RECONFIGURING RIVER MANAGEMENT IN THE PHILIPPINES

Nature-based solutions to manage flood risk ‘work with the river’

Geomorphic principles provide an integrating template for coherent, proactive and cost-effective strategies at the catchment-scale

New and emerging technologies present opportunities for communities of practice to codevelop and enact transformative policies and actions

OVERVIEW OF THE PROJECT

Reconfiguring River Management in the Philippines: Integrating Fluvial Geomorphology for Sustainable Solutions

The Philippines is highly vulnerable to hydrometeorological hazards such as floods, landslides and riverbank erosion. Sustainable river management is a national priority. Fluvial geomorphology provides key insight to help address these challenges. Integrating the study of river evolution and landscape change into policy and practice will support nature-based, catchment-scale visions of sustainable river management.

Recognising this need, the project *Catchment Susceptibility to Hydrometeorological Events: Sediment Flux and Geomorphic Change as Drivers of Flood Risk in the Philippines* or simply, *Catchment Project* was undertaken as a collaborative research initiative by the University of Glasgow with the University of the Philippines Diliman and various Philippine agencies. Funded by the Natural Environment Research Council (NERC) of the UK and the Philippines' Department of Science and Technology - Philippine Council for Industry, Energy, and Emerging Technology Research and Development (DOST-PCIEERD), the project spanned from October 2018 to November 2021. Subsequent funding has been obtained to support the use of project findings to improve river management in the Philippines.

The *Catchment Project* developed tools and approaches that apply geomorphic principles to river and flood management, advocating for practices that work with the river rather than against it. Findings identify and characterise the diverse nature of river systems across the Philippines, their distinctive morphologies, mobility and responses to human activities and extreme weather events. To illustrate these findings, this portfolio summarises contributions generated in this project that explore different aspects of river dynamics, sediment flux, and geomorphic change. Together, scientific insights provide guidelines to support nature-based approaches to sustainable river management strategies. The portfolio presents how the findings from each paper can be used to reconfigure river management, emphasising the importance of working with the river rather than against it, and highlight the coherence of landscape thinking at the catchment scale.

To build climate resilience and reduce disaster risks, we recommend integrating these tools and approaches into national and local policies and practice. Doing so will not only mitigate flood hazards but also enhance the long-term health of river ecosystems, ultimately fostering a more adaptive and sustainable approach to managing the country's waterways.

TIMELINE: FROM RESEARCH TO IMPACT

March 2017	*Infrastructure and River Stability Workshop, Singapore* Philippine and UK scientists shared perspectives on river management challenges and identified research priorities.
October 2017	*Understanding the Impacts of Hydrometeorological Hazards in Southeast Asia networking workshop, Indonesia* ASEAN and UK scientists gathered to foster collaboration and knowledge exchange to better understand hazard impacts, and inform adaptation and mitigation measures.
January 2018	*River channel change and flood risk fieldwork, Philippines* Philippine and UK scientists conducted collaborative fieldwork to learn about river management issues.
November 2018	*Catchment Project kick-off, Manila* Discussion with project partners, national government agencies and local government units.
November 2019	*River Styles Framework 5-day workshop, Ilocos Norte, Philippines* Training for 25 participants from local government units and project partners.
September 2020	*Online workshops* Training on Google Earth Engine, flood estimation and Geomorphic Change Detection attended by personnel from different national and regional government agencies, academe and private institutions.
March 2023	*Making Space for Philippine Rivers workshop, Manila* 100 delegates from government, industry and academe co-mapped impact pathways to achieve policy recommendations from the Catchment Project.
March 2024	*Reconfiguring river management in the Philippines workshop, Clark* Regional river basin managers gathered to discuss challenges and strategies for sustainable river management.
March 2025	*Application of Nature-based Solutions (NbS) for Water Resource and Flood Risk Management Interventions in 18 Major River Basins, Tagatay* Workshops facilitated the development of project proposals aimed at integrating geomorphology into nature-based and sustainable river management strategies.

RESEARCH OUTPUT 1:

NATIONAL-SCALE GEODATABASE OF CATCHMENT CHARACTERISTICS IN THE PHILIPPINES FOR RIVER MANAGEMENT APPLICATIONS

OVERVIEW

Topography is an important driver of hydrological, geomorphological and ecological processes in river systems. High-quality topographic data are widely available in the Philippines, including a nationwide digital elevation model (DEM). We used an existing 5m DEM to produce quantitative descriptions of stream networks and river catchment characteristics. We analysed 128 medium- to large-sized catchments (catchment area > 250 km^2) and organised the results in a freely accessible and openly available national-scale geodatabase. The results are available to view and download (or see QR code). The geodatabase can be used to support geomorphologically-informed sustainable river management, hydrology and water resource management and geohazard susceptibility applications.

Scan here

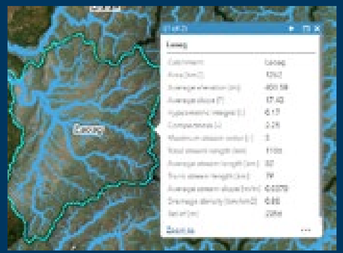
METHODS

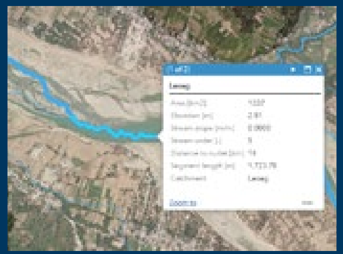
We applied a consistent workflow using TopoToolbox V2 to delineate stream networks and river catchments using standard flow-routing algorithms. Several attributes were extracted at all points along the stream network, including elevation, drainage area, steam slope, stream order and distance from outlet. Furthermore, for each catchment we calculated a set of morphometric and topographic characteristics (n = 91) to summarise key linear, areal and relief characteristics. We designed an ArcGIS web-application that allowed users to interactively explore the data.

KEY FINDINGS

- National-scale assessment of fundamental topographic characteristics is made freely available
- There is a wide diversity of stream network and river catchment characteristics across the Philippines
- Distinct characteristics within and between catchments show the need for place-based analyses in geomorphologically-informed sustainable river management

ArcGIS web-applicaton


Catchment properties


Stream network properties

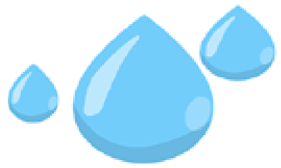
APPLICATIONS FOR RIVER MANAGEMENT

Geomorphologically-informed sustainable river management

- Make **inter-catchment comparisons** (e.g., catchment size and form)
- Make **intra-catchment comparisons** (e.g., drainage density within a catchment)
- Extract **longitudinal information** (elevation, channel slope, upstream area)
- Estimate **stream power** (requiring additional information on discharge) S
- Assess **trunk-tributary interactions** and **network topology**
- Inform **sediment connectivity analyses** at reach- to catchment-scales S
- Underpin detailed **fluvial morphology assessments** (e.g., Stage One of the River Styles Framework) S

EXAMPLE USE CASE
Inform locations where sustainable aggregate extraction activities may be permissible and identify reaches that require protection

