Water quality and ecological recovery of a mountain stream after 60 years of receiving sewage effluent

Wright IA[1], Morrison KG[1], Hurst E[1] and Ryan M[1]

1 Western Sydney University, Locked Bag 1797, Penrith NSW, 2751. Email: I.wright@westernsydney.edu.au

Key Points

- Hat Hill Creek was organically polluted and ecologically impaired due to decades of receiving poorly treated sewage effluent from Blackheath sewage treatment plant (STP).
- The recovery of Hat Hill Creek's water quality after the removal of sewage in 2008 was rapid.
- Macroinvertebrate results show that recovery of the stream ecological health takes much longer.
- Pollution sensitive mayflies, stoneflies and caddisflies are returning, but after 10 years since the sewage was stopped they are still less abundant than at the upstream reference site.
- The relative abundance of pollution tolerant invertebrates is gradually declining, but after 10 years since the STP closure, they are still more abundant than at the upstream reference site.
- The progress towards ecological recovery has been assisted by having such a clean and ecologically healthy waterway upstream of the former sewage discharge.
- The closure of the Blackheath STP cost millions of dollars and was the last of 12 poorly performing STPs in the Blue Mountains that were closed by Sydney Water over a 38-year period.
- It is suspected that residual sewage-derived pollutants remain in the environs of the STP and Hat Hill Creek that continue to impair full ecological recovery.
- Full recovery of stream ecological health from removal of organic pollution is going to take longer than 10 years.

Abstract

In 1980 the sewerage system of the Blue Mountains (NSW) townships was inadequate. It had 12 overloaded sewage treatment plants (STPs) that provided incomplete treatment that caused widespread pollution of its streams. The last major STP discharge to be removed was Blackheath STP. It was permanently closed in June 2008. This study was conducted over 15 years. We used stream macroinvertebrates to measure the ecological changes that resulted following the STP closure. This began when it was still operating in 2003, then 16 months later (2009), and then in 2018, almost 10 years after its closure. This case study was a rare opportunity to study the recovery of a previously chronically impaired freshwater stream by decades of receiving poorly treated sewage wastes. We used a replicated quantitative 'kick sampling' technique and identified invertebrates to the family level to measure ecological health recovery of the small headwater stream. We found that the degree of ecological recovery was large but not complete, indicating a possible residual disturbance remaining. We suggest that one of the important factors that has enabled the recovery to date was the clean water quality and environmental condition of Hat Hill Creek upstream of the pollution.

Keywords

organic pollution, nutrients, salinity, EPT, pollution ecology, montane upland stream

Introduction

It is rare for studies using freshwater macroinvertebrates to document many years of ecological changes that follow removal of a long-term polluting waste discharge. Dean & Haskin (1964) followed the recovery of an estuary in the United States of America for more than two years following removal of a sewage pollution source. Rabeni et al. (1985) studied response of macroinvertebrates to abatement of combined organic pollution (pulp and paper waste; sewage wastes) on the Penobscot River in Maine (USA). An Australian study by Besley and Chessman (2008) studied the response of macroinvertebrates, over multiple years, following the closure of sewage effluent discharges to streams in the Blue Mountains. They found that the ecosystem recovery of some Blue Mountains waterways was compromised by non-sewage sources of contamination that existed before and after the STP closures. A second Australian study, also in the Blue Mountains, reported the recovery of a partly urban creek following a devastating pesticide spill (St Lawrence et al., 2014).

The factors and ecological processes that contribute to recovery of riverine ecosystems from pollution, amongst other disturbances, have been studied by Wallace (1990) and also by Yount and Niemi (1990). Wallace (1990) outlines important factors such as position of the disturbance in the catchment as well as the severity and persistence of the pollutant. Yount and Niemi (1990) also highlight the importance of flushing upstream flows and the ability of invertebrates in a dynamic environment to respond to disturbance. They also stress the importance of a local 'supply' of clean water species.

The questions we address in this study are, (1) How do macroinvertebrates respond to the removal of a long-term organic pollution source (over 60 years of continuous sewage release)? (2) What is the relative effectiveness of commonly used biotic indices in measuring the changes? (3) What factors contribute to the pollution recovery?

