Protecting instream habitat with stormwater management: integrating flow-habitat relations into control algorithms

Protéger l'habitat aquatique grâce à la gestion des eaux pluviales : intégrer les relations entre le débit et l'habitat dans les algorithmes de contrôle

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RÉSUMÉ

La gestion des eaux pluviales vise à protéger les cours d'eau contre la dégradation des habitats, mais elle est souvent insuffisante en raison d'objectifs mal définis. Nous présentons ici une méthode permettant de définir des objectifs de débit pertinents sur le plan écologique et de les intégrer dans des algorithmes de gestion des eaux pluviales en temps réel. Cette méthode consiste à : (i) identifier les besoins physiques en matière d'habitat des espèces clés ; (ii) étudier le cours d'eau afin de cartographier les caractéristiques de l'habitat ; (iii) utiliser une modélisation hydrodynamique haute résolution pour définir la relation entre le débit et la disponibilité d'habitat ; (iv) la combinaison de ces relations entre les différents sites ; et (v) les intégrer dans des algorithmes de gestion des eaux pluviales. Nous avons appliqué cette méthode au réseau intelligent de gestion de l'eau de Monbulk Creek à Melbourne, en Australie, qui vise à utiliser des réservoirs d'eau de pluie et des lacs urbains, contrôlés en temps réel, pour soutenir une population vulnérable d'ornithorynques menacée par l'urbanisation et la réduction des débits d'étiage. En augmentant les faibles débits, le système accroit la superficie de l'habitat inondé et la productivité des macroinvertébrés, améliorant ainsi les zones d'alimentation et les sources de nourriture des ornithorynques. Cette approche permet de cibler directement des objectifs liés à l'habitat aquatique, tels que l'inondation d'une plus grande quantité de débris ligneux ou l'augmentation de la superficie avec une profondeur d'eau suffisante pour que les ornithorynques puissent nager et se cacher.

ABSTRACT

Stormwater management aims to protect waterways from habitat degradation but often falls short due to poorly defined objectives. We present a method to define ecologically-relevant flow objectives and embed them in real-time stormwater control algorithms. The method involves: (i) identifying the physical habitat needs of key species; (ii) surveying the stream to map habitat features; (iii) using high-resolution hydrodynamic modelling to relate flows to habitat availability; (iv) combining these relationships across sites; and (v) integrating them into stormwater control algorithms. We applied this method to the Monbulk Creek Smart Water Network in Melbourne, Australia, which aims to use real-time-controlled rainwater tanks and urban lakes to support a vulnerable platypus population affected by urbanisation and reduced baseflows. By supplementing low flows, the system increases wetted habitat and macroinvertebrate productivity, improving platypus foraging areas and food sources. This approach enables stormwater management to directly target habitat objectives such as inundating more large wood or increasing the area with sufficient water depth for platypus to swim and hide.

KEYWORDS

Courbes débit-habitat, contrôle en temps réel, réservoirs d'eau de pluie, algorithmes, optimisation, écohydraulique

Flow-habitat curves, real-time control, rainwater tanks, algorithms, optimisation, ecohydraulics

1 INTRODUCTION

Stormwater management goals have evolved from focusing narrowly on flood protection and drainage to a more holistic approach which considers multiple objectives, such as stream protection. By intercepting stormwater, damaging high flows can be reduced, and by infiltrating or slowly releasing it during dry periods, baseflow can be maintained. The benefit of these interventions to ecosystems depends greatly on the organisms present and their instream habitat requirements.

Instream physical habitat refers to the geomorphic and hydrodynamic conditions that provide spaces or niches for plants and animals to survive in streams. Different biota have different requirements in terms of preferred water depths and velocities, habitat complexity (e.g. fine-scale scour patterns versus large pools and riffles), bed materials, cover preferences (deep water or water shaded or hidden by vegetation), and the seasonality or short-term variability of these aspects. Biota also interact within food webs, meaning that the physical habitat needs for higher trophic levels also depend on physical habitat being provided for their food sources.

Environmental flow studies of flow-stressed rivers have long used physical habitat approaches to understand the flow regimes that need to be provided to support ecosystems (Acreman & Dunbar, 2004). Physical habitat approaches are more ecologically specific than hydromorphological approaches (like those applied under the EU Water Framework Directive, e.g. Rinaldi et al., (2017)) which provide a more general assessment of physical processes and conditions. They are therefore most useful when a particular species needs protection.

With the advent of real-time control, we can now apply physical habitat objectives to stormwater management systems (e.g. rainwater tanks and urban ponds/wetlands/lakes). This paper introduces a method to integrate flow-habitat relationships into stormwater control systems to guide stormwater storage and release patterns that can better support healthy stream ecosystems.

2 METHOD: FLOW-HABITAT RELATIONS

Step 1: Physical habitat requirements. The first step of the method involves defining the habitat requirements of the species of interest. Physical habitat requirements can be defined through literature review, targeted research or expert elicitation. They can vary in specification, but must relate to physical or hydraulic conditions that can be derived from site survey and hydrodynamic modelling, for example:

- Shallow slow-water habitat areas suitable as juvenile fish refuges (Bowen et al., 2003)
- Riffle areas with certain flow depth, velocity and substrate conditions (e.g. areas suitable for Salmonid spawning or fish passage; Bjorn and Reiser, 1991)
- Inundated large wood which can provide a rich substrate for macroinvertebrates (Johnson et al., 2003).