Hydrology and water resource management



EXAMPLE USE CASE
Develop catchment-based approaches to manage the legacy impacts of contaminated mine tailings

- Supply topographic information for **river basin management plans**
- Support varied hydrological analyses, including **flood estimation** S
- Derive **attributes at gauging station sites**
- Extract physical **catchment descriptors**
- Provide baseline understanding for **climate resilience applications** S

Geohazard susceptibility

- Use **topographic and morphometric characteristics** within flash flood, debris flow and landslide susceptibility analyses S
- Leverage existing hazard maps to assess **hazard-conditioning factors** (e.g., influence of drainage density on flood hazard) S
- Assess **landslide-channel connectivity** using existing landslide hazard analyses and mapped inventories S
- Apply **location-based analyses** between the stream network and critical facilities/infrastructure (e.g., schools, hospitals, road network) S

EXAMPLE USE CASE
Develop an inventory of geohazard mitigation measures along the stream network (e.g., flood defence structures and bank erosion measures)

S *Denotes that supporting datasets are required to realise the potential application*

Reference: Boothroyd, R., Williams, R. D., Hoey, T. B., MacDonell, C., Tolentino, P. L. M., Quick, L., Guardian, E. L., Reyes, J. C. M. O., Sabillo, C. J., Perez, J. E. G., & David, C. P. C. (2023). National-scale geodatabase of catchment characteristics in the Philippines for river management applications. *PLOS ONE*, 18(3), e0281933.

Full paper access: https://doi.org/10.1371/journal.pone.0281933

Data access: http://dx.doi.org/10.5525/gla.researchdata.1396

Geodatabase: https://tinyurl.com/PHCatchmentDatabase

RESEARCH OUTPUT 2:

NATURAL FLOOD RISK MANAGEMENT IN TROPICAL SOUTHEAST ASIA: PROSPECTS IN THE BIODIVERSE ARCHIPELAGIC NATION OF THE PHILIPPINES

OVERVIEW

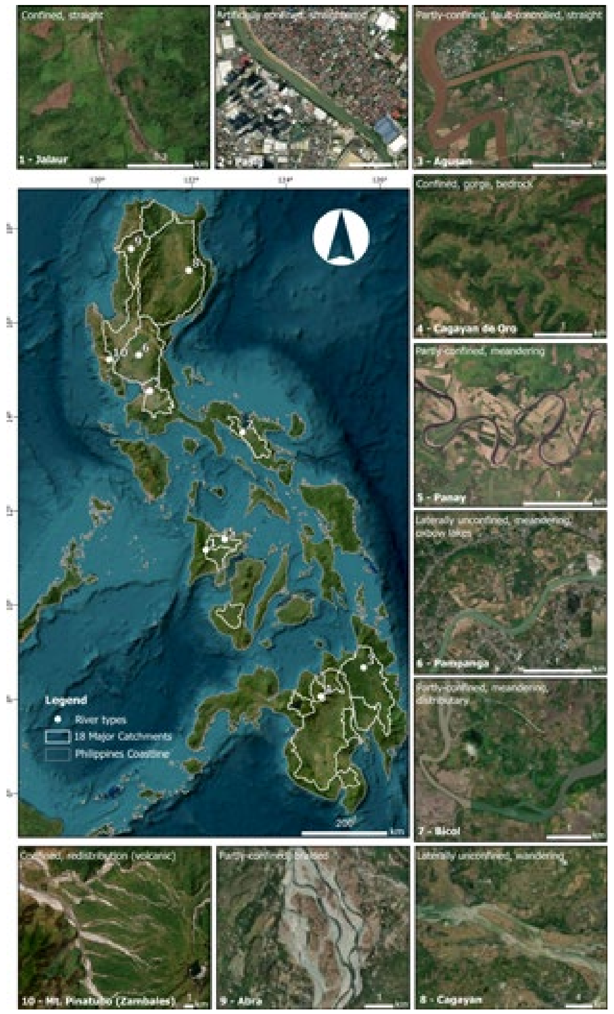
Natural flood management (NFM), which involves using natural processes to reduce flood risk, is gaining attention in temperate regions but lacks extensive application in tropical settings like the Philippines, despite high flood risk and ecosystem degradation. Tropical river catchments experience intense rainfall, flash floods, and major, sometimes destructive sediment-transporting flows, highlighting the need for NFM approaches. The Philippines' small, diverse catchments, with rapid hydrological response times and extensive urbanisation present both challenges and opportunities for NFM. Emerging evidence supports NFM's effectiveness in select Southeast Asian countries, emphasising the need for continued monitoring and adaptation. A shift from traditional river management to integrated flood risk management, including nature-based solutions, requires long-term commitment, public engagement, and robust evidence.

METHODS

We conducted a comprehensive literature review of the challenges associated with integrating Nature-based Solutions into flood risk management in tropical Southeast Asia, with an emphasis on the Philippines. We described the context for natural flood risk management in tropical settings with a review of 1) hydrometeorological context, 2) land use and land cover change, 3) institutional and legal frameworks, 4) reliance on structural interventions, 5) short project life cycles and limited technical capabilities, and 6) public perception. We then outlined the opportunities in a representative conceptual Philippine catchment that we divide into four nested connected parts.

KEY FINDINGS

- Effective river and flood risk management requires holistic, catchment-scale approaches.
- To design and implement effective NFM strategies you need to know your catchment and know your position in the catchment
- Advancing NFM requires local champions, long-term monitoring, investment and a strong evidence-base.

