Headwater streams restoration: "Two creek systems are not the same!"

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Key Points
- Headwater streams are under threat due to rapid urbanization and poor management practices.
- Headwater streams can have unique fluvial features and processes that deviate from those of conventional rivers, warranting special attention.
- Sensitive creek systems with threatening processes need tailor made rehabilitation strategies and regular monitoring for effective management.

Abstract
Headwater streams worldwide face significant threats from rapid urbanization, despite their critical role as the most upstream segments of river networks. Protecting these streams is crucial in improving the resilience of catchments, especially under changing climatic conditions. However, major knowledge gaps persist in understanding these creek systems, resulting in inadequate management practices. This study, undertaken by Hydrobiology, aims to address these gaps with the goal of improving the management of headwater streams in urban catchments.

A residential development was proposed at the headwaters of Bundamba Creek in Brisbane. A geomorphic assessment was conducted to understand the creek system. Additionally, a soil assessment was undertaken to determine the soil condition and associated risks. Based on the findings, rehabilitation measures were proposed and implemented. Regular monitoring inspections were carried out to verify the effectiveness of the rehabilitation efforts. The waterway at the site was identified as a chain of ponds system featuring a discontinuous channel within a broad floodplain. The presence of dispersive soils made it a highly sensitive creek system. Historical disturbances from 4WD tracks and rapid urbanization of the catchment were threatening the integrity of the creek system. Managing this creek system presented several challenges, notably its distinct behavioural regime and the highly erosive soil conditions. Recognising this uniqueness was crucial in developing tailored, effective management measures.

Keywords
Geomorphology, headwater streams, urbanization, chain of ponds, dispersive soils, sensitive creek systems, rehabilitation, management

Introduction

Background
Headwater streams are the small swales, creeks and streams that serve as the most upstream natural segments of a river network (Imberger et al., 2023). These creek systems play crucial roles in various ecological, hydrological, and geomorphological processes (Alexander et al., 2007; Meyer & Wallace, 2001; Wohl, 2017). Despite their significance, headwater streams are often severely impacted by urbanisation and land use changes (Barmuta et al., 2009; Meyer & Wallace, 2001). Major knowledge gaps persist in understanding these creek systems, resulting in inadequate management practices (Barmuta et al., 2009; Imberger et al., 2023).

The term 'headwater streams' often conjures images of steep, confined systems. However, in lower relief catchments, the headwater streams reflect the surrounding topography and can frequently comprise valley fills or chain of ponds morphology (Williams & Fryirs, 2020). These creek systems are often overlooked and neglected in catchment management due to a lack of awareness regarding their significance (Hartman et al., 2005; Wallace & Eggert, 2015).

As an environmental consulting company, Hydrobiology is involved with numerous urban residential development projects. Most of these developments occur at the outskirts of urban areas often in headwaters of the catchments. This paper aims to share insights gained from one of Hydrobiology's projects involving a chain of ponds creek system and address fundamental questions:

- What are the fluvial features and processes within a chain of ponds creek system?
- What are the potential threatening processes within a chain of ponds creek system?
- How to effectively manage a chain of ponds creek system within an urbanized catchment?

The findings of this study not only contribute to bridging existing knowledge gaps but also useful for enhancing the management of these unique types of headwater streams within urban catchments.

Study area

A residential development was proposed in Ripley Valley urban development area, to the south of Ipswich in Brisbane. The development site (here after called 'the site') is located in the headwaters of Bundamba Creek catchment close to the western drainage divide (Figure 1). The site is drained through an unnamed tributary of Bundamba Creek which subsequently flows into the Bremer River and then into the Brisbane River. Although multiple first order drainage lines traverse the site, the focus of this study was on the second order stream (here after called 'the study reach') that runs through its centre (Figure 1). The length of the study reach is approximately 700 m and drains an upstream catchment area of approximately 1.8 km^2.

