, of about 245 km^2. The Opuha River has a continuous flow recorder at Skipton Bridge about 12 km downstream of the Opuha dam, and had a pre-dam mean flow of 9.7 m^3s^{-1} and a mean annual flood of 203 m^3s^{-1} (Lessard *et al*., 2013). Skipton Bridge is also a National River Water Quality Network (NRWQN) site, where water quality data are recorded at selected locations throughout New Zealand to monitor the state of the freshwater environment. The Ōpihi-Opuha catchment historically experienced low summer flows, with natural droughts and high levels of water abstraction resulting in water quality degradation, loss of fish habitat and river passage, reduction of recreational opportunities, supply shortages for irrigation and municipal users, and various other impacts (Lessard *et al*., 2013).

The dam is operated by Opuha Water Ltd (OWL) to maximise storage and use of water from Lake Opuha for the irrigation season by capturing higher inflows where possible and controlling outflows to meet irrigation demand and minimum environmental flows. Construction started in November 1995 and the dam was commissioned in December 1998. The dam impounds the 700 Ha Lake Opuha, with a storage volume of about 90 million cubic metres (Gibbs and Hickey, 2012), which in dry years cannot fully meet irrigation demand in the region. The lake has a maximum depth of about 35 metres when full (Gibbs and Hickey, 2012), and the offtake is about five to eight metres off the lake bed down near the dam face (Gibbs and Hickey, 2012; Eveleens and Young, 2024). The maximum flow through the dam offtake,

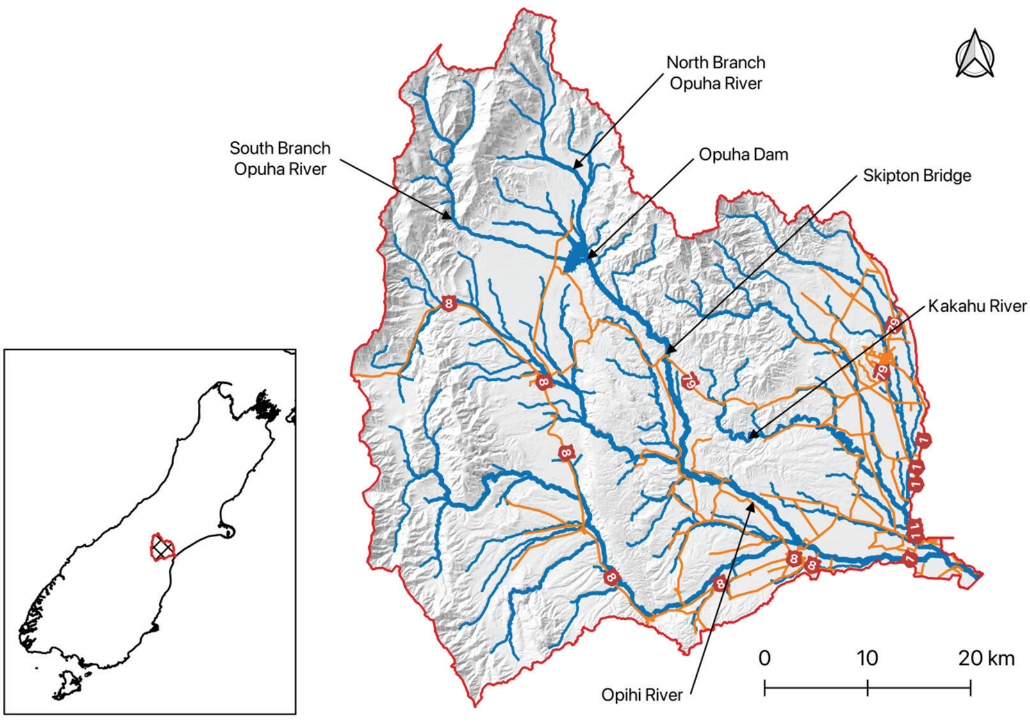

Figure 1 - Ōpihi River catchment and its location in the South Island of New Zealand.

via a hydro-electric turbine, is 16 m^3s^{-1}. A balancing pond and a secondary weir about one kilometre below the dam are used to control water flow releases for irrigation and environmental needs (Gibbs and Hickey, 2012). Discharges are also controlled via a spillway to prevent the dam being overtopped during high rainfall events in the catchment. The Opuha River is used as a conduit for supply of irrigation water to various irrigation schemes, including the Kakahu Irrigation Scheme (KIS). Opuha River water is piped across into the Kakahu River catchment from an intake just below the Skipton Bridge.

Sediment management was not identified as a potential adverse effect of the Opuha dam when the project was conceived (Lessard *et al*., 2013). The importance of sediment management in reservoirs and regulated rivers is becoming more widely recognised, in order to collect clean water free of sediment for irrigation or other needs, preserve reservoir capacity and minimise downstream environmental impacts (Vijverberg *et al*., 2011; Biggs and Hickey, 2012; Lessard *et al*., 2013; Kondolf *et al*., 2014).

Since the dam was commissioned, a substantial decline has occurred in the ecological health of Lake Opuha, the Opuha and Ōpihi Rivers below the dam, and the Kakahu River below where it receives irrigation water from the Opuha River for the KIS (Lessard *et al*., 2013; Kilroy and Jellyman, 2018; Eveleens and Young, 2024). Expert fishers have noted a regular discharge of turbid water down the river systems and that the Opuha and Ōpihi Rivers no longer run as clear as they used to in low flows. The rivers are considered no longer suitable for swimming because of the increased turbidity (G. Smillie, Kakahu landowner, pers. comm., 2023). Turbid water and excess fine sediment are known to be detrimental to the health of freshwater biota (Clapcott *et al*., 2011; Henley *et al*., 2000; Gupta *et al*., 2023; Wood *et al*., 1997) and so could be playing a key role in the health of these rivers.