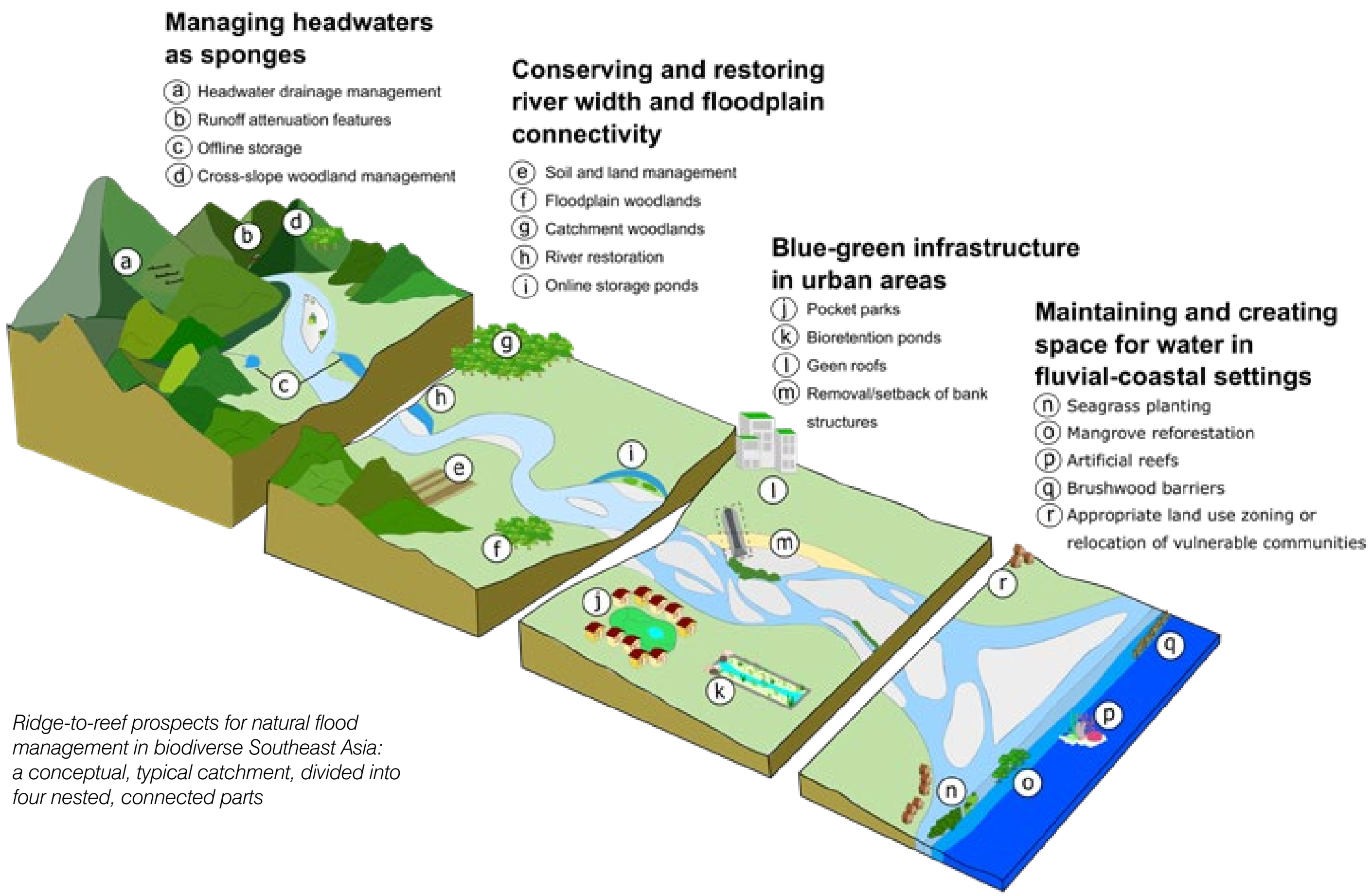


Diversity of river types in the Philippines. Recognition of the diversity of catchment and river types in the Philippines needs to be used to underpin geomorphologically informed, place-specific assessments of NFM potential.

APPLICATIONS FOR RIVER MANAGEMENT

A multipronged approach can address challenges by targeting different landscape features. One such approach was conceptualised in a typical catchment, divided into four nested, connected parts:

1. **Managing headwaters as sponges:**
   Implementing strategies to enhance water retention capacity of headwaters.
2. **Conserving and restoring river and floodplain width:**
   Allowing these areas to act as buffers that absorb excess water during heavy rainfall events.
3. **Blue-green infrastructure in urban areas:**
   Enhancing natural hydrological processes to help manage stormwater in urban environments.
4. **Maintaining and creating space for water in fluvial-coastal settings:**
   Accommodating fluctuations in water levels due to riverine and coastal influences.



Ridge-to-reef prospects for natural flood management in biodiverse Southeast Asia: a conceptual, typical catchment, divided into four nested, connected parts

Reference: Tolentino, P. L. M., Williams, R. D., & Hurst, M. D. (2025). Natural Flood Risk Management in Tropical Southeast Asia: Prospects in the Biodiverse Archipelagic Nation of the Philippines. *WIREs Water*, 12(1), e70000.

Full paper access: https://doi.org/10.1002/wat2.70000

RESEARCH OUTPUT 3:

NATIONAL-SCALE ASSESSMENT OF DECADAL RIVER MIGRATION AT CRITICAL BRIDGE INFRASTRUCTURE IN THE PHILIPPINES

OVERVIEW

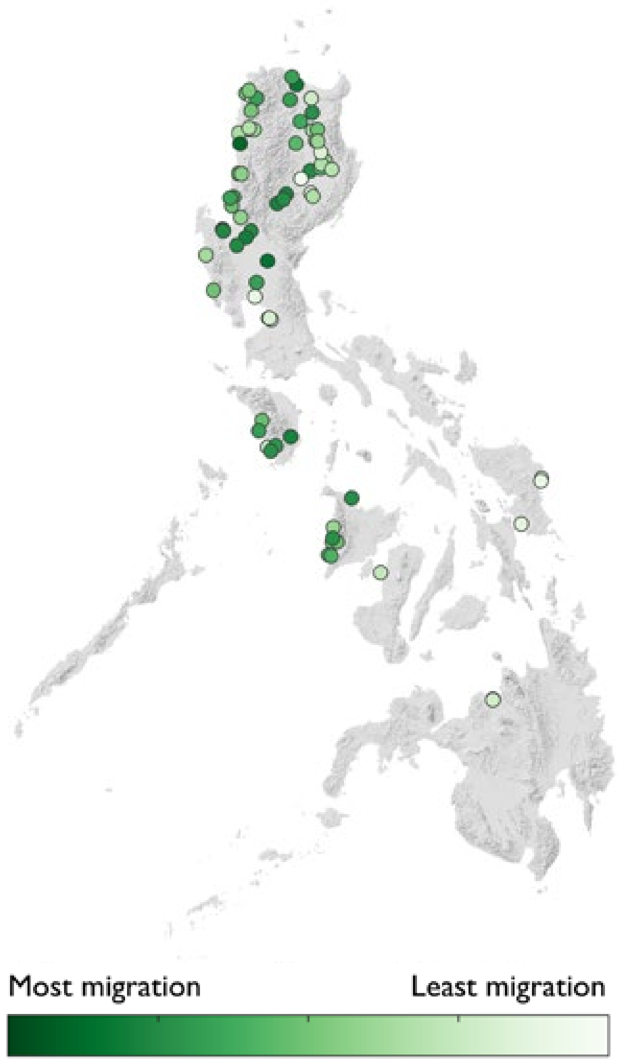
River migration poses significant geomorphic hazards to bridge infrastructure, especially in tropical regions like the Philippines, where migration rates are high. The country's susceptibility to flooding and geomorphic risks, coupled with recent infrastructural developments, necessitates a comprehensive assessment of river migration near bridge assets. This study analysed publicly available bridge inventory data from the Philippines Department of Public Works and Highways (DPWH) and utilised three decades of Landsat satellite imagery within Google Earth Engine (GEE). It provides new insights into lateral channel adjustment in the vicinity of large bridges.

METHODS

The study combined satellite remote sensing with geomorphological analysis to monitor river channel changes from 1988 to 2019. Key steps included: (1) selection and geomorphic characterisation of large bridges over 200m long that crossed river channels; (2) satellite data analysis using Landsat imagery, processed using GEE; and (3) river channel change analysis. We calculated similarity coefficients and quantified changes in width for the active river channel over decadal and engineering (30 year) timescales.