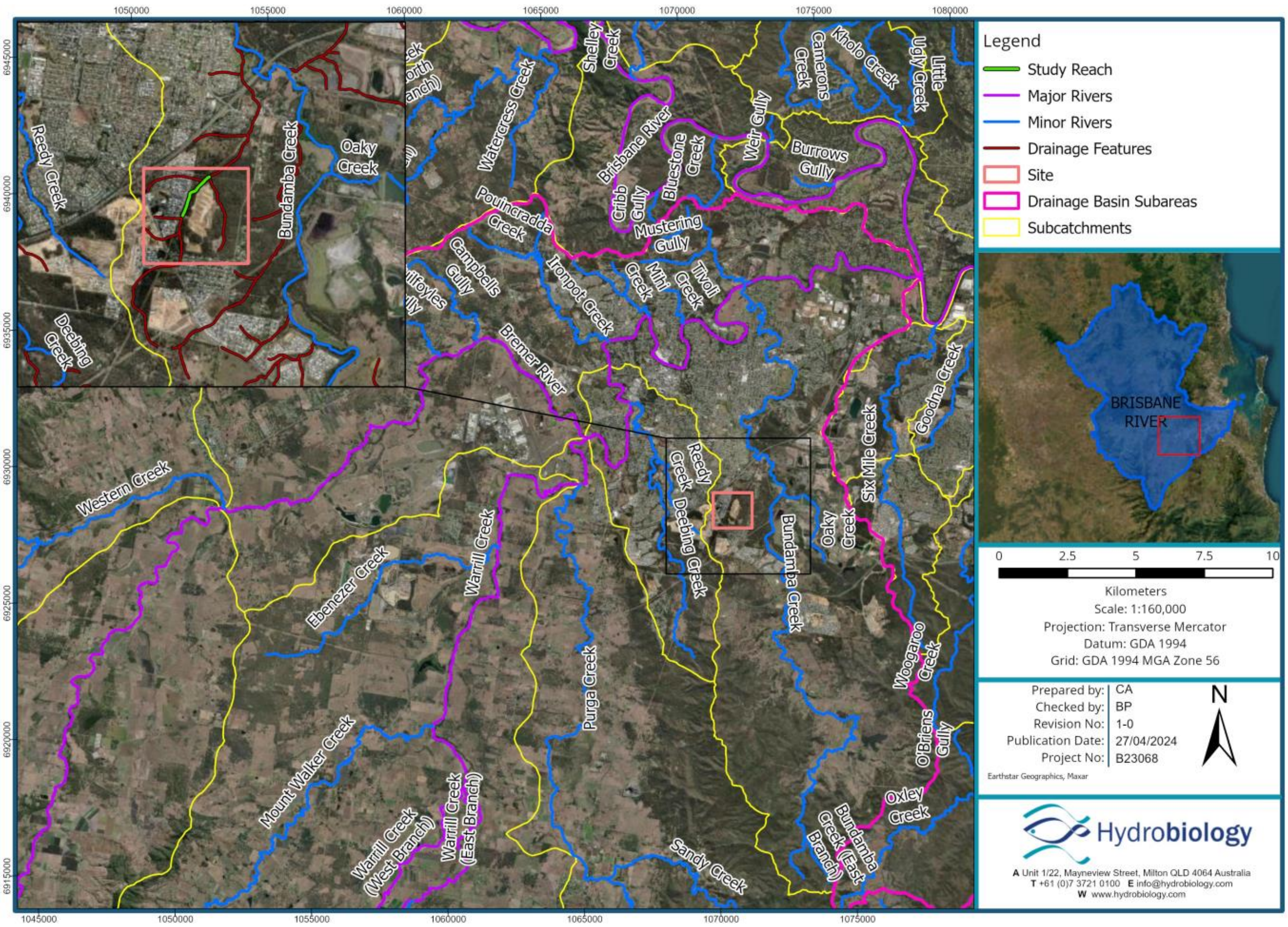

Figure 1. Catchment position of the site and the location of the study reach

Method

Geomorphic assessment

The geomorphic assessment consisted of both a desktop assessment and a site visit. The desktop assessment involved a review of existing literature, development plans and hydraulic modelling results. In addition, historical aerial images were analysed to understand the historical condition and to identify any significant disturbances that have occurred over time.