Shortly after the dam was commissioned poor water quality in the lake associated with stratification was identified (Ewert *et al*., 2003) and mitigated by installing an aeration system, which was operational by 2001 (Gibbs and Hickey, 2012). However, this did not rectify the aquatic health issues in the Opuha River below the dam (Eveleens and Young, 2024). Excessive growths of periphyton algal mats, including the potentially toxic benthic cyanobacteria *Microcoleus autumnalis* (formerly *Phormidium autumnale*) and the introduced invasive algae didymo (*Didymosphenia geminata*), have been a recurring problem in the Opuha River downstream of the dam and control weir and in reaches of the Ōpihi River below the Opuha confluence since the dam was commissioned (Gibbs and Hickey, 2012; Lessard *et al*., 2013; Eveleens and Young, 2024). Lessard *et al*. (2013) attributed enhanced algal mat growth in the Opuha River to the reduced frequency and magnitude of high-flow events capable of removing nuisance periphyton growth and resetting the algal community to thin biofilms. However, they did not identify what is responsible for the algal blooms. Trials to reduce periphyton accumulations using higher flushing flows than those assessed by Lessard *et al*. (2013) only temporarily reduced periphyton cover (Measures and Kilroy, 2013; Hopley and Measures, 2017). Therefore, there are likely to be other factors primarily responsible for the blooms that will also need to be addressed.

Hayward *et al*. (2019) reported that macroinvertebrate community index (MCI) and quantitative MCI (QMCI) scores in the Opuha River at Skipton Bridge indicate poor water and/or habitat quality and show a clear decline over time. NRWQN data show that MCI scores are consistently just above the national bottom line for the macroinvertebrate attribute for ecosystem health in the National Policy Statement for Freshwater Management (NPSFM) 2020 (NPSFM, 2024), whereas QMCI scores often fall below the NPSFM macroinvertebrate attribute national bottom line (Eveleens and Young, 2024). Poor ecological health (as indicated by low MCI and QMCI scores) can arise as a result of excess fine sediment in river systems (Clapcott *et al*., 2011; NPSFM, 2024). Hayward *et al*. (2019) also noted relatively high turbidity at Skipton Bridge since the dam compared with other monitoring sites around the catchment. Thus increased fine sediment could be playing a pivotal role in the decline in macroinvertebrate metrics.

Kilroy and Jellyman (2018) and Eveleens and Young (2024) both proposed didymo is a key contributor to the decline in ecological health of the Opuha River below the dam. However, Eveleens and Young (2024) suggested that this cannot be the sole cause as the decline in macroinvertebrate communities in the Opuha River started before the arrival of didymo. They concluded that the regulated flow regime is also a key driver of poor ecological health in the Opuha River. Again, the regulated flow regime cannot be the only factor causing ecological health decline, because this driver was also present previously when cyanobacteria blooms were problematic prior to the arrival of didymo. This suggests there is another unrecognised key factor at play. Eveleens and Young (2024) concluded that lake water quality and fine sediment are also likely influencing ecological health.

Eveleens and Young (2024) compared pre-1995 (when construction began) water quality data with that collected following completion of the dam and reported a statistically significant reduction in the visual clarity at Skipton Bridge (P = 0.002). However, they did not report the median visual clarity for the period after the dam was completed (December 1998 to June 2021). The median visual clarity before 1995 was 3.08 m, indicating a minimal impact of suspended sediment on instream biota before the dam. In contrast, the five-year (July 2016 to June 2021) median for visual clarity fell into the B band of the NPSFM, indicating a low to moderate impact of suspended sediment on instream biota (Eveleens and Young, 2024; NPSFM, 2024).

Poor ecological health was also identified in the Kakahu River below the KIS discharge (Eveleens and Young, 2024). Fine sediment from the KIS discharge is likely the key ecological driver of concern, whilst volume and increased variability of flow is also likely playing a major role (Eveleens and Young, 2024). As suspended sediment is a specific concern in the Kakahu River it is likely to be a concern for the Opuha River also, given it provides sediment-laden water to the Kakahu River. Given the apparent continuing good health of the North and South Opuha Rivers above the lake (B. Stone, expert fisher, pers. comm., 2023), the data collectively suggest that the Opuha dam is contributing to the poor ecological health of the waterways and that excess fine sediment could be playing a key role.

The purpose of this paper is to examine and analyse NRWQN monitoring data for the Opuha River at Skipton Bridge, and particularly discharge, water clarity, turbidity and macroinvertebrate data, before and after the Opuha dam was installed. The aim is to see if this data might confirm the anecdotal changes in turbidity noted by fishers in the rivers and provide further insight into the poor ecological health observed in the Opuha, Ōpihi and Kakahu Rivers since the Opuha dam was installed. A key aim is to determine whether the dam is responsible for the ecological health decline in the catchments, either directly or indirectly. In particular, we wish to determine whether excess fine sediment is responsible for the poor health of the Opuha River, and if so, how this might arise. In addition, we aim to explore what role some other factors, such as organic or inorganic pollution, changes in flow regime, changes in sediment transport, cyanobacteria and didymo incursion, and dam design, might play in the ecological health of the Opuha River. Implications for the health of rivers downstream of water storage schemes are also considered, as the Opuha dam may be a model for future irrigation storage dams in New Zealand (Lessard *et al*., 2013).