Methodology

We used quantitative surveys of benthic macroinvertebrates to compare the effects of the cessation of treated sewage discharges on stream macroinvertebrates within a small mountain stream, to investigate the impact of removal of a major pollution source (Figure 1). The study used an inverse 'BACI' (before vs. after, control vs. impact) design (see Underwood, 1981) following methods based on those used by Wright & Burgin (2009a). The 'before' was the operation of the STP and discharge of waste to the stream. This was assessed by sampling the 'impact' site 'Hat Hill downstream (HHD)' 50 metres below the entry of the STP wastes, when the STP was in operation. The 'after' was the same site 'HHD' following the closure of the STP. In this study the 'after' samples were collected 16 months (2009), and then nearly 10 years after the STP closure (April 2018) in June 2008 (Figure 1; Figure 2). The study also used an upstream (reference) site 'Hat Hill upstream (HHU)' as the reference 'control' site.

Sampling was undertaken on Hat Hill Creek, at an altitude of c. 980-920 m ASL in the upper Grose River catchment in the Blue Mountains (Figure 1; 33°35'S, 150°15'E), which lies on the Great Dividing Range in south-eastern Australia. The area is highly valued for conservation and a majority of the area is managed as part of Blue Mountains National Park estate. This National Park forms part of the Greater Blue Mountains World Heritage Area (NPWS, 2001; BMCC, 2002). Management of the National Park areas is complex and involves both the NSW and Federal Australian Governments (Wright et al., 2011). Previous research indicated that streams in the area are generally very clean, except for organic pollution originating from Blackheath STP and heavy-metal pollution from an abandoned coal mine near Dalpura Creek (Figure 1. Figure 2; Wright & Burgin, 2009a,b).

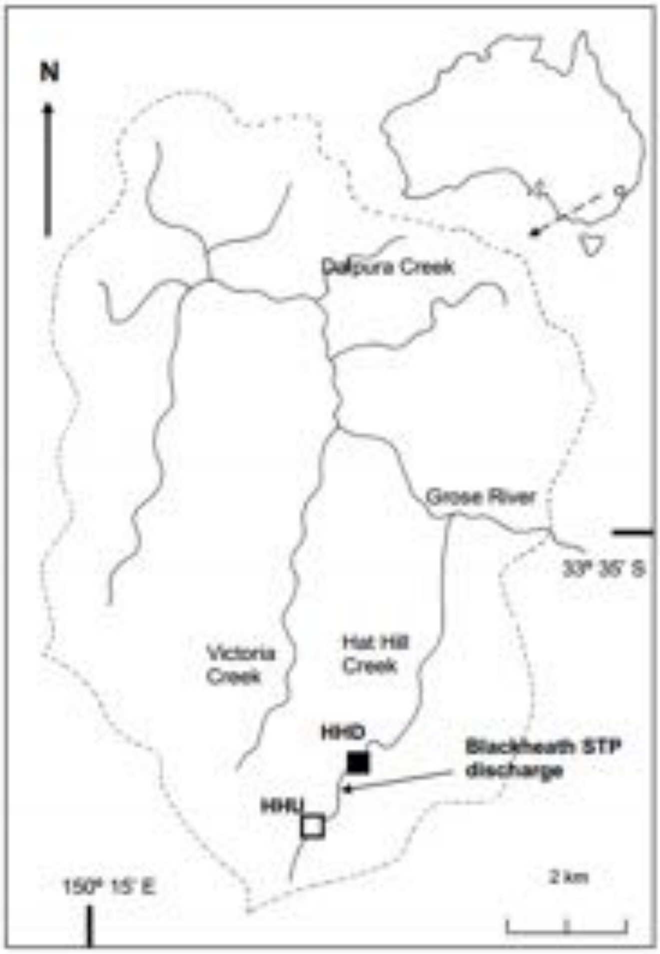


Figure 1: Map of the upper Grose River catchment (dotted line) and main tributaries of the upper reaches of the Grose River. Sample sites HHU (Hat Hill Creek upstream) and HHD (Hat Hill Creek downstream) and relative location of the Blackheath STP are indicated. The study area in south east Australia is shown.

Macroinvertebrates were collected from both sites on three occasions in 2003 (April, May and June), five years prior to the STP being closed. This was part of an earlier study (Wright, 2006; Wright & Burgin 2009 a,b). One round of sampling was conducted in November 2009, 16 months after the sewage discharge had ceased. The final sampling occasion was in April 2018. On each sampling occasion, at each site, five quantitative benthic samples were collected from riffle zones (Resh & Jackson, 1993; Wright et al., 1995). The location of each replicate was randomly selected within a 15 m stream reach.