KEY FINDINGS

- Of the 74 large bridges analysed, approximately half showed a signal of river channel change.
- Satellite data analyses offer a low-cost approach for monitoring the relative risk of river migration for large rivers.
- Adaptive design, remote sensing, and geomorphological analysis are essential for resilient bridge planning and maintenance.



River migration at bridges in the Philippines

APPLICATIONS FOR RIVER MANAGEMENT

This study highlights the importance of integrating geomorphological insights into infrastructure planning. With proactive strategies, bridges and other critical structures can be designed to withstand the ever-changing nature of river systems.

1. **Bridge resilience and maintenance:**
Designing bridges with projections of future river migration is crucial. Regular monitoring of river change can also help identify high-risk sites early, guiding maintenance efforts and retrofits.

2. **Hazard mitigation and risk assessment:**
Mapping river migration zones allows planners to anticipate erosion risks and implement protective measures.

3. **Policy and planning integration:**
Incorporating river migration data into national infrastructure policies can help prevent costly damages. Guidelines for construction near rivers should consider historical and projected river migration.

4. **Cost-effective remote sensing for monitoring:**
Satellite-based tracking offers a scalable way to monitor river changes without expensive field surveys. Expanding this approach could benefit roads, railways, and other key infrastructure.

5. **Balancing development and conservation:**
Recognising natural river movement is vital for both infrastructure safety and ecological health. Sustainable management should balance engineering solutions with environmental preservation.

Detailed bridge Inventory geodatabase + Multi-temporal river platform adjustment analyses in Google Earth Engine

Example of damages to infrastructure associated with flooding and geomorphic hazards in the Philippines. Damage associated with Typhoon Urduja (2017) on Biliran Island at Caraycaray. Satellite imagery at Caraycaray Bridge shows large-scale geomorphic change immediately upstream of the bridge.

Reference: Boothroyd, R. J., Williams, R. D., Hoey, T. B., Tolentino, P. L. M., & Yang, X. (2021). National-scale assessment of decadal river migration at critical bridge infrastructure in the Philippines. *Science of The Total Environment*, 768, 144460.

Full paper access: https://doi.org/10.1016/j.scitotenv.2020.144460

RESEARCH OUTPUT 4:

BIG DATA SHOW IDIOSYNCRATIC PATTERNS AND RATES OF GEOMORPHIC RIVER MOBILITY

OVERVIEW

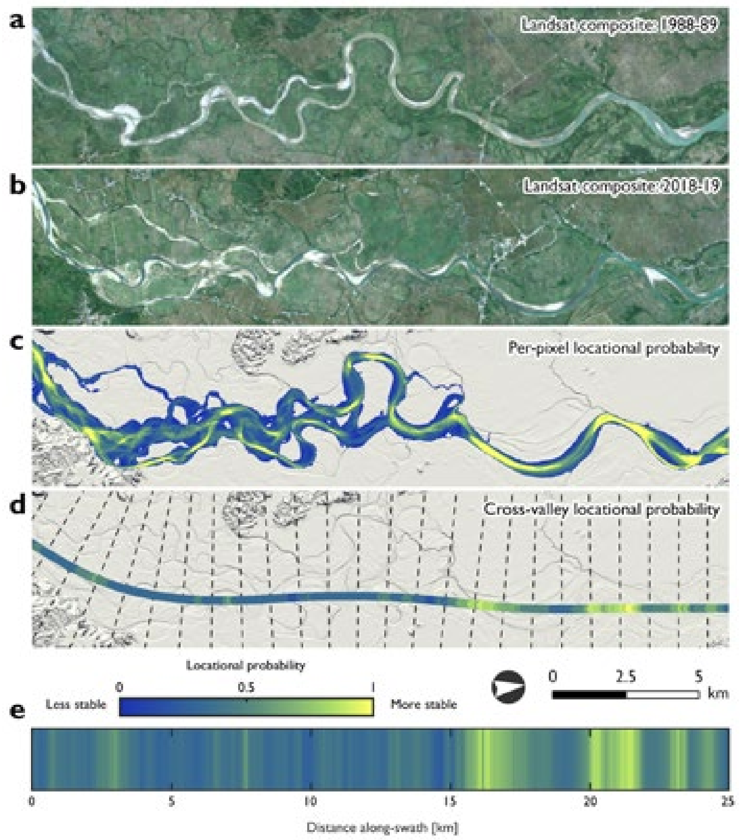
Big data present unprecedented opportunities to test long-standing theories regarding patterns and rates of geomorphic river adjustments. Understanding river mobility is essential for managing flood risk and infrastructure resilience. This study across ten Philippine catchments revealed highly variable patterns of stability and instability. Hotspots of mobility vary in magnitude, size and location between catchments. Findings challenge traditional assumptions that river movement follows simple relationships with factors like valley width or channel type, emphasising the need for place-based, data-driven understandings that allow the river to “speak for itself” as a basis for sustainable approaches to river management.

METHODS

We analysed a 32-year long record of Landsat satellite imagery between 1988 and 2019 to quantify river mobility. Having classified the active channel, we calculated the locational probability that measures the proportion of time that a channel occupies a particular location. We assessed the influence of local factors (e.g., valley floor width) on observed patterns of river movement and investigated adjustment behaviour for different channel pattern types.

KEY FINDINGS

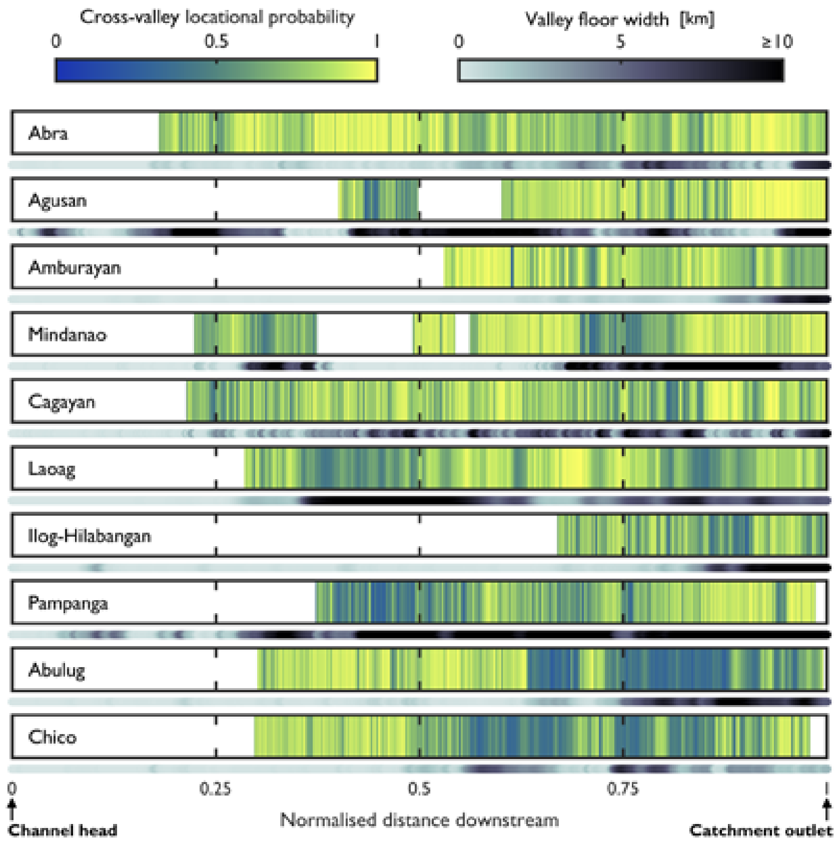
- Satellite-derived locational probabilities provide a continuous and recurrently updatable record of geomorphic river mobility.
- Hotspots of mobility vary in magnitude, size and location both along rivers and between catchments.
- Place-based, data-driven understandings are needed to allow each river to ‘speak for itself’ as a platform for sustainable approaches to river management.