Methodology

Data from monthly sampling of the NRWQN monitoring site Opuha River at Skipton Bridge over the January 1989 to June 2021 record period were downloaded from the NIWA portal (https://hydrowebportal.niwa.co.nz/Data). The record included five-day biological oxygen demand (BOD_5), nitrite and nitrate nitrogen, total nitrogen (N), dissolved reactive phosphorus (DRP), water clarity, and turbidity data, along with river flow at time of sampling. Samples were collected at random and regardless of weather and flow conditions, in accordance with the NRWQN protocols. Annual macroinvertebrate survey data for the same period were obtained from NIWA in Christchurch and MCI and QMCI calculated using the updated methodology of Greenwood *et al*. (2015).

Data were examined to see if there were any statistically significant differences in various parameters before and after the dam was commissioned in December 1998. Preliminary analysis of water clarity data indicated that significant reductions in water clarity occurred in the Opuha River during the construction phase of the dam from November 1995 to November 1998, similar to those observed after the dam was completed. Thus, data from the construction phase were not included in most of the statistical analyses (but were included in some; for example, see Table 2), with the before dam construction data set ranging from January 1989 to October 1995 and the after dam commissioning data set ranging from December 1998 to June 2021, except for BOD_5 data which were only available up until July 2002.

As well as testing for significant differences in the pre- and post-dam water quality and ecological data, pre-dam water clarity data were compared with data for various five-year (and longer) periods after the dam was commissioned. Two sets of five-year monthly clarity data were examined. One considered five-year blocks from dam commissioning onwards, and the other going back in time from the most recent NRWQN data (2021), which aligned with the most recent five-year clarity data set used by Eveleens and Young (2024) to estimate the impacts of fine sediment on biota in the Opuha River. Median clarity values were calculated for determining the NPSFM suspended fine sediment attribute gradings (bands) for each five-year period.

Mean annual clarity and turbidity data, overall and in the 0–5, 5.01–10, 10.01–20 and >20.01 m^3s^{-1} flow ranges, were examined to see if there were any significant differences in water clarity in particular parts of the flow regime before and after the dam was installed. The mean annual clarity and turbidity data were calculated using the monthly samples taken within each flow range for each year. Mean discharge data in each flow range for each year were derived from the monthly discharge data recorded at the time the respective clarity/turbidity data were measured. Two-tailed t-tests for two samples assuming unequal variance were conducted using Microsoft Excel to determine statistical significance at a 5% level. The ecosystem health of the Opuha River was assessed using

MCI and QMCI national guidelines of Boothroyd and Stark (2000) and Stark and Maxted (2007), and the assessment criteria of the NPSFM 2020. The NPSFM suspended fine sediment attribute criteria were assessed using visual clarity data, based on rivers in the suspended sediment class 3 (which is derived using the River Environment Classification for the relevant river reach). Both the Ōpihi River (CD_Hill_HS category) and the Opuha River (CD_Hill_HS category; CD_Lake_Any category) are in this class.

Results

Changes in water clarity

The overall mean annual clarity in the Opuha River at Skipton Bridge was about 20% lower post-dam compared with pre-dam ($P = 0.048$; Table 1).

Reductions in water clarity occurred in the Opuha River during dam construction and after the dam was commissioned. Before construction of the dam, the Opuha exhibited a mean and median clarity of 2.91 and 3.0 m, respectively (Table 2). The mean clarity (2.91 m) in Table 2 is slightly different to the mean annual clarity (2.89 m) reported in Table 1, as they are different statistics. The median clarity before construction (3.0 m) corresponds to a river in the NPSFM suspended fine sediment attribute 'A' band, indicative of a healthy hill-fed river showing minimal impact of suspended sediment on instream biota and where ecological communities are similar to those observed in natural reference conditions (NPSFM, 2024).

During the three-year dam construction period the mean clarity in the Opuha River was reduced significantly ($P = 0.030$) to 2.17 m with the median clarity being 2.05 m. Although this period is shorter than the five years specified in the NPSFM for determining attribute state, the indicative attribute band is 'D' – the lowest band for ecosystem health and below the national bottom line of 2.22 m for the relevant suspended sediment class. The D band is indicative of a river showing

Table 1 - Mean BOD_5, nitrite and nitrate N, total N, DRP, MCI and QMCI scores (median values in parentheses); and mean annual discharge (at time of sampling), clarity and turbidity for the Opuha River before construction and after commissioning of the Opuha dam.

Parameter	Before dam (Jan 1989 to Oct 1995)	After dam (Dec 1998 to June 2021)	% change	Significance (P)[a]
BOD_5 (mg/l)	0.36	0.35	-3	ns (0.85)
NO_2^- & NO_3^- as N (mg/l)	0.23	0.27	17	ns (0.092)
Total N (mg/l)	0.33	0.44	33	< 0.001
DRP (µg/l)	1.7	2.4	41	< 0.001
MCI score	139 (136)	114 (113)	–	< 0.001
QMCI score	6.6 (6.7)	5.1 (5.0)	–	< 0.001
Discharge (m^3s^{-1})	9.09	8.31	-8.6	ns
Clarity (m)	2.89	2.30	-20	0.048
Turbidity (NTU)	4.68	4.07	-13	ns (0.067)

[a] ns – not significant using a 5% level t-test assuming unequal variances

a high impact of suspended fine sediment on instream biota. Significantly altered ecological communities would be expected, with sensitive fish and macroinvertebrate species lost or at high risk of being lost and habitats exhibiting poor ecosystem health (NPSFM, 2024).

Over the 22-year period following the dam commissioning (December 1998 to June 2021) the mean clarity reduced significantly (P = 0.0082) compared to the mean clarity before dam construction, i.e., from 2.91 m to 2.31 m (Table 2). The median clarity for this period (2.26 m) falls into the suspended fine sediment attribute 'C' band, just above the D band threshold and national bottom line of 2.22 m. The C band is indicative of a moderate to high impact of fine sediment on biota. There was no significant difference between the mean and median clarities during dam construction and after dam commissioning.