The site visit involved a walkthrough of the study reach, immediate upstream and downstream reaches, and the connected drainage lines. During the walkthrough, a detailed examination of creek morphology, geomorphic features and associated processes was undertaken. Special attention was given to active processes, areas of instability and potential threats. Geotagged photographs and notes were captured to serve as a reference for future analyses.

Soil assessment

Soil samples were collected at the site using boreholes excavated to a maximum depth of 1 mbgl (meter below ground level) or until refusal, whichever was encountered first. This depth was nominated due to the presence of shallow bedrock identified from previous geotechnical studies. Eight sampling locations were selected to ensure even coverage across the site. From each borehole, one topsoil sample and one representative subsoil sample were selected for the analysis.

All the samples were analysed by NATA (National Association of Testing Authorities) accredited laboratories. The soil properties assessed included Electrical Conductivity (EC), pH, exchangeable cations, Cation Exchange Capacity (CEC) and Exchangeable Sodium Percentage (ESP). The findings of the soil investigation were used to identify the erosion risk and to inform management recommendations.

Rehabilitation and monitoring

Rehabilitation measures were developed using nature-based solutions alongside soft engineering techniques. Nature-based solutions were used to preserve the natural characteristics and processes of the creek. Field investigation indicated that the stability of the ponds was related to the presence of vegetation. Where vegetation was lacking, small gullies and/or pond expansion had occurred (Figure 2). Therefore, assisted regeneration and revegetation were used as the main strategy of rehabilitation. Further, there were strong limits placed on encroachment into the floodplain, given the identification of channel or floodplain confinement being an important driver of change within this reach and other similar cut and fill reaches in the region (City of Ipswich, 2020). Moreover, throughout the development process the disturbances within the floodplain were minimised.

Alongside the nature based solutions, soft engineering techniques were used to stabilise threatening processes until vegetation could establish. Stabilisation of headcuts and gullies were achieved by using rock chutes, coir logs and geotextile. The dispersive soils were managed by using appropriate amounts of gypsum and treated topsoil. All the rehabilitation efforts were implemented with a focus on the entire floodplain rather than solely on the channel.

Site inspections were conducted annually to assess the effectiveness of rehabilitation. This involved a walkthrough of the study reach and evaluation of the geomorphic condition. During these inspections special attention was given to any emerging or persistent issues despite previous rehabilitation efforts. The insights gained from monitoring were then utilized to reassess and adjust the rehabilitation strategy.

Results

Geomorphic condition

The study reach was identified as a chain of ponds system consisting of ponds and discontinuous flow paths set within a broad floodplain (Figure 3). The shape of the ponds varied from elliptical to more elongated and narrow shapes. The widths ranged from 0.5 m to 10 m while the depth ranged from 0.5 m to 1.5 m. Preferential flow paths existed between the ponds while flood runners and infilled paleochannels were present on the floodplain. These morphological features indicated the occurrence of cut and fill processes and deviation from a conventional creek system with a well defined continuous channel. At low flow conditions the ponds were filled with water, but no surface flow was observed between the ponds. Despite the overall stability of the creek system some signs of degradation were observed including headward eroding gullies, sediment slugs and incision and/or expansion of ponds along with noticeable lack of vegetation possibly due to historical disturbances.

The reach upstream from the study reach was impacted by urbanization. Multiple housing developments have occurred in the catchment resulting in floodplain encroachment and modification of the channel. The upstream drainage line had been modified into a constructed, straight, trapezoidal channel, consisting of a concrete lined low flow channel and grass-lined upper banks. This was then followed by a short well-defined channel (depth <1.5 m, width <10 m) set within a narrow floodplain (Figure 4). It was likely that the reach had previously been an extension of the downstream chain of ponds reach, and that a headcut had formed in a pond which had migrated upstream in response to increased flow energy from the upstream catchment.