Geomorphic river mobility for a 25 km segment of the Abulug River, Luzon. Cloud-free satellite imagery at (a) the start and (b) the end of the analysis period (1988-2019). Geomorphic river mobility expressed as (c) the per-pixel locational probability and (d) the cross-valley locational probability. Locational probability values closer to 1 indicate that the active channel was consistently positioned at that location through time (i.e., more stable). Cross-valley locational probabilities average the per-pixel location probabilities within a swath in the transverse direction along the valley floor centreline at 0.01 km intervals (dashed lines denote 1 km interval). The same cross-valley locational probabilities are displayed longitudinally in (e).

APPLICATIONS FOR RIVER MANAGEMENT

1. **Integrating mobility data into planning:** River movement should be factored into infrastructure design, land use planning and flood risk assessments. Adaptive strategies can reduce long-term damage and costs.
2. **Enhancing predictive model:** Big data provides an accurate tool to measure and interpret river behaviour. Incorporating satellite-derived mobility metrics can improve floodplain development strategies.
3. **Sustainable river corridor management:** Policies should define river mobility zones to allow for natural adjustments, reducing long-term risks to people and infrastructure.
4. **Remote sensing for continuous monitoring:** Satellite-based tracking enables early detection of unstable segments. Expanding its use can support erosion and flood risk management.
5. **Rethinking river classification:** Traditional static classifications do not capture dynamic river behaviour. A data-driven approach incorporating mobility metrics can improve river management decisions.



Along-valley patterns of river mobility, sorted with most stable rivers at the top and least stable rivers at the bottom. Individual bars represent regular 0.01 km intervals in the downstream direction. White spaces indicate zones of no data. Grayscale shading beneath barcode plots represents the valley floor width smoothed over 1 km river segments using a moving mean.

Reference: Boothroyd, R. J., Williams, R. D., Hoey, T. B., Brierley, G. J., Tolentino, P. L. M., Guardian, E. L., Reyes, J. C. M. O., Sabillo, C. J., Quick, L., Perez, J. E. G., and David, C. P. C. (2025). Big data show idiosyncratic patterns and rates of geomorphic river mobility. *Nature Communications*, 16, 3263.

Full paper access: https://doi.org/10.1038/s41467-025-58427-9

RESEARCH OUTPUT 5:

INTEGRATING HISTORICAL ARCHIVES AND GEOSPATIAL DATA TO REVISE FLOOD ESTIMATION EQUATIONS FOR PHILIPPINE RIVERS

OVERVIEW

River are products of water and sediment flux; without understanding discharge we cannot work with a river. Flood magnitude and frequency estimation is therefore essential for the design of structural and nature-based flood risk management interventions and water resources planning. The accuracy of flood magnitude and frequency estimation depends on the temporal duration, spatial distribution and accuracy of river flow observations. In the Philippines there are few continuous long river flow records available but many short (3 to 35 years) records exist from all regions of the country. Pooling of information from the available records, taking account of climatic variability across the country, forms the basis of the analysis in this paper. This leads to the development of equations to estimate flood magnitudes at national scale.

METHODS

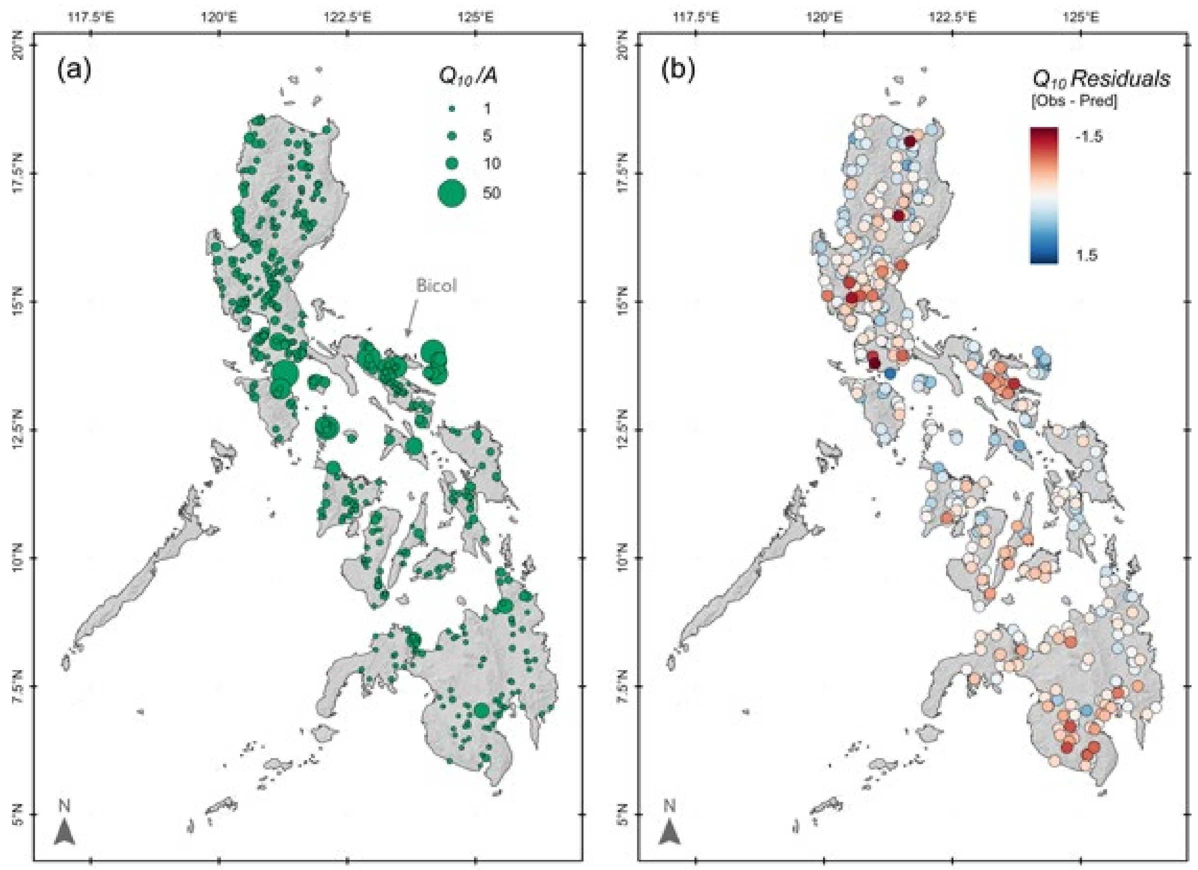
We pooled daily mean river discharge data from publications covering 842 sites, with data spanning from 1908 to 2018. Of these, 513 candidate sites met criteria to estimate a reliable annual maximum flood. Using the index flood approach, a range of controls were assessed at national and regional scales using land cover and rainfall datasets, and geospatial catchment characteristics.