The five-year mean and median clarity of the Opuha River in different periods since the dam was built fluctuated (Table 3). In most five-year periods, there was a significant reduction in clarity compared to before the dam and the median clarity fell into the C or D band of the NPSFM suspended fine sediment attribute.

In the most recent 5-year period, from July 2016 to June 2021, the mean clarity was higher (2.65 m) and significantly different to those in other post-dam periods that showed poor ecosystem health (ranging from 2.04 m to 2.38 m), but not significantly different to the mean clarity before the dam was constructed (2.91 m). The median clarity for this post-dam period was 2.63 m, corresponding to a river in the lower part of the B attribute band, indicative of a moderate impact of fine sediment on biota.

Mean annual water clarity in the 0 to 5 and 5 to 10 m^3s^{-1} ranges in the Opuha River (Table 4) was significantly reduced, by about 30% post-dam compared with pre-dam. In contrast at high flows (> 20 m^3s^{-1}), mean annual clarity increased significantly, by 250%, presumably as a result of sediment capture by the dam and relatively clearer water being discharged at such flows than prior to the dam.

Table 2 - Mean and median clarity (m), and NPSFM 2020 suspended fine sediment attribute bands in parentheses, in different periods for the Opuha River before (1989–95) and during (1995–98) construction, and after commissioning (1998–2021) of the Opuha dam.

Period of comparison	**Mean monthly clarity**		**Significance (P)**[a]	**Median clarity (NPSFM band)**[§]	
	Before/ During	**During/ After**		**Before/ During**	**During/ After**
Before vs during construction	2.91	2.17[†]	0.030	3.00 (A)	2.05 (D)
During vs after construction	2.17[†]	2.31	ns	2.05 (D)	2.26 (C)
Before vs after construction	2.91	2.31	0.0082	3.00 (A)	2.26 (C)

[a] ns – not significant using a 5% level t-test assuming unequal variances

[§] The NPSFM 2020 ecosystem health (water quality) suspended fine sediment attribute bands for median visual clarity in rivers of suspended sediment class 3 are: A, > = 2.95 m; B, < 2.95 and > = 2.57 m; C, < 2.57 and >= 2.22 m; and D, < 2.22 m

[†] Derived from only three years of monthly clarity data rather than from five years of data as recommended by the NPSFM 2020 – see text

Table 3 – Mean and median clarity (m; and NPSFM 2020 suspended fine sediment attribute bands in parentheses) in different five-year (and other) periods for the Opuha River after installation of the dam, and significance compared with the mean before dam construction (1989-1995).

Period after installation of dam	Mean	Median	Significance (P)[a]
Overall, December 1998 to June 2021‡	2.31	2.26 (C)	0.0082
December 1998 to November 2003	2.31	2.19 (D)	0.021
December 2003 to November 2008	2.28	2.36 (C)	0.012
December 2008 to November 2013	2.04	1.85 (D)	0.0013
December 2013 to November 2018	2.38	2.43 (C)	0.049
Overall, December 1998 to June 2016†	2.21	2.18 (D)	0.0025
July 2001 to June 2006	2.24	2.28 (C)	0.0077
July 2006 to June 2011	2.21	2.11 (D)	0.0060
July 2011 to June 2016	2.25	2.15 (D)	0.018
July 2016 to June 2021	2.65	2.63 (B)	ns (0.34)

[a] ns – not significant using a 5% level t-test assuming unequal variances
‡ 22-year period overall
† 17-year period overall

Table 4 - Mean annual clarity (m) (and number of annual means in each flow range in parentheses) in different flow ranges for the Opuha River before and after commissioning of the Opuha dam.

Flow range (m^3s^{-1})	Mean clarity		% change	Significance (P)[a]
	Before dam (Jan 1989 to Oct 1995)	After dam (Dec 1998 to June 2021)		
0–5	4.18 (7)	2.80 (21)	-33	0.0019
5.01–10	3.60 (7)	2.38 (22)	-34	0.024
10.01–20	1.08 (7)	1.62 (19)	50	ns
> 20.01	0.26 (5)	0.92 (10)	250	0.0015
Overall	2.89 (7)	2.30 (22)	-20	0.048

[a] ns – not significant using a 5% level t-test assuming unequal variances

Changes in water turbidity

The overall mean turbidity has been reduced by 13% since the dam was commissioned, although the change is not significant at the 95% confidence level (Table 1). The turbidity in the Opuha River has increased at lower flows but decreased at higher flows since the dam was commissioned (Table 5). A significant increase in the mean turbidity in the lowest flow band (< 5 m^3s^{-1}; 350%), and potentially in the 5 to 10 m^3s^{-1} flow range (400%), reflects the presence of more fine sediment suspended in the water at lower flows. At flows > 20 m^3s^{-1} the mean turbidity decreased significantly, by 65%. The decrease in mean turbidity at high flows is expected,

Table 5 - Mean annual turbidity (NTU) (and number of annual means in each flow range in parentheses) in different flow ranges for the Opuha River before and after commissioning of the Opuha dam.

Flow range (m^3s^{-1})	Mean turbidity		% change	Significance (P)[a]
	Before dam (Jan 1989 to Oct 1995)	After dam (Dec 1998 to June 2021)		
0 – 5	0.51 (7)	2.31 (21)	350	< 0.001
5.01 – 10	0.88 (7)	4.42 (22)	400	ns (0.12)
10.01 – 20	5.58 (7)	5.68 (19)	2	ns
> 20.01	29.7(5)	10.5 (10)	-65	0.0059
Overall	4.68 (7)	4.07 (22)	-13	ns (0.067)

[a] ns – not significant using a 5% level t-test assuming unequal variances

as the dam will capture essentially all of the coarse sediment and some of the fine sediment that flowed down the river system during higher flows prior to the installation of the dam.