All insect groups were identified to family level as this has been demonstrated to provide adequate taxonomic resolution for pollution assessment (Wright et al.,1995; Wright and Ryan, 2016). Some non-insect groups (Oligochaeta, Temnocephalidae, Hydracarina, non-Ancylidae Gastropoda) were not identified to the family level due to identification difficulties. All specimens were also counted. The macroinvertebrate data matrix was used to calculate biotic index results for each sample on each occasion. The overall proportion of each macroinvertebrate sample that were in the sensitive three orders (Ephemeroptera, Plecoptera or Trichoptera) or 'EPT' groups was calculated (Lenat and Penrose, 1996). The simple biotic indices 'abundance' (number of invertebrates collected per sample) and 'family richness' were also calculated (Rosenberg and Resh, 1993). A pollution tolerant index was also calculated using the proportion of invertebrates in the tolerant (Chessman, 1995) Gastropod, Worm, Simuliidae, Chironomidae and Bivalve taxonomic groups.

At the two Hat Hill Creek sites, above and below the STP, water samples were collected for laboratory analysis, in a NATA accredited laboratory, of Total Phosphorus and Total Nitrogen. The site below the STP had been shown to have highly elevated nutrient levels during the STP operation (Wright & Burgin, 2009a)

Results

This study collected and identified 15,011 macroinvertebrates from 51 families, with most being insects, over a 15-year period. This represented samples collected from the two sites on Hat Hill Creek. One above the STP (HHU) and the other downstream of the STP (HHD) from sampled collected in 2003, 2009 and 2018. Macroinvertebrate family richness at Hat Hill Creek (upstream; HHU) averaged 14.5 families per sample (Table 1). This was greater than family richness at Hat Hill Creek below the STP (HHD), on all occasions. Family richness was highest (13.5 families per sample) at HHD in 2003 when the STP was operating. It was 12.8 families per sample in 2009 and was lowest with 11.0 families per sample in 2018. Macroinvertebrate abundance, per sample, was higher on all occasions at HHD (averaging from 231.8 animals per sample in 2018 to 587 animals per sample in 2009), compared to HHU (average 212.8 animals per sample; Table 1).

The mean proportion of macroinvertebrates in the three pollution sensitive orders (Ephemeroptera, Plecoptera and Trichoptera; 'EPT') was always highest upstream of the STP (HHU; average 50.5%; Figure 3). In comparison, the lowest mean EPT proportion was 10.2 % recorded at HHD in 2003 when the STP was operating. The mean EPT proportion progressively increased to 22.5% (2009) and 39.3% in 2018 (Table 1).

The proportion of macroinvertebrates in the taxonomic groups that have a reputation for tolerance of organic pollution (aquatic worms, gastropods, Simuliidae, Chironomidae and bivalves; Chessman, 1995) at HHU had an average proportion of 11.9 % (2003 to 2018; Figure 3). In contrast, the proportion of these groups accounted for 85.6% of the macroinvertebrates collected from HHD (below the STP) when it was operating in 2003. This fell to 61.2% at HHD in 2009 and then fell further to 40.5%, in 2018 (Table 1).

Water quality at the site below the STP (HHD) rapidly changed once the STP was closed (Table 1). Total phosphorus (TP) concentrations downstream of the STP (HHD) declined from a mean of 506 µg/l in 2003 to <10 µg/l in 2009 and <5 µg/l in 2018 (Table 1). After the closure Hat Hill Creek water quality was similar, below the STP, to levels recorded from the upstream (HHU). The previous mean TP concentration of 506 µg/l was more than 25 times higher than the Australian water quality guidelines for ecosystem protection (20 µg/l: ANZECC, 2000). Total nitrogen concentrations below the STP in 2003 also dropped from levels more than 50 times higher (mean 14300 µg/l) than ecosystem protection guidelines (250 µg/l: ANZECC, 2000) to a mean of 200 µg/l in 2009 and then 100 µg/l in 2018 (Table 1). The salinity level in Hat Hill Creek also dropped sharply from a mean of 326 µS/cm in 2003 to 18 µS/cm in 2009, and then 32.8 µS/cm (Table 1).

a.

b.

