Weir drawdown desilting: balancing water quality risks with sediment connectivity and cost-effectiveness benefits.

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Key Points

- A gravity flushing technique at McMahons Weir shows potential for low-impact and cost-effective desilting.
- The proposed method fosters sediment connectivity, crucial for sustaining channel form and supporting aquatic and riparian ecosystems.
- Difficulties encountered include maintaining safe dissolved oxygen levels due to mobilisation of anoxic mud, posing a risk to fish.
- A revised method will be tested at Armstrong Weir, employing an extended drawdown to slowly mobilise accumulated anoxic material and enable a full drawdown.

Abstract

The presence of water supply reservoirs disrupt sediment transport pathways along waterways, accumulating sediment behind the weirs that must then be removed to maintain normal operations. Traditional desilting methods adversely impact aquatic ecosystems and involve costly transportation and disposal of sediment. A gravity drawdown method that fosters sediment connectivity, critical for maintaining channel form and supporting waterway ecosystems, while minimising environmental impact was tested. Two desilting events were conducted at McMahons Weir located on McMahons Creek, a small tributary of the Yarra River. A scour valve was opened allowing the reservoir water level to draw down, mobilising sediment with it. Dissolved oxygen was monitored and used to as a trigger for halting the drawdown. The effectiveness of the desilting approach was assessed through a range of techniques including pre- and post- bathymetric surveys, drone photography captured during drawdown, and the monitoring of suspended sediment concentrations in the reservoir outflow. The effects of the desilting on the geomorphology and water quality of McMahons Creek were also monitored. Overall, the sediment flushing method showed potential to achieve improved removal of accumulated sediment, with some redistribution of material in the weir pool during the trial. With a full drawdown over a long enough period, significant sediment transport through the low-flow channel would be possible. However, the trials were halted early due to a rapid decline in dissolved oxygen downstream as a result of mobilised anoxic mud. This presented a risk to fish. If dissolved oxygen concentrations can be maintained at safe levels through a gradual and extended drawdown period, then this method and its benefits to both operations and sediment connectivity may be viable.

Keywords

Weir, desilt, sediment transport, waterway management, sediment connectivity, McMahons Creek

Introduction

Weirs interrupt the continuity of sediment transport through river systems, causing sediment to accumulate within the reservoir, impairing weir operations and decreasing the available water storage. This also deprives the downstream reaches of sediments essential to maintain channel form and support aquatic and riparian ecosystems. To ensure weirs maintain their useful function, river managers require suitable reservoir desilting techniques that deliver operational and cost efficiency as well as safeguard against further impacts on river ecosystems.

Traditional methods of desilting (e.g., reservoir drawdown and mechanical excavation) require lengthy drawdown and drying periods, flow diversion, and heavy machinery. This negatively impacts fauna that use weir pools as habitat. They also require costly transportation and disposal of sediments. For small to medium-sized weirs, desilting by drawing down the water level and allowing sediment to flush through the scour pipe (drawdown flushing) is potentially a lower-cost option that can restore sediment connectivity.

Previously, in 2018 and 2019, Melbourne Water, RMIT, Streamology and University of Melbourne examined the feasibility, risks and benefits of drawdown flushing of Starvation Creek weir, Victoria. That research confirmed that drawdown desilting was a feasible management option for that particular weir. In 2020 and 2021 the team extended this work to Armstrong Creek's east and west weirs. This paper focuses on the most recent geomorphic investigation of the drawdown flushing technique at McMahons Creek weir in 2023. Macroinvertebrate and fish investigations were done alongside this work but are not reported here.

Site Description

McMahons Creek is a tributary of the Yarra River situated within the upper Yarra River catchment. It flows from the ranges near Cambarville to join the Yarra River at Reefton. McMahons Creek is a partly confined stream with a bed consisting of coarse gravel, cobbles, and boulders. Desilting trials were undertaken at the flow diversion weir at McMahons Creek used for water supply by Melbourne Water, this function was suspended during the trials (Figure 1).