Changes in macroinvertebrate metrics

The mean MCI score reduced from 139 to 114 (P < 0.001) and the mean QMCI score from 6.6 to 5.1 (P < 0.001; Table 1) after the dam was commissioned. The decreases in MCI and QMCI scores could reflect changes from clean water to water of doubtful quality, according to the criteria of Boothroyd and Stark (2000), or changes from excellent to good water and/or habitat quality according to the criteria of Stark and Maxted (2007), respectively.

The median respective MCI and QMCI scores of 136 and 6.7 before the dam was installed correspond to NPSFM attribute states in the A band for ecosystem health (> 130 and > 6.5, for MCI and QMCI, respectively) indicative of pristine conditions with almost no organic pollution or nutrient enrichment. The median MCI and QMCI scores after the dam of 113 and 5.0, respectively, correspond to numeric attribute states in the bottom of the B band and in the middle of the C band (≥ 110 and < 130, and ≥ 4.5 and < 5.5, respectively), and could be indicative of moderate organic pollution or nutrient enrichment with a mix of taxa sensitive and insensitive to such conditions (NPSFM 2024).

Changes in other metrics

Mean BOD_5 and nitrite and nitrate N concentrations have not significantly changed, but total N and DRP have significantly increased (P < 0.001) since the dam was commissioned (Table 1).

Observations of sediment deposition in the Ōpihi River catchment

Fine sediment that has settled out and accumulated over time since the dam was first filled covers shallower areas of the bed of Lake Opuha relatively uniformly and is readily visible when the lake is low. The sediment layer observed on the exposed lake bed in 2024 about halfway along the western edge, and about 600 metres from the margin of the full lake, was about 150–200 mm deep on top of original farmland topsoil. Towards the lake outer margins the layer was progressively less thick. When a small sample of this wet or dry lake bed sediment was rubbed between fingers in water it was quickly and entirely entrained, producing a turbid suspension, and no coarse material was observed.

Fine sediment deposition has also been observed in other parts of the Ōpihi catchment including on the bed of the Kakahu River after releases of irrigation water from the KIS (Rankin, 2023). Fine sediment collects in eddies and pools in the first gorge of the Kakahu River and can build up to about half a metre deep in some places during the irigation season (G. Smillie, pers. comm., 2024). Such deposited fine sediment is normally flushed downriver once a suitable-sized fresh has occurred. Dried deposits of hard, fine white/light grey sediment on rocks uncovered after releases often contain fibrous organic matter, and can be up to one centimetre thick if an irrigation water release has been running uninterrupted for some time (G. Smillie, pers. comm., 2024). Similar deposits have also been observed on rocks in the Opuha River above the Ōpihi River confluence. Such fine sediment deposition was not observed in the Kakahu River prior to the KIS (G. Smillie, pers. comm., 2023).

Discussion

Changes in clarity, turbidity and sedimentation in the Opuha River

Analysis of the NRWQN monitoring data shows that significant decreases in water clarity and significant increases in turbidity have occurred in the Opuha River at Skipton at lower flows since the dam was commissioned, whilst at higher flows water clarity is significantly higher and turbidity significantly lower. The changes were only revealed when analysis of monitoring data was done in different flow bands. Increases in clarity and reductions in turbidity might be expected at both lower and higher flows as a result of fine sediment capture by the dam, and so a decrease in clarity or an increase in turbidity at lower flows was not expected.

The decrease in clarity and increase in turbidity at lower river flows means that more fine sediment is discharged from Lake Opuha at lower flows since the dam was installed. This situation is consistent with the anecdotal observations of fishers that the Opuha River at Skipton Bridge is regularly turbid and no longer as clear as it used to be in low flows. In contrast, the North and South Branches of the Opuha River above the lake still exhibit exceptional clarity in periods of low flow, as they also did before the dam (B. Stone, pers. comm., 2023).

Although less-turbid water and less fine sediment is discharged at higher flows since the dam was installed, such flows still contain significant quantities of fine sediment. Thus, overall, the changes in fine sediment release found in the Opuha River since the dam are consistent with anecdotal comments from fishers noting a regular discharge of turbid water down the river systems. This includes the Kakahu River when it receives turbid water from the Opuha River via the KIS.

The quantity of fine sediment settling out down the Opuha and Ōpihi Rivers in the past is not known. Before the dam, much of the finer sediment would have been flushed down the river during freshets, entrained in the turbulent higher flows along with some coarser sediment. Since the dam, essentially all coarser sediment from rivers feeding into the lake will have settled out and been retained in the lake, and only fine suspended sediment that has not settled out will be discharged. This fine sediment may have a greater chance of settling out downriver, as the controlled lower flows will likely be less turbulent and less able to keep the fine sediment in suspension compared to flow in a freshet situation.

Why does the dam result in a regular discharge of turbid water down the Opuha River?

The dam infrastructure has significantly altered the continuity of sediment transport and water flow in the upper Opuha River system. It is clear that some fine sediment from lake inflows settles out on the lakebed and presumably the remainder is routinely discharged in water leaving the lake, as is reflected in the decreased median clarity and increased turbidity at Skipton Bridge since the dam was installed. The Opuha dam infrastructure has not been designed for sediment management and this has a number of implications for the quality of water discharged from the lake. The dam has no scour valve at the bottom to allow settled sediment to be discharged (Biggs and Hickey, 2012). The storage lake with a hydraulic residence time of about 0.30 years is small enough for successful drawdown flushing to be used to control sediment in the dam (Kondolf *et al.*, 2014). However, the small maximum flow of 16 m^3s^{-1} through the dam via the offtake valve also has no ability to vent turbidity-current sediment-laden water from freshets or provide flushing flows, and therefore effectively minimise sediment capture and help maintain aquatic habitats downstream (Lessard *et al.*, 2013; Kondolf *et al.*, 2014).