The channel downstream from the study reach also contained sections of chains of ponds. However, disturbances caused by 4WD tracks had initiated headcuts within the system. These headcuts had migrated upstream forming incised continuous channels (Figure 4). The sediment generated from gullying was deposited downstream forming wide flat depositional zones. As a result of incision, the chain of ponds system was transforming to an anabranching system with continuous incised channels. The aerial image analysis further confirmed the historical disturbances at the site. The presence of 4WD tracks were evident from the images which have initiated the headward eroding gullies observed at present (Figure 5).

Soil condition

The topsoil at the site was categorised as either loamy sand or sandy loam. The analytical results indicated that the topsoil was nondispersive and nonsaline. All the samples were rated as Emerson class 8 indicating nondispersive and nonsodic conditions (Hazelton & Murphy, 2007). This was further confirmed by low ESP values ranging from 0.7% to 1.4 %.

In contrast to topsoil, subsoils indicated dispersive and sodic conditions. All the samples were rated as either Emerson class 2 or 3 indicating high dispersibility (Hazelton & Murphy, 2007). Moreover, all the subsoil samples indicated relatively high sodic conditions compared to the topsoil with ESP values ranging from 4.4% to 24.0%. These dispersive properties of the sub soils were reflective of the underlying sandstone which quickly becomes soft and loses strength when subject to pressure and moisture.

Monitoring findings

Following rehabilitation efforts in 2017, the creek system was monitored over a period of six years from 2017 to 2023. During this period, notable improvements were observed in the creek system. Increased vegetation density has restricted the formation, development, and migration of headcuts (Figure 6). However, minor degradational processes were identified during the monitoring phase, particularly in areas where disturbances had occurred. This included erosion and headcut migration along concentrated flow paths originating from bioretention basins, stormwater outlets and culverts (Figure 7). These were identified at the early stages of their development and were remediated to prevent evolving into major headcuts.

Figure 2. Headward erosion of a pond where vegetation is lacking (left) and a headcut migration stopped by established woody vegetation (right).

Figure 3. Chain of ponds creek system set within a broad floodplain.

Figure 4. Incised continuous channel upstream from the study reach (left) and a headward eroding gully downstream from the study reach (right).

Figure 5. Aerial image of 2017 showing the historical disturbances at the site caused by 4WD drive tracks (left) and aerial image of 2023 showing the intact chain of ponds creek system with well-established vegetation despite the ongoing constructions and urbanization of the catchment (right).

Figure 6. Increased vegetation cover on the floodplain (left) and a rehabilitated gully with stable bed and bank conditions (right).

Figure 7. Monitoring findings showing erosion and exposure of subsoils downtream of a bioretention basin outlet (left) and a headcut bypassing a rock chute and migrating upstream (right).

Discussion

Headwater streams exhibit significant diversity, showcasing a variety of fluvial features and processes. These may encompass streams with continuous channels with well defined, persistent channel banks, as well as swales or valley fills lacking distinct banks. Additionally, the flow regime within these streams can vary from perennial to intermittent or ephemeral (Imberger et al., 2023). In this study a chain of ponds system was identified at the headwaters of Bundamba Creek catchment. The geomorphology of the system was unique and deviated from a conventional river. Moreover, during low-flow conditions, the absence of continuous surface flow gave the impression that there was no stream at all. However, this is a common characteristic of chain of ponds systems and understanding this uniqueness is critical to developing appropriate rehabilitation and management measures (Mould & Fryirs, 2017).