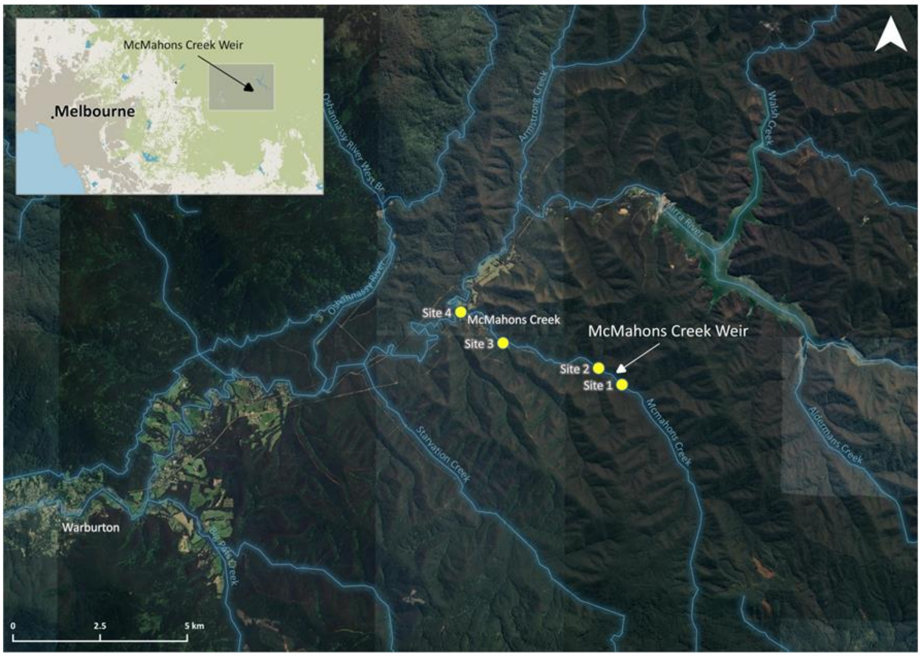

Figure 1. Map of the study area. Sites where geomorphic surveys were undertaken before and after desilting are indicated by yellow markers.

Method

Desilting program

Two desilting events were conducted, the first on 26th of April 2023 and the second on the 2nd of May 2023. Both events used a drawdown flushing method. The scour valve was opened fully, and the reservoir water level allowed to draw down over a period of around 3 hours. To maintain a safe level of oxygen for fish, dissolved oxygen (DO) monitoring just downstream of the weir was used as a trigger for halting the trial. A trigger of 50% DO was applied for the first event. However, a rapid reduction in DO was observed during the first event, with DO levels continuing to decline for a short period after the desilt was halted before recovering. Because of this the DO trigger was increased to 75% for the second desilt.

Desilting effectiveness

Desilting effectiveness was determined by the volume of sediment mobilised downstream (while considering environmental impact and cost) and was estimated with three lines of evidence:

1. Repeat bathymetric survey before and after the desilt events.
2. Drone photography during desilt events (used to validate bathymetric survey results).
3. Monitoring of suspended sediment concentrations in reservoir outflow.

Bathymetric survey data was collected at the weir pool pre- and post-desilting events 1 and 2 in July 2022 and May 2023. The extended period between surveys was due to the desilting events being postponed to 2023 after the failure of the scour pipe penstock during the initial desilt attempt on the 19th of August 2022. Ideally, the surveys would have been conducted immediately before and after the desilt event to avoid changes within the weir pool caused by additional sediment deposition or high flow events.

The 2022 survey provides a baseline for estimating deposition and erosion across the monitoring period. The accuracy of the bathymetric method was +/- 0.05m for each depth measurement. Error was also introduced when interpolating the data points into a solid surface for comparison; however, given the high point density and low slope of the bed surface we considered these errors to be minor.

During both desilting events, a drone was used to capture aerial imagery of the weir and weir pool to assist in understanding the effectiveness of the desilt and aid in validating the bathymetric survey results. Geomorphic features that developed within the weir pool (i.e. channel formation) during the events were recorded with the drone and later compared to changes observed between the bathymetric surveys.

For each event, turbidity was monitored immediately downstream of the weir, and water samples were taken and analysed for total suspended solids (TSS) concentration at multiple times throughout the event. A rating curve was developed between TSS and turbidity and applied to estimate TSS between samples. Flow was estimated using a culvert calculator (HY-8) and observed head levels for the second desilting event. The water level gauge malfunctioned for the first desilting event, so flow was estimated using field notes. Flow and TSS concentration were multiplied, and then integrated over time using a rectangular approximation to give an estimate of sediment load.