Under freshet conditions turbidity currents, where denser, sediment-laden water travels along the bottom of the reservoir toward the dam without mixing with upper less-dense waters, may transport turbid, muddy water and cause deposition of new silt to the bed and cause the deep intake to draw muddy water (Biggs and Hickey, 2012). As sediment accumulates in the deep areas near the base of the dam, and infilling and loss of storage capacity increase, the risk of drawing muddy water will increase. The lack of alternative offtake valves spaced at different depths to allow the selection of different clarity waters to be discharged from the lake also removes the ability to discharge flows from the lake of suitable quality for maintaining minimum environmental flows and irrigation supply (Biggs and Hickey, 2012).

Another factor that may be relevant is the aeration system installed to deal with the anoxic conditions and stratification that occurs on the bottom of the lake normally between early January and late March each year. As part of the consent conditions the aeration system must be turned on when the dissolved oxygen content near the lake bottom falls to a critical level. This system contains a pipe about 200 metres long anchored by chains to concrete blocks sitting on the lake bed near the dam face and outlet pipe. When air is pumped into and emerges from holes in the perforated pipe, the pipe floats up off the lake bed where it remains constrained above the bed by the chains (A. Meredith, pers. comm., 2025). As sediment builds up over time in this part of the lakebed, this aeration system, when in use, may disturb and mix settled sediment with the water column, adding to the sediment discharged from the lake outlet.

Lake Opuha has a maximum depth of about 35 metres near the dam face when the lake is full, with shallower lake margins. Actual fine sediment concentrations in the lake water at the outlet pipe will be defined by the complex interaction of various factors. These will include the degree and rates of settling of fine sediment, wave action from wind re-suspending fine sediment near the lake margins, currents circulating both sediment and water within the lake, water and sediment inflows into the lake, the propensity for sediment to collect in deeper parts of the lake, sedimentation near the outlet pipe, and water and sediment outflows from the lake (Elçi, 2008; Vijverberg *et al.*, 2011; Biggs and Hickey, 2012; Kondolf *et al.*, 2014). Thus, the Opuha dam effectively captures most of the sediment coming down its catchment and stores clear and muddy water and sediment alike, and is less able to produce settled, clear water than a larger deep artificial lake (Biggs and Hickey, 2012).

Large inflows of turbid, sediment-laden water from freshets in large tributaries are observed to take less than 24 hours to travel through the lake system and be discharged as turbid water via the outlet and reach Skipton Bridge (D. A. Rankin, unpublished results), whilst relatively clear water can be discharged over the dam spillway. Such inflows are likely to be turbidity currents (Kondolf *et al*., 2014), and can result in large reductions in water clarity and very turbid water being discharged. It may take some time for such sediment introduced into the system to mix with the lake water and settle, depending on how large and frequent such events are, and therefore for the turbidity in the Opuha River to reduce. Previously, before the dam, such large inflows of turbid, fine-sediment-laden water would largely and relatively quickly move past Skipton Bridge, and much of the fine sediment would remain entrained in the turbulent flow.

Discharge of water from the dam during the irrigation season is at controlled flows, typically between 5 and 30 m^3s^{-1}. Turbidities were between four to five times higher, the same, and three times lower in the 0 to 10 m^3s^{-1}, 10 to 20 m^3s^{-1}, and > 20 m^3s^{-1} flow ranges, respectively, compared to before the dam. As much of this flow contains fine sediment, the Opuha River (and Ōpihi River downstream of the Opuha confluence) will most likely be routinely subjected to more prolonged exposure to fine sediment and/or sediment deposition than before the dam was installed. Previously, in the natural situation, high suspended sediment only occurred during higher flows. Now it can occur during lower flows, which means that sediment has a greater chance of settling out in the river. The increased deposition of fine sediment observed in the Kakahu River, after receipt of water from the Opuha River delivered via the KIS, is an illustration of this effect.

Nutrient enrichment in the lake has resulted in regular algal blooms (Eveleens and Young, 2024), which, along with sloughed-off didymo and other periphyton, will also contribute organic suspended solids and add to the turbidity of the water downstream of the lake. The observations of fibrous organic matter embedded in the sludge/sediment deposited on the bed of the Kakahu River and in dried deposits of sediment on uncovered rocks, after releases from the KIS into the Kakahu River, are consistent with this.

Considering the factors discussed above, we consider the Opuha dam is responsible for more prolonged exposure of the Opuha River, and Ōpihi River downstream, to fine sediment and fine sediment deposition than before the dam was installed.

A similar situation is probably occurring in the Heathcote River in Christchurch city, following the installation of the Upper Heathcote Storage Scheme. This scheme uses a number of shallow water storage ponds to capture flood flows in the headwaters, to prevent flooding of residential areas further down the catchment during high-intensity rainfall events. The flood flows contain elevated levels of very fine loess clay sediment washed off adjacent hill slopes. High turbidity is now routinely observed (D. A. Rankin, 2025) in the river for prolonged periods after rainfall events as the ponds are slowly drained. Previously, sediment-laden flood flows would pass down the river unrestrained in a matter of days and the river would clear relatively quickly, as the flows receded to normal (P. Christensen, Christchurch City Council, pers. comm., 2025).