KEY FINDINGS

- Flood prediction equations based on catchment area and annual median rainfall (RMED) show moderate accuracy, with R^2 values ranging from 0.56 to 0.66.
- The resulting predictive equations are suitable for use as design equations in ungauged catchments for the Philippines.
- Investing in an enhanced river monitoring network and regional data collection will significantly improve flood predictions and model reliability.

APPLICATIONS FOR RIVER MANAGEMENT

1. **Design of flood risk management interventions:** The predictive equations developed can inform the design of both structural and nature-based flood risk management strategies. This will ensure that they are appropriately scaled to anticipated flood magnitudes, and function to enhance public safety and reduce economic losses from flooding.
2. **Water resources planning:** Accurate flood frequency estimates assist in the planning and allocation of water resources, contributing to sustainable management practices.
3. **Policy development:** The findings can guide policymakers in formulating evidence-based policies for flood mitigation and water resource management.
4. **Risk assessment:** The study provides a framework for assessing flood risks in ungauged catchments, enabling better preparedness and response strategies.



(a) Specific 10-year flood discharge (Q_{10}/A), showing generally higher values in the central Philippines and southern Luzon, and lower values across Mindanao. (b) Residuals (in log10 units) from Philippines-wide equations for Q_{10}. Note the absence of regional trends, although there are some sub-regional clusters of both positive and negative residuals.

Reference: Hoey, T. B., Tolentino, P. L. M., Guardian, E. L., Perez, J. E. G., Williams, R. D., Boothroyd, R. J., David, C. P. C., & Paringit, E. C. (in revision). Integrating historical archives and geospatial data to revise flood estimation equations for Philippine rivers. *Hydrology and Earth System Sciences Discussions*, 1–26.

Full paper access: https://doi.org/10.5194/hess-2024-188 (in revision)

RESEARCH OUTPUT 6:

RIVER STYLES AND STREAM POWER ANALYSIS REVEAL THE DIVERSITY OF FLUVIAL MORPHOLOGY IN A PHILIPPINE TROPICAL CATCHMENT

OVERVIEW

Rivers exhibit diverse morphological characteristics influenced by geological, hydrological, and climatic factors, making their classification essential for effective river management. The River Styles Framework provides a systematic approach to understanding river diversity by categorising rivers based on their geomorphic attributes and behaviour. This study applies the framework in the Bislak catchment, a tropical river system in North-West Luzon, to assess river morphology and dynamics. By integrating stream power analysis, the research evaluates how energy distribution influences erosion, sediment transport, and channel formation. The study aims to inform sustainable river management by highlighting the natural diversity of river forms and processes.

METHODS

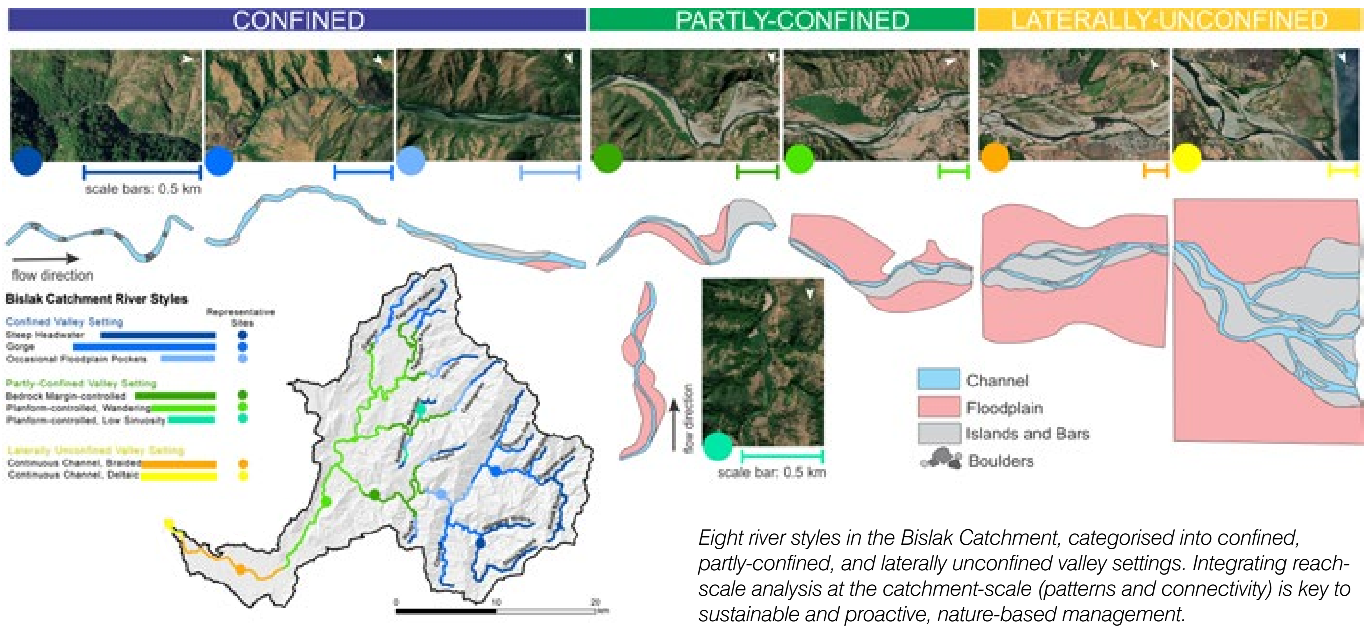
We used the River Styles Framework to classify river reaches based on geomorphic attributes, such as channel shape, sediment transport processes, and flow characteristics. Stream power analysis is used to quantify the energy available for erosion, providing insights into river dynamics. A combination of field surveys, remote sensing, and GIS mapping ensures a comprehensive assessment of river morphology across the Bislak catchment.

KEY FINDINGS

- The River Styles Framework highlights the importance of geomorphic insights into both river character and behaviour for sustainable management.
- The River Styles Framework and stream power analysis reveal eight distinct River Styles in Bislak Catchment; each requires tailored management strategies.
- Respecting river diversity and recognising downstream patterns are essential for developing sustainable, geomorphologically informed river management at the catchment scale.