Geomorphic monitoring

Geomorphic survey was undertaken before and after desilting, on 21st of April 2023 and again on 29th of May 2023. Four sites were surveyed, three below the weir and one above for comparison (see, Figure 1).

At each site, the following data was collected:

- Cross-sectional morphology survey using a dumpy level at one cross-section;
- 100-pebble count along diagonal transects to characterize the grain size distribution of the streambed (Bunte and Abt., 2001); and
- Photos (diagonally upstream and downstream and straight across channel) from a fixed photo point.

Results

Desilting Effectiveness

The event TSS monitoring and repeat bathymetric survey gave different estimates of the amount of sediment removed. Turbidity and TSS monitoring showed that desilting resulted in the removal of around 0.9 t of sediment in the first event and 0.5 t of sediment in the second event (Table 1). These are modest amounts of sediment given the size of the weir pool and are unlikely to make a noticeable difference to weir operations.

Table 1. Desilting effectiveness

Date	Desilting duration	Maximum drawdown	Sediment removed (t) - TSS method
26 April 2023	3 h	-1.5 m	0.9
2 May 2023	3 h	-1.6 m	0.5

The bathymetric survey showed that there was a redistribution of sediment in the weir pool over the period from July 2022 to May 2033 which included the two desilting events (Figure 2). There was more erosion (517m^3) than deposition (314m^2) between the bathymetric surveys (Table 2), indicating that around 200 m^3 of sediment was mobilised downstream in the period. The bulk density of sediment was not measured but various published estimates give a range of around 0.8 to 1.3 t/m^3 for near-surface reservoir sediment (Verstraeten and Poesen., 2001; Beckers et al., 2018), meaning that around 160-260 t of sediment may have been removed.

Most of the erosion occurred at the downstream end of the weir pool, closest to the weir and outlet (Figure 2). During the long period between surveys, sediment was deposited upstream of the weir pool. The deposited sediment was sorted by size, with the coarser material sediment settling first as the flow velocity reduced substantially upon entering the pool.

A low-flow channel formed at the upstream end of the weir pool during both desilt events. It developed as the tailwater level reduced and flow from upstream eroded stored sediments, activating bed sediment transport processes. Erosion in this area is visible in the bathymetric comparison.

Table 2. ***Deposition and erosion volumes between 2022 and 2023.***

Weir	Deposition	Erosion
McMahons Weir	314	517

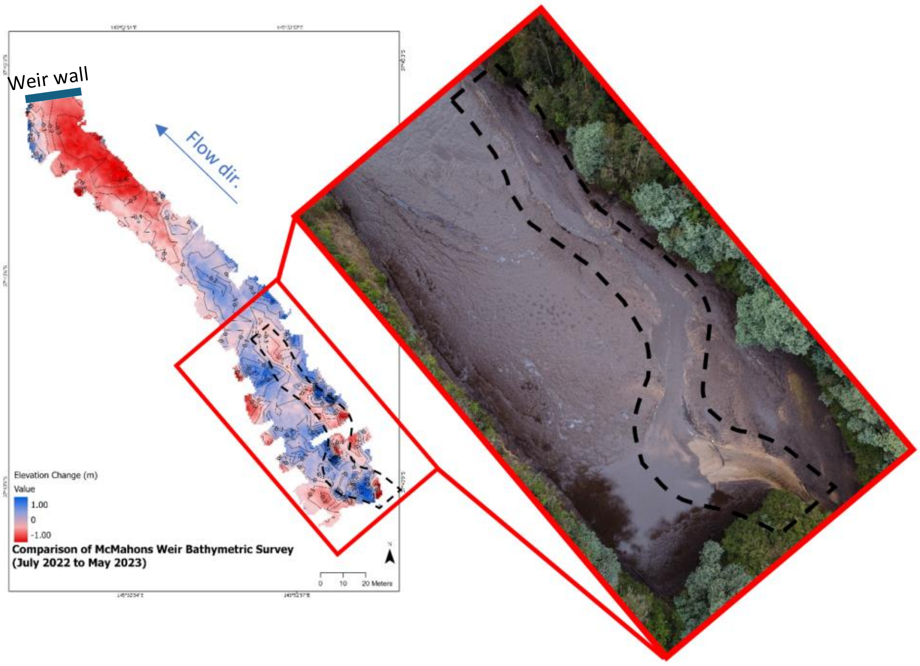

Figure 2. Plot showing erosion and deposition behind McMahons Weir over the period July 2022 to May 2023. A positive change (blue) indicates deposition, and a negative change (red) indicates erosion. The enlargement shows the low-flow channel (outlined by dashed line) scoured through sediments near the upstream extent of the weir pool during a desilting event.