Impacts of the dam on the ecological integrity of the Opuha River

The pre-dam Opuha River median MCI and QMCI scores of 136 and 6.7, respectively, were indicative of pristine conditions with almost no organic pollution or nutrient enrichment or impacts from fine sediment. In contrast, the median MCI and QMCI scores after the dam of 113 and 5.0, respectively, could be indicative of moderate organic pollution or nutrient enrichment from farm activities and/or may reflect invertebrate responses to fine sediment (Clapcott *et al.*, 2011; NPSFM, 2024).

Assuming BOD_5 and nitrite and nitrate N are suitable proxies for organic pollution and nutrient enrichment, respectively, and as neither of these parameters have shown a significant change in the Opuha River following commissioning of the dam, it is unlikely that either can explain the decline in macroinvertebrate metrics. Therefore, another factor (or factors) is likely responsible. Mean total N and DRP in the Opuha River have both increased significantly post-dam, which could reflect land use change and/or the presence of algal and planktonic blooms in the lake water.

The median clarity (3.0 m) of the Opuha River prior to dam construction beginning in 1995 placed the Opuha River in the A band for the suspended fine sediment attribute in the NPSFM 2020, reflecting a healthy hill-fed river showing minimal impact of suspended sediment on instream biota. The median monthly clarity of 2.05 m observed during the dam construction period, suggesting a potentially high impact of suspended fine sediment on instream biota, could be expected, as increased sediment release to the river during the dam construction phase would be expected to reduce water clarity and impact negatively on biota. After the dam was commissioned, the significantly reduced median clarity of 2.26 m over the 22-year period from December 1998 through to June 2021 (compared to prior to dam construction) is indicative of a river close to the bottom of the C attribute band of the NPSFM. Here, moderate to high impacts of suspended fine sediment would be expected on instream biota (NPSFM, 2024). Thus, excess fine suspended sediment is most likely playing a key role in the ecological degradation observed in the Opuha and Ōpihi Rivers since the dam was installed.

Eveleens and Young (2024) found a statistically significant reduction in visual clarity in the Opuha River post-dam but did not report the median visual clarity (2.26 m; Table 2) that, according to the NPSFM attribute band descriptions, would indicate a high potential impact of suspended sediment on instream biota. Instead, they reported the most recent five-year post-dam period (July 2016 to June 2021) median clarity of 2.62 m (2.63 m in this work; Table 3), which they concluded indicates a low to moderate impact of suspended sediment on Opuha River biota.

The five-year median for visual clarity reported by Eveleens and Young (2024) is not significantly different to the pre-dam median visual clarity of 3.0 m ($P = 0.34$; Table 3), but is significantly higher ($P = 0.022$) than the median post-dam visual clarity of 2.18 m (D attribute band of the NPSFM) at Skipton Bridge for the preceding 17-year monitoring period (December 1998 to June 2016; Table 3). Thus, the 5-year median clarity of 2.62 m, suggesting a low to moderate impact on biota from suspended sediment, is clearly at odds with earlier and overall post-dam data that suggest impacts are high. It is clear that the 2016 to 2021 five-year median clarity should not be used to draw conclusions about the impact of suspended sediment on biota in the Opuha River. It is unclear why median water clarity was better during the period 2016 to 2021, but the most recent five-year median clarity (from July 2019 to June 2024, as reported by LAWA, 2025), was much lower at 1.48 m, further suggesting ongoing high impacts of fine sediment on biota in the Opuha River.

Other factors possibly affecting ecological health

Eveleens and Young (2024) discussed the factors that contribute to poor ecological health in the Opuha and Kakahu Rivers. In the case of the Opuha River, they concluded that pesticides and other toxicants, large-scale climatic influences, and the temperature of the lake discharge make negligible contributions. Legacy effects of the dam collapse during construction, where very large quantities of sediment were catastrophically washed down the Opuha and lower Ōpihi Rivers, are unlikely to be a contributor. They also considered that altered flow volumes, land use change and intensity, and bed armouring and restriction of fine sediment supply make potentially minor contributions. Lake water quality and excess fine sediment were considered to be more important factors, but they determined altered flow variability and incursion of didymo are likely to be the dominant drivers contributing to the current state of the Opuha River. Eveleens and Young (2024) also concluded that fine sediment from Opuha River water in the KIS discharge is the key ecological driver of concern in the Kakahu River and that increased variability and volume of flow is also likely to be playing a major role. Although Kilroy and Jellyman (2018) also proposed didymo is a key driver of poor ecological health of the Opuha River, along with the regulated flow regime, Eveleens and Young (2024) concluded that there is still another key unrecognised factor at play.

The next two most significant factors likely influencing ecological health in the Opuha River are lake water quality and fine sediment (Eveleens and Young, 2024). No water quality changes reflecting organic pollution and nutrient enrichment that could impinge on macroinvertebrate metrics have been found since the dam was constructed. However, based on water clarity metrics analysed in this study, there has been a significant increase in suspended sediment, and this is most likely the additional driver of ecological health in the Opuha River.

This conclusion is consistent with the observations and conclusions of Eveleens and Young (2024) that fine sediment arising from the KIS discharge, which comes from the Opuha River, is the key ecological driver of concern in the Kakahu River. It would make sense that if sediment in Opuha River water, when transferred to the Kakahu River and where it is diluted with better clarity Kakahu River water, would cause poor ecological health in the Kakahu River, such sediment would also cause poor ecological health in the Opuha River. It is also consistent with the conclusions of Eveleen and Young (2024) that didymo and the regulated flow regime alone are not responsible for the poor health. The result is also consistent with the observations of Hayward *et al.* (2019) of the relatively high turbidity at Skipton Bridge since the dam compared with other monitoring sites around the catchment.