APPLICATIONS FOR RIVER MANAGEMENT

1. **Informed Decision-Making:** Understanding the specific characteristics and behaviours of each River Style enables managers to make decisions tailored to the unique needs and dynamics of different river reaches.
2. **Sustainable Management Practices:** The study advocates for a shift from traditional engineering-based approaches to more sustainable, ecosystem-based management. By recognising and preserving the natural diversity and dynamics of river systems, interventions can be designed to work with natural processes rather than against them.
3. **Prioritisation of Conservation Efforts:** Identifying areas with high geomorphic diversity or those that play crucial roles in the overall health of the catchment allows for targeted conservation efforts, ensuring that resources are allocated effectively.
4. **Assessment of Human Impacts:** The framework provides a baseline against which human-induced changes can be measured. This is essential for assessing the impact of activities such as dam construction, land-use changes, or extraction practices on river morphology and function.
5. **Restoration Planning:** In areas where river health is poor, the River Styles Framework can guide restoration efforts by providing reference conditions and highlighting natural recovery pathways suitable for specific river types.



Eight river styles in the Bislak Catchment, categorised into confined, partly-confined, and laterally unconfined valley settings. Integrating reach-scale analysis at the catchment-scale (patterns and connectivity) is key to sustainable and proactive, nature-based management.

Reference: Tolentino, P. L. M., Perez, J. E. G., Guardian, E. L., Boothroyd, R. J., Hoey, T. B., Williams, R. D., Fryirs, K. A., Brierley, G. J., & David, C. P. C. (2022). River Styles and stream power analysis reveal the diversity of fluvial morphology in a Philippine tropical catchment. *Geoscience Letters*, 9(1), 6.

Full paper access: https://doi.org/10.1186/s40562-022-00211-4

RESEARCH OUTPUT 7:

CONFINED AND MINED: ANTHROPOGENIC RIVER MODIFICATION AS A DRIVER OF FLOOD RISK CHANGE

OVERVIEW

Rivers modify their topography by redistributing sediment, but sediment and geomorphic changes are often overlooked in flood risk modelling. However, in regions where geomorphic changes occur due to natural or human activities, these changes in topography can influence flood magnitude and extent. This study tests the hypothesis that morphological change associated with anthropogenic river modification alters flood inundation extent over an annual timescale. Results show that anthropogenic confinement and aggregate mining alter flood dynamics, with consequences for the integrity of river and transport infrastructure.

METHODS

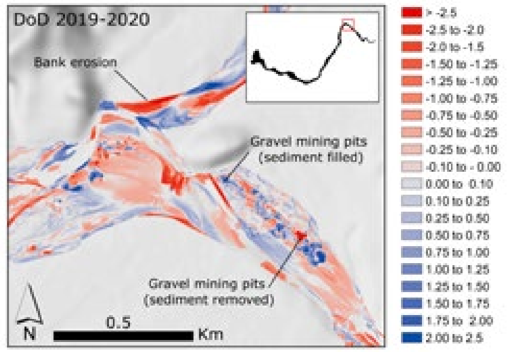
Topographic surveys of the Bislak River were acquired in 2019 and 2020, using a combination of airborne Light Detection and Ranging (LiDAR) and bathymetric survey techniques. Geomorphic change detection (GCD) software was used to generate 0.5 m resolution Digital Elevation Models (DEMs) of Difference (DoD) to assess topographic changes, sediment budgets, and mining-related alteration during a one-year time period. Hydraulic modelling, calibrated with observed data, simulated flood events across different return periods to predict the effects of geomorphic changes on flood routing and inundation.

KEY FINDINGS

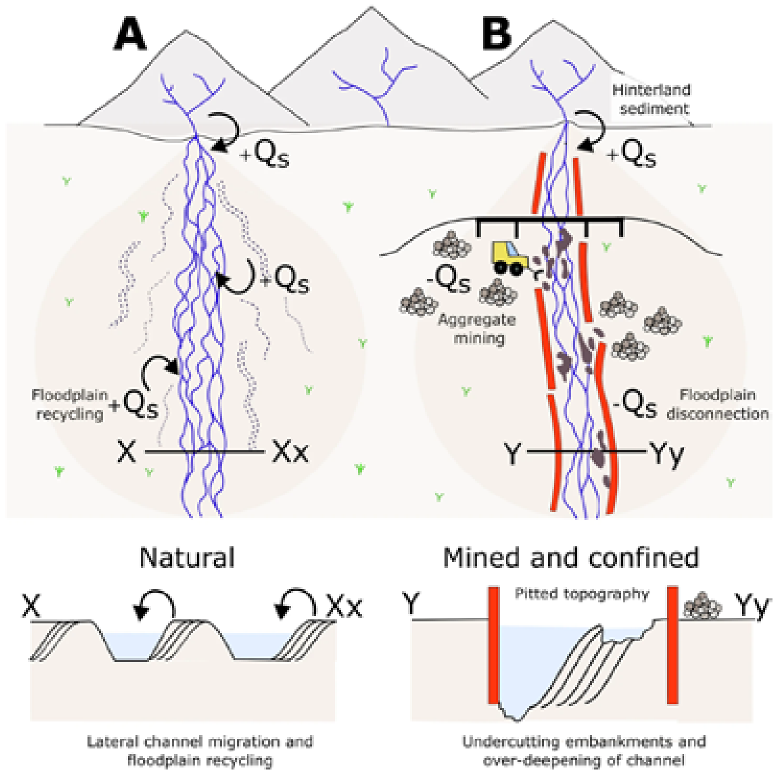
- Morphological changes from 2019–2020 reduced flood inundation on the floodplain for 10- and 50-year events but increased shear stress within the channel.
- Confined river segments with extensive aggregate mining experienced the most significant decrease in flood extent.
- Sediment loss due to confinement and mining increases erosion risks to infrastructure, with potential long-term impacts exacerbated by climate change and rising aggregate demand.

APPLICATIONS FOR RIVER MANAGEMENT

1. **Improve flood risk models:** In rivers that are geomorphologically dynamic, flood models need to be updated to include changes in river morphology. Ignoring these shifts can lead to over- or under-estimated flood hazards and infrastructure risks.
2. **Sustainable sediment management:** Excessive aggregate mining disrupts sediment transport, altering river configuration and potentially causing instability. Controlled extraction and replenishment strategies can help maintain river stability.
3. **Protect critical infrastructure from scour:** In a mined and confined river, increased riverbed erosion can destabilise bridges, roads, and other critical infrastructure. Regular monitoring and adaptive management can mitigate risks and prevent costly damage.
4. **Balance development and environment:** Urbanisation and rising aggregate demand require careful river management. Stronger policies can minimise flood risks while supporting economic needs.
5. **Adaptive river policies:** River and floodplain management should integrate geomorphic monitoring to account for changing river conditions. Adaptive policies ensure long-term flood protection and sustainable development.



DoD reveals bank erosion, bar changes, and anthropogenic impacts such as aggregate extraction on river morphology.



(A) A natural river with no flood embankments or aggregate mining activity. (B) A 'confined and mined' river which has extensive flood and bank erosion protection structures along the channel banks. Flood embankments prevent lateral channel erosion and migration, depriving the river of a main source of sediment (i.e., floodplain recycling). Aggregate mining in the active channel combined with a sediment deficiency from floodplain disconnection results in river incision and an overdeepening of the channel which can lead to increased bed shear stress and the scouring of critical infrastructure foundations.