The considerable difference between the estimates given by the two methods is likely due to sediment remobilisation caused by flow events other than the desilting events during the 10-month period between surveys, including the major flow event in October-November 2022 (Figure 3). Although there are gaps in the discharge records during both events, the data shows that flows in McMahons Creek upstream of the weir (Station 229106A) reached at least 4.6 and 4.7m^3/s on the 30th of October and the 2nd of November, respectively (Bureau of Meteorology Water Data Online, accessed 27/09/2023). Both events exceeded the estimated 25-year average recurrence interval (ARI) flood event magnitude at the gauge making them significant flow events and likely capable of mobilising sediment within the weir pool.

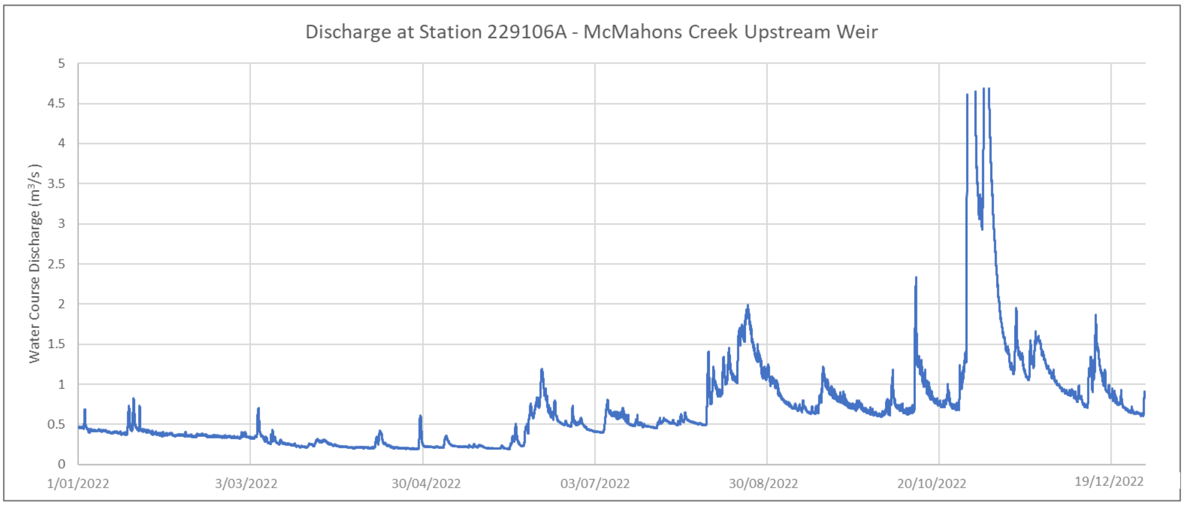

Figure 3. ***Water course discharge (m^3/s) at Station 229106A – McMahons Creek Upstream Weir.***

Overall, we consider the TSS-turbidity monitoring to give the more reliable estimate of sediment mobilised specifically during each desilting event, while the bathymetry survey gives a useful indication of sediment redistribution patterns in the upstream part of the weir pool.

Desilting water quality

Both desilting events were halted due to the rapid decline in DO as a result of the mobilisation of anoxic mud. In both events, DO began to rapidly decline when the weir water level was drawn down around 1.1 to 1.3 m below the weir crest, and the pipe was flowing at around 1 m^3/s, and when the TSS concentration of the scour pipe outflow was around 70 mg/L. The desilting was halted when the DO level dropped below 50% in the first event, after which it continued to decline rapidly to near-zero. In the second event, the desilting was halted when the DO level dropped below 75%. The DO reached a minimum of around 60% in the reach downstream, and a minimum of around 20% in the weir pool, before beginning to recover.

Geomorphic monitoring

Minimal geomorphic effects of the desilting were detected downstream of the weir. This was the expected outcome as the amount of sediment released by the desilting trial (~ 1.4 t) was small compared to likely background sediment supply and transport capacity. Repeated photos at fixed photo points did not indicate any qualitative geomorphic changes.