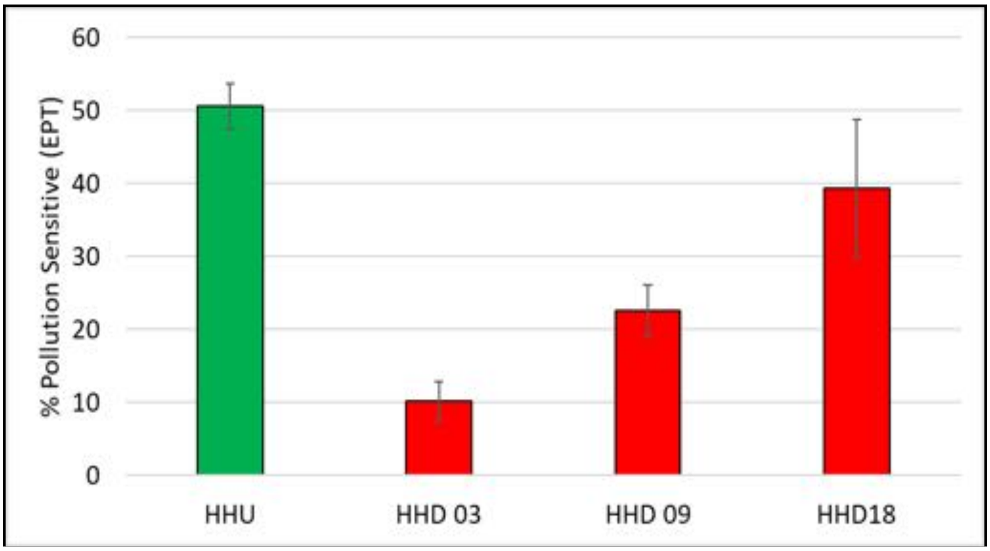
c.

d.

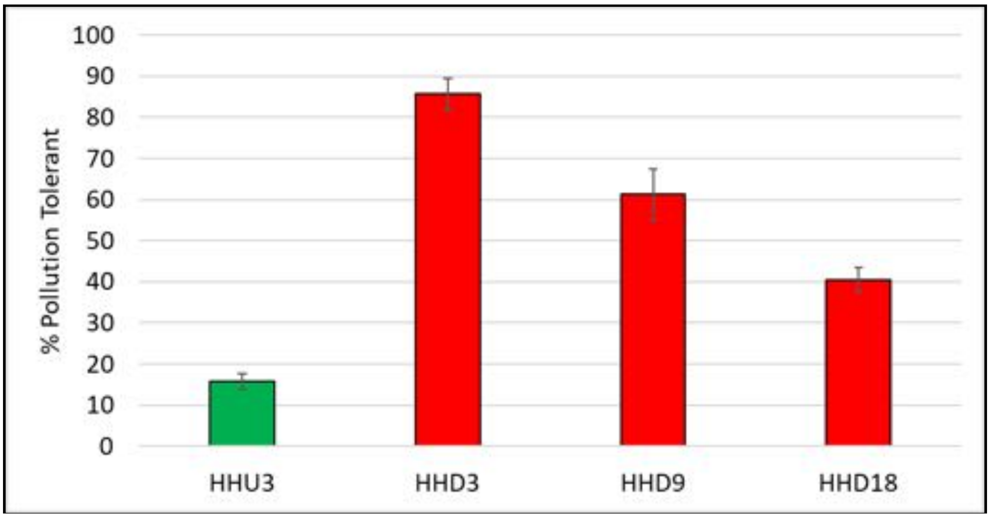
Figure 2. Photographs of Blackheath STP and Hat Hill Creek. a). Blackheath STP in operation in 2003; b). Top right. Removal of STP in 2008; c). Hat Hill Creek upstream of the STP (2003); d). STP effluent outfall into Hat Hill Creek in 2003. Photographs by Ian Wright.

Table 1. Summary statistics of macroinvertebrate and water quality resulted collected from Hat Hill Creek above the STP (HHU) and downstream of the STP (HHD) over the period 2003-2018.