Step 2: Near-census instream habitat survey. Next, physical habitat is surveyed using tools such as aircraft or drone-mounted lidar, sonar, GNSS, or total station. The goal is a near-census survey that resolves sufficient detail to capture every element of relevant physical habitat features (e.g. Ledoyen and Pasternack, 2025). The approach recognises that sparse sampling schemes underestimate habitat variability and can miss important but small habitat patches altogether. A major challenge is deciding on the sampling scheme: the number, location and extent of reaches, the survey resolution and features of interest. These decisions depend on the size and complexity of the stream, ensuring that surveys cover large-scale variability along the stream, and fine-scale variability and target habitat types within each reach.

Step 3: High-resolution hydrodynamic modelling. Survey data from Step 2 is then processed to create hydrodynamic models (e.g. TUFLOW, HEC-2D, MIKE by DHI, River2D) that preserve their level of detail. Usually, 2D models will be most appropriate to simulate instream habitat. A computational mesh is developed with similar resolution to the survey. Calibration to water level and velocity over the range of flows of interest is critical. Simulations are then run for various flow conditions and results such as depth and velocity are output.

Step 4: Development of flow-habitat curves. Simulation results from Step 3 are processed to give the amount of habitat for each flow rate, and the data is compiled into a *flow-habitat curve* for each specified habitat type. For example, for a habitat type of “inundated large wood”, the simulated water level at each piece of large wood is extracted, and the surface area of large wood inundated under each flow rate is calculated. For the habitat type of “shallow slow-water habitat”, the area with velocity and depth lower than a defined threshold is calculated for each flow rate.

Step 5: Integration with stormwater control systems. Flow-habitat curves can be used to set design and operation objectives for stormwater management systems. Ecological objectives defined in this way can be managed or optimised alongside more typical objectives related to water quality and flood protection. They can be applied to passive or actively managed systems, but are particularly well suited to real-time-controlled systems, where different objectives can be applied depending on shifting conditions and priorities (e.g. adapting to climate change, applying different rules for different seasons, integrating new research on habitat needs).

3 APPLICATION: MONBULK CREEK SMART WATER NETWORK

The Monbulk Creek Smart Water Network project is establishing a grid of rainwater tanks and urban lakes retrofitted with real-time control technology to improve stormwater management in a peri-urban catchment in Greater Melbourne, Australia. The objectives include reducing nuisance flooding and improving instream conditions for platypus in Monbulk Creek, the receiving waterway. The iconic platypus was once widespread across Melbourne and surrounds but is now listed as vulnerable in Victoria. Monbulk Creek supports an isolated platypus population which is under threat from ongoing urbanisation, changes to stream flows, and habitat fragmentation and loss. We applied the flow-habitat relationship method to Monbulk Creek platypus habitat to develop ecologically-relevant objectives for real-time stormwater control systems.

Step 1: Physical habitat requirements were developed based on literature and preliminary observations of platypus. Platypus require flow conditions that support macroinvertebrate productivity (their main food source) and space to swim and hide from predators. We defined four physical habitat metrics:

1. Wetted habitat: total wetted area
2. Swimmable habitat: area with > 0.15 m flow depth (allowing platypus to be fully submerged)
3. Pool habitat: area with velocity < 0.2 m/s and depth > 0.3 m
4. Large wood habitat: wetted large wood surface area

Step 2: Eight survey reaches were selected which encompass the longitudinal variability of conditions in the stream. Reaches are around 180 m in length on average, and the stream is around 1-2.5 m deep and 5 m wide at bankfull stage. Survey was undertaken using a total station, and picked up the channel centreline, top and toe of each bank, other defined edges and breaks of slope, and additional points to infill details as required (Figure 1A). The point density averaged around 0.3 points per square metre with greater density in the low-flow channel. Every piece of large wood greater than 0.1 m in diameter and 1 m in length was also surveyed.

Step 3: A 2D HPC TUFLOW model was constructed for each reach. The grid-based model was used with a resolution of 0.5 m, including sub-grid-sampling, to capture the fine detail of the survey data. A range of steady-state flows was simulated in each reach, ranging from very low baseflows (0.5 ML/d) up to overbank flows (500 ML/d). The models were calibrated to observed flow and water level conditions.

Step 4: A custom script in R was used to calculate each habitat metric for each flow rate, from the simulated water level and velocity grids outputted by TUFLOW (Figure 1C). The habitat-flow curves were then normalised by reach length to make them comparable between reaches, and aggregated over all the reaches downstream of the stormwater interventions to give an overall flow-habitat relationship for the study area (Figure 1D).

Step 5: The flow-habitat curves were integrated into algorithms for stormwater control, specifying release rates from real-time controlled stormwater storages to optimise for the physical habitat metrics, within the limits of the water (during low-flow periods) or retention capacity (during high-flow periods) available within the network.