Evidence from multiple aforementioned sources suggests the Opuha dam is directly responsible for the poor health of the Opuha and Ōpihi Rivers downstream. The decrease in clarity and increase in turbidity in the Opuha River at lower flows, changes in flow variability since the dam was installed, coupled with more prolonged fine sediment release and deposition below the dam, are most likely playing a key role in the ecological degradation observed, and in the Kakahu River below the KIS discharge. Whilst it is now clear that turbid water from Lake Opuha may be responsible for the poor health of the Opuha, Ōpihi and Kakahu Rivers, further work is needed to confirm the extent to which other factors, such as didymo and water quality, may be involved.

Observations of river users

The increases in downstream turbidity and fine sediment and degradation in ecological health since the commissioning of the Opuha dam, found in this study, are consistent with the observations of river users. Expert anglers report the Opuha and Ōpihi Rivers have been regularly turbid since the dam was installed, and no longer as clear as they used to be. Notable large declines in the stonefly and mayfly hatches that the Ōpihi was renowned for, and notable declines in the numbers of trout below the Opuha dam, the Ōpihi River downstream of the Opuha confluence, and in the Kakahu gorges, have also been reported. In contrast, the environment in the Ōpihi River upstream of the Opuha confluence is much healthier (B. Stone, pers. comm., 2024). The Kakahu River becomes turbid when releases are made for the KIS, and fine sediment is readily visible deposited on the riverbed during and after releases. Aquatic life is virtually absent in a small gorge about three kilometres below the KIS discharge point. Before the KIS was installed the gorge had a vibrant, healthy ecosystem containing invertebrates, freshwater mussels and crayfish, and trout and eels in every pool (MacDuff, 2022). Increased turbidity in the Ōpihi River has also meant spotting of fish in deep holes is now problematic, and periphyton growths, such as didymo and cyanobacteria, and sloughed-off material make fishing more difficult and less rewarding, and swimming less safe (reduced visibility of underwater hazards) and less desirable (loss of clarity).

Ramifications for irrigation storage schemes and their impacts on rivers

Analysis of the impacts of the dam on the Opuha River has revealed a notable and perhaps largely unrecognised consequence. Fine sediment routinely released from the dam is likely to be causing significant damage to the ecological health of rivers downstream. Such potential impacts have been recognised elsewhere (Young *et al.*, 2004) but until recently appear to have not been considered in the Opuha, Ōpihi and Kakahu Rivers. If other schemes are constructed in a similar fashion, then there will be a real risk that they too will release turbid water that could compromise the ecological health of rivers downstream.

The recently commissioned 52-metre-high Waimea Dam on the upper Lee River near Nelson, with a 13 Mm^3 storage lake designed for water augmentation for irrigation, residual river flow, and community water supply on the Waimea Plains (Tonkin and Taylor, 2019), may also release turbid water to the Lee River and Waimea River downstream. The dam has no facility to discharge sediment from the lake bottom at the foot of the dam, or to bypass or flush sediment at any appreciable rate (Tonkin and Taylor, 2019), and so, like the Opuha dam, may result in negative physical and ecological impacts in the lake and rivers downstream. A proposed 83-metre-high dam on the Makaroro River, to create a 93 Mm^3 water storage reservoir (formerly the Ruataniwha Water Storage Scheme) to enable regional irrigation water security and minimum flows in the Tukituki River in Hawkes Bay (Ministry for the Environment, 2024), may also lead to similar negative ecological impacts for the Tukituki River downstream, unless the dam is appropriately designed.

The health impacts on the Opuha, Ōpihi and Kakahu Rivers may be prevented by stopping the discharge of sediment-laden Lake Opuha water into the rivers. This can be achieved by not using the rivers as conduits for turbid irrigation water, instead piping the water directly to irrigation schemes. This solution is currently being investigated by Opuha Water Ltd to restore the health of the Kakahu River in the gorges immediately below the current discharge point. In addition, allowing only settled, sediment-free water to be discharged from storage lakes, and ensuring storage lakes are the right size, in the right location, and properly designed to provide for sufficient sediment removal may help alleviate this issue (Kondolf *et al.*, 2014). Lessard *et al.* (2013) and Kondolf *et al.* (2014) recommend dams be planned and designed for sediment management from the start, and where possible bypassing sediment around or through the reservoirs, to best protect reservoir function long term and environments downstream.

Conclusions

Examination of long-term river monitoring data from the NRWQN site Opuha River at Skipton Bridge has shown that installation of the Opuha dam in 1998 has unexpectedly and significantly decreased the water clarity and significantly increased the turbidity at low flows, and this corresponds with a reduction in the aquatic health of the Opuha River. According to the NPSFM ecosystem health assessment criteria the Opuha River has changed from one with minimal impacts to a river with high impacts on instream biota from suspended fine sediment.

This situation has arisen through a cascade of impacts as a result of the dam and the design of the irrigation storage lake infrastructure and water offtake. The normal hydrological cycle has been interrupted and prolonged discharge of water containing fine sediment has occurred from the lake since the dam was installed. Well-settled water cannot be accessed for discharge from the lake. Future similar water storage or power generation schemes need to be better designed to prevent similar consequences for the ecological health of rivers downstream.

Other factors impacting on the health of the Opuha and Ōpihi Rivers cannot be ruled out at present but more work is needed to confirm such possibilities and the magnitude of their contributions.

Restoration of the health of the rivers impacted by the Opuha dam requires ceasing the discharge of sediment-laden water. This could be achieved by piping irrigation water from the dam to all irrigation schemes, and not using any rivers as a conduit for this purpose. Parallel to this, clearer, settled water could be taken from the lake in a reconfigured and suitably constructed water offtake system, to supply the residual minimum flows needed to maintain healthy Opuha and Ōpihi River habitats downstream of the dam.

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