	Hat Hill US	Hat Hill DS 2003	Hat Hill DS 2009	Hat Hill DS 2018
	Upstream STP (2003-2018)	Downstream STP (2003)	Downstream STP (2009)	Downstream STP (2018)
Variables	Range (Mean)	Range (Mean)	Range (Mean)	Range (Mean)
EPT (%)	11.7 – 80.6 (50.5)	0.6 – 34.3 (10.2)	12.1 – 32.0 (22.5)	6.3 – 60.1 (39.3)
Ephemeroptera (%)	2.2 – 26.7 (13.2)	0 – 0.9 (0.2)	2.5 – 28.5 (12.5)	0 – 31.1 (17.0)
Plecoptera (%)	8.0 – 48.6 (28.7)	0.2 – 7.9 (1.8)	2.5 – 12.9 (7.2)	0.3 – 4.5 (2.1)
Trichoptera (%)	0 – 48.4 (8.6)	0.5 – 25.4 (8.2)	0.6 – 4.9 (2.8)	5.4 – 37.7 (20.2)
Chironomidae (%)	0 – 20.6 (7.1)	0.5 – 53.4 (20.9)	35.9 – 74.7 (59)	29.7 – 46.5 (39.2)
Pollution Tolerant (%)	0 – 29.6 (15.8)	40.9 – 98.3 (85.6)	37.6 – 75.1 (61.2)	31.1 – 47.1 (40.5)
Abundance	31 – 434 (212.8)	148 – 565 (372.4)	319 – 852 (587)	111 - 443 (231.8)
Family Richness	11 – 19 (14.5)	10 – 18 (13.5)	12 – 14 (12.8)	7 – 14 (11.0)
pH (pH units)	5.4 – 6.2 (5.8)	6.7 – 7.4 (7.2)	6.24	5.8
Salinity (EC: µS/cm)	18 – 33 (27)	132 – 462 (327)	18	32.8
Total Nitrogen (µg/l)	90 – 200 (101.7)	4400 – 21200 (14300)	200	100
Total Phosphorus (µg/l)	<5 – 8	204 – 820 (506)	<10	<5



a.



b.

Figure 3. Macroinvertebrate biotic indices (mean +/- standard error of mean) from samples collected from Hat Hill Creek upstream of the STP (HHU, green bar) and at Hat Hill Creek downstream STP (HHD, red bars). Sampling was done in 2003, 2009 and 2018. HHU results cover all three periods (2003 to 2018). a). Top. % EPT (proportion of invertebrates in the sensitive Mayfly, Stonefly and Caddisfly orders); b). Bottom. % Pollution Tolerant (proportion of invertebrates in the tolerant Gastropod, Worm, Simuliidae, Chironomidae and Bivalve taxonomic groups).

Discussion

This study found that the 2008 removal of treated sewage discharges from Hat Hill Creek has resulted in a substantial, yet incomplete, 'recovery' of ecological health of the formerly heavily-polluted mountain stream. Blackheath STP was in operation for approximately 60 years and caused organic pollution-related changes to a small and otherwise unimpaired stream on the edge of a major conservation area (Blue Mountains National Park and World Heritage Area (Wright et al., 2011). This case study provides an insight into the stages and timing associated with the progressive 'recovery' of an upland stream ecosystem from a chronic 'press' stressor, in this case a long-term pollution disturbance.

Water quality of Hat Hill Creek showed a rapid response to the removal of the organic pollution point-source. The drop in phosphorus concentrations below the STP, went from a mean of 506 µg/L in 2003 to <10 µg/L in 2009 and <5 µg/L in 2018. Similar dramatic declines in two other highly elevated pollutants (nitrogen and salinity) are indicative of organic water pollution dropping to levels compliant within Australian water quality guidelines for protection of aquatic ecosystems (ANZECC, 2000).

Macroinvertebrate results collected over a 15-year period reveal that the extent of ecological recovery for the formerly organically polluted site (HHD 2003) was considerable. There has been a progressive change in the macroinvertebrate community that began to show major changes in 2009 (16 months after the STP closure) and further changes also evident in 2018, 10 years after the STP closure. In particular, we found that the pollution sensitive macroinvertebrates ('EPT': mayflies, stoneflies and caddis flies) were progressively returning to the formerly organically polluted site below the sewage discharge (HHD). In 2003 when the sewage discharge was active, this site had only 10.2 % of its macroinvertebrates in these three sensitive groups. Sampling 16 months after the cessation of the impact (2009) showed that the relative proportion of sensitive animals doubled to 22.5%. Samples collected 10 years after the sewage discharge stopped showed that 39.3% of the community were in the sensitive groups. In comparison, the upstream reference (HHU) site maintained a mean level of 50.5% of the community in these three groups. These results show that the ecologically recovery for the formerly heavily polluted Hat Hill was considerable but was not yet complete.