Still to be resolved in this framework is how to quantify uncertainty, how to account for the spatial arrangement of stormwater releases and habitat availability (e.g. releasing water further downstream has a more localised impact, whereas releasing water further upstream can have a more systemic benefit along the creek) and how to account for routing of flow along the creek.

4 CONCLUSIONS: INTEGRATING HABITAT INTO STORMWATER CONTROL SYSTEMS

The method and case study presented here offer a pathway to greater ecological relevance in stormwater management. Real-time control enables more adaptive, multi-objective systems with greater environmental and societal benefit. Defining sound ecological objectives for smart stormwater grids requires understanding target organism requirements, modelling flow-habitat conditions, and aggregating habitat metrics through clear conceptual models, from which ecologically-appropriate management objectives can be derived.

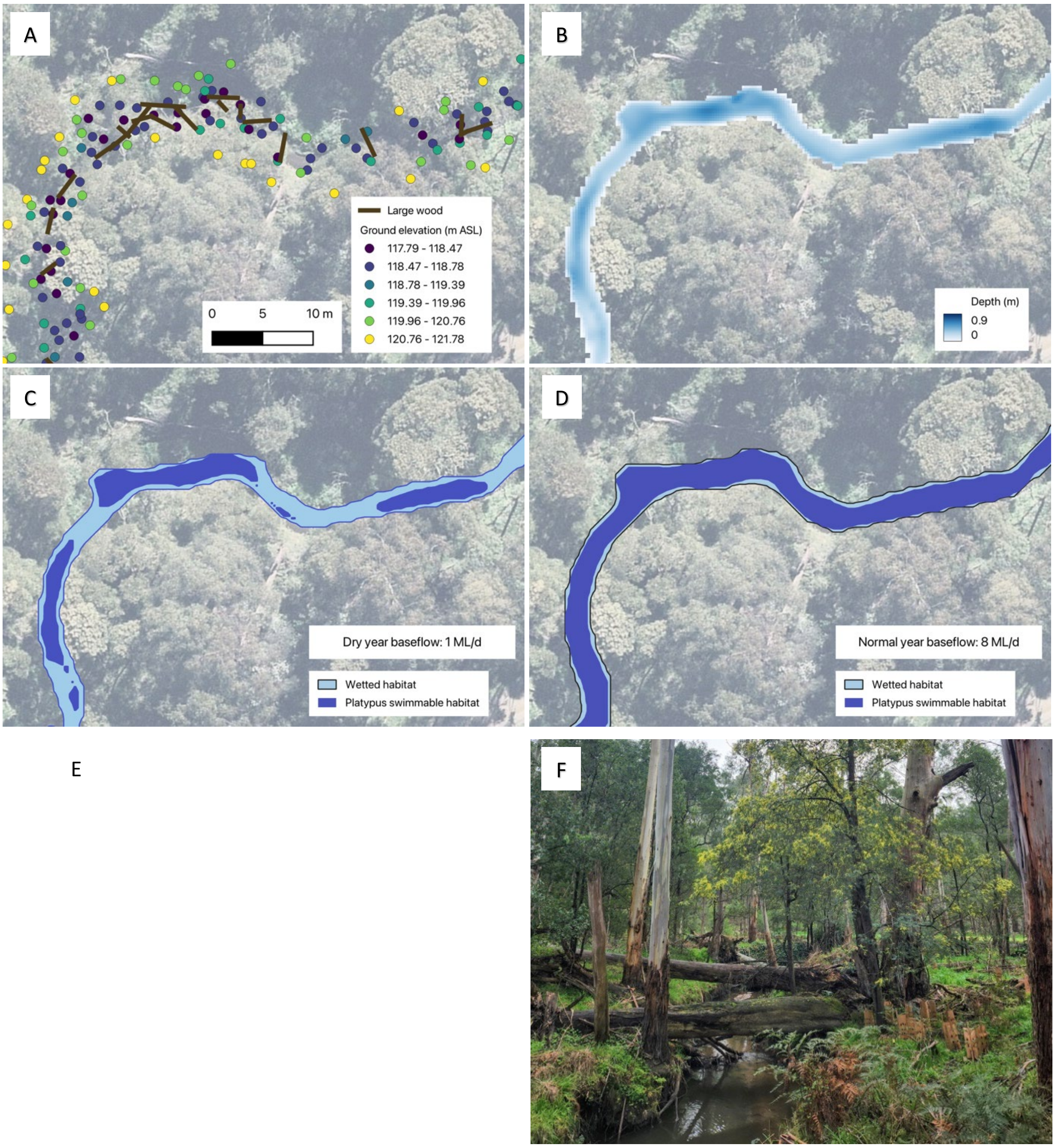

Figure 1: Example of (A) survey data, (B) hydraulic model depth results (for 8 ML/d), (C) platypus swimmable habitat map for 0.5 ML/d and (D) 8 ML/d, (E) habitat-flow relation for platypus swimmable habitat, and (F) typical instream habitat.

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