Cut and fill processes usually occur within chain of ponds systems. During the ‘fill’ phase suspended load sediment deposits on the valley floor resulting in vertical accretion while, during the ‘cut’ phase, incised channels form by headcut activity (Fryirs & Brierley, 2012). Due to the wide valley settings and deep valley fills, chain of ponds systems can undergo significant adjustments (both vertically and laterally) during the ‘cut’ phase. If there are significant changes to boundary conditions (stream power, sediment load and fill slope), these changes can lead to a complete transition into a different type of river (Fryirs & Brierley, 2012). On top of these inherent risks of chain of ponds systems, the study reach is set within a valley fill with highly dispersive sub soils indicating a highly sensitive creek system.

Several threatening processes were identified which would impact the integrity of the study reach. Overtime the headcuts in the downstream reach can migrate upstream transforming the chain of ponds system to a continuous incised channel. The upstream reach also can undergo further incision and widening resulting in sediment generation and sediment slug movement through the system. In addition, the urbanization of the surrounding catchment can potentially increase the hydraulic forces leading to the incision of the valley fill. These threatening processes posed a high risk due to the high sensitivity of the creek system.

Despite the reach being in relatively good geomorphic condition, the historical disturbances and urbanization of the upstream catchment has resulted in degradation of the watercourse morphology and vegetation. Moreover, the threatening processes identified in the immediate upstream and downstream reaches posed risks to its integrity and has diminished its potential for recovery (Brierley & Fryirs, 2005). Therefore, rehabilitation efforts focussed on addressing the moderate degradation in the study reach while mitigating impacts of surrounding urbanization. Concurrently, the adjacent reaches were rehabilitated to eliminate the threatening processes and to accelerate the recovery of the study reach.

The use of nature-based solutions proved to be effective in managing the creek system. This was clear within the study reach where the geomorphic condition showed an improvement despite the ongoing housing development in surrounding catchment. The soft engineering solutions also played a significant role in controlling the threatening processes. The immediate stability achieved helped to prevent the threatening processes impacting adjoining reaches while providing enough time for vegetation establishment for long term stability. Further, the focus on minimising floodplain confinement ensured that hydraulic forces within the study reach remained relatively unchanged compared to pre-development conditions, lowering the risk of development related channel change. In conventional waterway management this element of the rehabilitation is one that is frequently ignored resulting in floodplain confinement and in some instances conversion to straight concrete channels (City of Ipswich, 2020). This has resulted in disconnection and loss of floodplains in Ipswich Local Government Area (LGA) leading to increased flood risk and degradation of waterways (City of Ipswich, 2020; Phoenix Resilience, 2022).

Although the initial rehabilitation was generally successful, several minor issues were identified during the monitoring period. Most of these were the result of disturbances caused by the construction work and stormwater releases from the increasingly urbanized catchment. Given the sensitivity of the system, ongoing monitoring was crucial in early identification and management of these issues prior to the issues escalating and requiring more costly interventions. Moreover, the monitoring findings were useful in identifying risks that were not identified at the beginning of the project and were incorporated into the management plan to enhance future management practices.

Conclusion

The chain of ponds system encountered in this study diverges from conventional rivers characterized by continuous, well-defined channels and differs from what many might consider a 'headwater stream'. Rapid urbanization of the catchment and the threatening processes within the system are impacting the integrity of the creek system while the presence of dispersive soils, makes the study reach particularly sensitive to change. Similar systems exist throughout the Ripley Valley and greater Ipswich LGA where conventional waterway management practices have resulted in disconnection of floodplain increasing the risk of erosion and flooding. It is evident that these management practices are ignoring the geomorphic processes occurring within the channel and in the broader floodplain.

In recognition of the uniqueness of the study reach and similar systems in Ripley Valley urban development area, a waterway management paradigm shift is required to ensure that these systems are not lost within the region. This includes restrictions on floodplain encroachment, management of cumulative effects of urban development, identification of threatening processes, use of nature-based solutions supported by soft engineering techniques and implementation of ongoing monitoring alongside adaptive management practices. These changes have proven instrumental in safeguarding the headwater streams against the impacts of urbanization and should be implemented throughout the region.

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