Further insight into the ecological recovery of Hat Hill Creek is possible through evaluation of the declining relative abundance of pollution tolerant invertebrates. These are invertebrates that have a reputation for their higher tolerance of organically polluted conditions (Chessman, 1995). This group includes aquatic worms, snails (Gastropods), bivalves, and larvae of two families of true-flies (Diptera: Simuliidae and Chironomidae). When Hat Hill Creek was contaminated with sewage the mean proportion of invertebrates in the pollution tolerant groups accounted for 85.6% of the community. In comparison, the upstream site (HHU: 2003-2018) had an average of 15.8% of invertebrates in these pollution tolerant groups. 16 months after the sewage discharge into Hat Hill had ceased, the proportion of pollution tolerant invertebrates dropped to 61.2% and 10 years after the STP closure (2018) the proportion was 40.5%. This remains more than twice the proportion found at the upstream reference site (HHU).

The extent of the recovery in for Hat Hill in 16 months (2003 compared to 2009) was broadly similar to that reported by Yount and Niemi et al. (1990). They reviewed more than 150 studies of freshwater disturbance recovery and many other case studies had an approximate 80 – 95 % recovery of macroinvertebrate density and richness after 12 to 18 months following the removal of the stressor. Based on the review by Yount and Niemi et al. (1990) we had expected that full ecosystem recovery will take two to three years. Besley and Chessman (2007) had found that about two years was needed following closure of treated sewage release at other Blue Mountains streams. Now, after nearly 10 years since the STP closure, this study shows that the time taken to recovery from pollution takes much longer. There is very little information on this topic, and this Australian case study contributes important information on the process of ecological pollution recovery.

We suggest that one of the most important factors that contributed to the progress towards ecological recovery was the location of the formerly polluted reaches of Hat Hill Creek are downstream of such an uncontaminated mountain stream with unimpaired water quality and ecological health (Wright & Burgin, 2009a,b). The Blackheath STP outfall was located about two km below the Hat Hill Creek catchment watershed, although the upstream waterway was small, it flowed permanently and was fed by adjoining hanging swamps and probably benefitted from groundwater inflow (Wright, 2006). Hat Hill Creek also retained diverse and healthy macroinvertebrate assemblages that were missing from the polluted reaches in 2003. This acted as a 'refuge' for a broad spectrum of sensitive invertebrate groups. Given that recruitment in flowing freshwater streams is predominantly driven by downstream drift of individuals (Brittain and Eikeland, 1988), we hypothesise that this clean upstream refuge provided a constant 'seeding' of the once polluted reaches of Hat Hill Creek with juveniles from a wide range of invertebrate guilds.

The ecological recovery of Hat Hill Creek, following the closure of Blackheath STP in 2008, reflects an ambitious and commendable 40-year program by Sydney Water to rebuild the sewerage system of the Blue Mountains (Berman et al. 1987; MWS&DB, 1987). Water pollution across many streams and rivers in the Blue Mountains area was once widespread, caused by poorly treated sewage effluent. In July 1980 there were 12 sewage treatment plants (STPs) effluent from almost 50,000 residents into mountain streams in the Blue Mountains (MWS&DB, 1987). Of the twelve STPs that were active in 1980, when they were transferred from local Government to the NSW Government (now Sydney Water). Blackheath STP was one of six STPs that discharged poorly treated effluent into high conservation value National Park headwater streams (Berman et al., 1987). Previous research by the senior author confirmed that although Blackheath STP effluent discharges were operating outside of the National Park boundary, the pollution was rapidly transferred deep into the Blue Mountains National Park via Hat Hill Creek (Wright, 2006; Wright & Burgin, 2009a,b). The Blackheath STP point source was responsible for elevation of nutrient levels many km below the discharge, into the iconic Grose River, part of the Grose River Wilderness area, and also part of the Greater Blue Mountains World Heritage Area. Sadly the pollution of the Grose River from a second pollution source, heavy-metal contaminated coal mine seepage from the Canyon Colliery into Dalpura Creek (Wright & Burgin, 2009a,b) continues, testimony to the inadequate environmental protection of high-conservation value waterways from water pollution (Wright et al., 2011; Price & Wright).

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