Cross section surveys

There were only minor changes between the before and after cross-sectional morphology surveys along McMahons Creek. None of the changes were large enough to suggest that the desilting program has had a significant impact on the morphology of the creek (Figure 4). Rather, they reflect a redistribution of sediment within the cross-section itself.

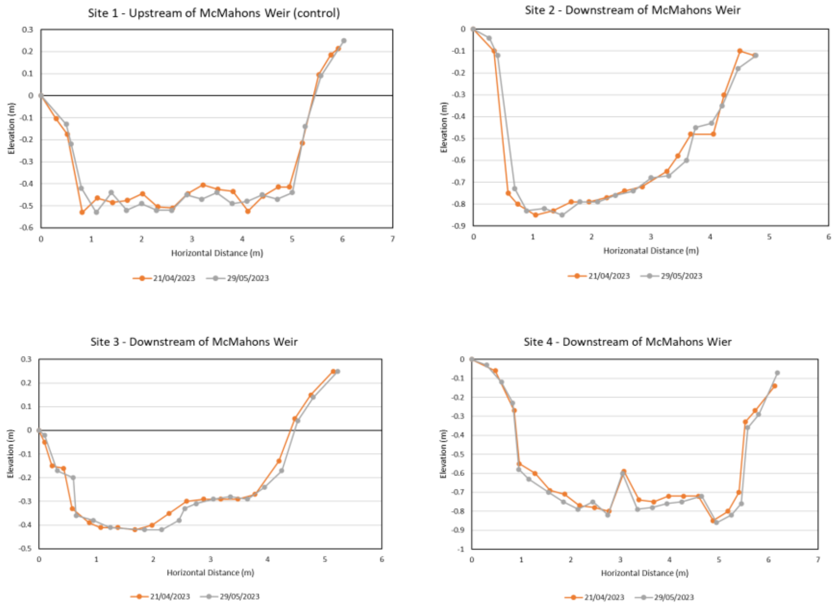

Figure 4. Cross-sectional morphology surveys conducted before and after the desilting program at McMahons Weir.

Bed sediment size distributions

The proportions of sediment size remained similar across each site, also suggesting that the desilting program had negligible effect on the morphology of the creek.

Desilting process

Figure 5 shows a bird's eye view of the upstream end of the weir pool at the end of each desilt (post desilt 1 - left image, post desilt 2 - right image). The water level was higher after the second desilt as the scour pipe was closed earlier to avoid dissolved oxygen levels becoming too low.

During the second desilt, flow from upstream continued to develop the low-flow channel along the right side of weir pool. While the bed appears similar in both images there are some differences that show additional sediment was mobilised during the second trial. For example, after the second desilt, the channel was slightly wider and more sinuous, likely due to channel widening and outside bend migration processes.

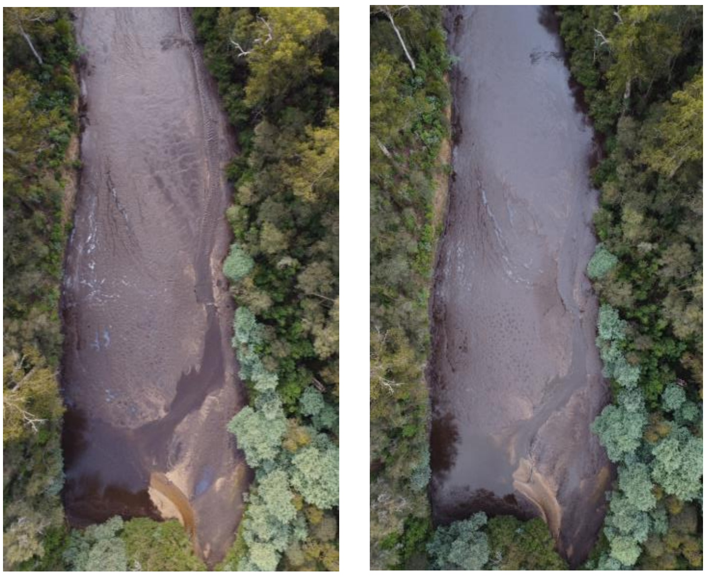

Figure 5. Aerial view of the upper weir pool bed post desilt 1 (left) and desilt 2 (right).

Figure 6 demonstrates two interesting morphological processes that occurred during the desilting process. Firstly, erosion through a surface layer of coarse sediment where the creek enters the weir pool (left image) and secondly the cracking and fracturing that occurred in the silt (right image).

During normal operational conditions when flow first enters the weir pool and begins to decelerate the coarse sediment is deposited out first. During desilting as the water level in the weir dropped this deposited coarse armour layer was eroded by flow entering the weir pool from upstream. A channel quickly formed once the armour layer was removed and erosion along the outside bank occurred in the finer sediment below via scouring, undercutting, and slumping. This continued throughout the desilting process (Figure 6, left image).

Within the silty sediment, cracking and slumping of sediment occurred as saturated sediment dewatered (Figure 6, right image). Saturated sediments have low strength and are prone to mass failure as the buoyancy provided by water is removed.

Figure 6. Two morphological processes that occurred during the desilting process. Erosion through coarse sediment where the creek enters the weir pool (left image) and the cracking/fracturing and slumping that occurred in the silt (right image).

Discussion

Drawdown desilting at McMahon's Creek weir was limited in effectiveness. Desilting was only undertaken for two events of around 3 hours duration each. In both events, most of the sediment was released in the final 20-30 minutes of the operation. The events were halted due to rapidly declining DO as a result of mobilisation of anoxic mud, presenting an acute risk to fish. Balancing effectiveness and environmental risk is therefore tricky.

Effectiveness could be maximised by fully drawing down the water level and allowing slumping and scouring of sediments along the flow channel through the accumulated sediment for an extended period. However, under current conditions it is not possible to fully draw down the water level without causing an unacceptable rapid reduction in dissolved oxygen levels.

It may be possible to run an extended drawdown event aimed at slowly mobilising accumulated anoxic material. In the two desilting events, dissolved oxygen was relatively stable when the TSS concentration was less than 70 mg/L. An extended drawdown event which aims to maintain the TSS concentration at around 70 mg/L in the scour pipe outflow (and the DO level above 90%) could mobilise around 0.25 t/hr. At this rate, meaningful amounts of sediment could be mobilised over a period of days. Careful monitoring and adjustment of the drawdown process would be required.

The desilting events did redistribute sediment in the upstream part of the weir pool, indicating that full drawdown over a long enough period should result in increased sediment transport through the low-flow channel, and sediment slumping from side deposits towards the channel. It is estimated that ~3 days should be sufficient to mobilise sediment while maintaining safe DO levels. The required duration of the desilt process also reflects the size and shape of the pool, the inflowing streamflow conditions, and the sediment size range and volumes entering the pool.

While this process would not remove all the silt within the weir, it would remain significantly more cost-effective and have far less impact on the environment than traditional desilting methods. Excavation of silt within a weir of this size usually requires months, as the weir needs to be drawndown and a flow diversion pipeline installed to allow the silt to dry before sediment can be physically removed. This prolonged process involves the extensive use of heavy machinery and disposal of the excavated sediment offsite which are both costly. It also disturbs the surrounding ecosystem (e.g. loss of habitat pools for platypus).

The desilting had no discernible negative impact on the waterway geomorphology downstream. Channel cross-sections and bed sediment size distributions showed only minor changes, as was expected from the short-lived trial desilting events where only lesser amounts of sediment were mobilised. Further monitoring of this aspect under a longer duration drawdown is necessary and will be the focus of additional trials at the nearby Armstrong Weir in June 2024.

Conclusion

The drawdown flushing method shows potential for cost-effective desilting of small to medium sized weirs with minimal environmental impact, provided dissolved oxygen concentrations can be maintained at safe levels for aquatic fauna. Sediment redistribution in the weir pool during the trial indicated that a full drawdown over a long duration (~3 days) could mobilise a significant proportion of the accumulated sediment. Our assessment demonstrated the importance of trialing new methods at each individual weir and highlighted that desilting protocols need to be tailored to the size, shape, hydrology, sediment quantity and sediment quality of each weir pool. Using the results of these trials and previous assessments at Starvation Creek weir and Armstrong East Weir, a revised methodology for the drawdown flushing method will be tested at the nearby Armstrong Weir site in 2024. If the revised method is successful, it will provide a useful technique for mobilising sediment trapped behind small weirs, which will maintain their water supply capacity while ensuring sediment connectivity, preserving channel form, and supporting downstream aquatic and riparian ecosystems.

Acknowledgments

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