Reference: Quick, L., Williams, R. D., Boothroyd, R. J., Hoey, T. B., Tolentino, P. L. M., MacDonell, C., Guardian, E., Reyes, J., Sabillo, C., Perez, J., & David, C. P. C. (2025). Confined and mined: anthropogenic river modification as a driver of flood risk change. *Npj Natural Hazards,* 2(1), 1–1.

Full paper access: https://doi.org/10.1038/s44304-024-00051-6

RESEARCH OUTPUT 8:

CASCADING CONSEQUENCES OF STRUCTURAL INTERVENTIONS IN A TROPICAL WANDERING GRAVEL-BED RIVER

OVERVIEW

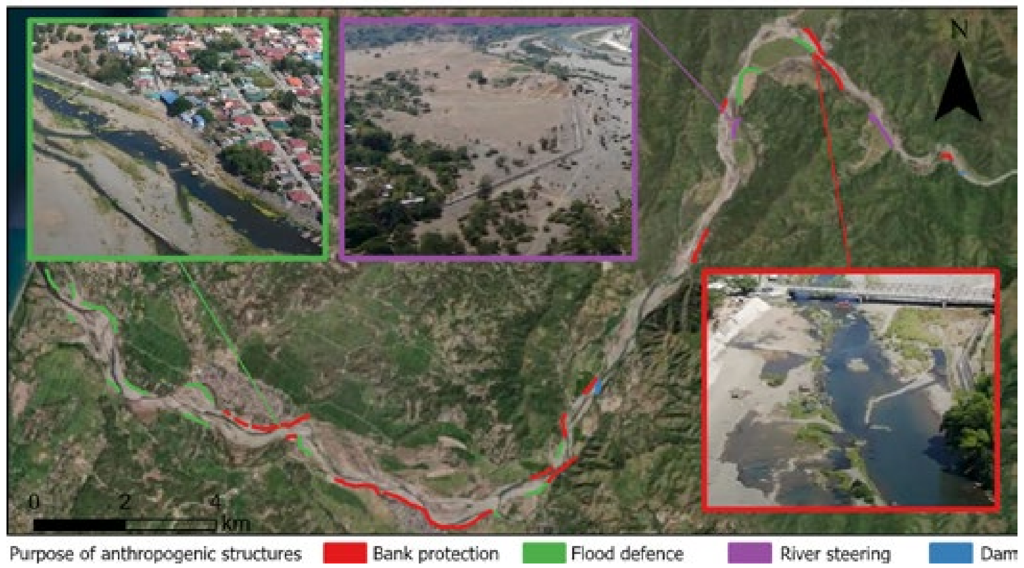
Riverscapes have been subjected to extensive modification to meet human needs. Practices such as river channelisation often provide a false sense of security that flood risk has been eliminated, as they merely transfer the problem downstream. Overall, this disconnection and disruption has led to floodplain ecosystems becoming the most threatened among all ecosystem types. However, emerging approaches to river management now recognise their functional value and ecosystem services, through natural flood risk management (NFM) and river restoration programmes. Reconnecting channels and floodplains promotes the restored functional floodplain ecosystems and can contribute to reducing flood risk.

METHODS

Focusing on the Bislak River, Ilocos Norte, we used hydrodynamic modelling and geomorphological change analysis to assess the impacts of existing flood structures and potential responses to their removal. Our approach informs a systematic decision-making process to screen opportunities for channel reconnection. Two-dimensional hydraulic modelling showed flood structures confine flood water within the active channel for more frequent flood events, but banks are overtopped during larger magnitude events (>50-year recurrence interval). Incorporating modelling results, a multi-criteria analysis was developed to appraise opportunities for river reconnection based on structure purpose, functionality, and local land-use.

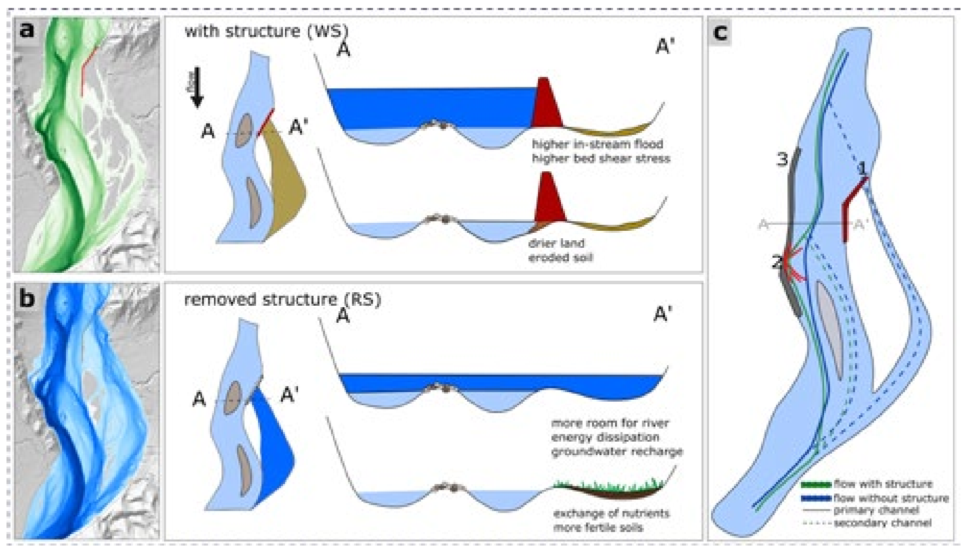
KEY FINDINGS

- Hydrodynamic and geomorphological change assessments can be used to assess the impacts of existing flood structures, supporting systematic decision-making process for channel reconnection opportunities.
- The decision-making process identifies how a structure that reduces inundation area but also redirects flow to the opposite bank, creating cascading consequences of bed and bank erosion that required further structural interventions.
- Adaptive management is crucial to evaluate the effectiveness of flood risk strategies, ensuring they are updated based on ongoing assessments.



APPLICATIONS FOR RIVER MANAGEMENT

1. **Balancing static structures with dynamic river systems:** Engineering structures influence flood dynamics, but their effectiveness is limited by discharge, costs and environmental factors. Sustainable river management requires integrating long-term river morphodynamics rather than relying on rigid, reactive flood defences.
2. **Cascading effects of structural interventions:** Structural interventions often trigger unintended consequences, such as increased downstream erosion and altered flow patterns. Predictive modelling helps assess long-term impacts, ensuring interventions address root causes rather than just symptoms.
3. **Managing river confinement and sediment transport:** Confining rivers with engineering structures can alter sediment movement, often leading to unintended consequences. Strategies like setback levees and controlled aggregate extraction help mitigate these effects while allowing natural river processes to function.
4. **Natural Flood Management (NFM) as a sustainable approach:** Relying solely on structural defences can create a false sense of security and encourage risky urban expansion in flood-prone areas. Restoring floodplain connectivity slows water flow, improves sediment exchange, and enhances ecological diversity for long-term sustainability.
5. **Adapting management strategies to local conditions:** River management is not a one-size-fits-all approach and requires context-specific solutions that balance infrastructure needs with ecological sustainability. A proactive, evidence-based approach prevents irreversible degradation and ensures both rivers and communities can coexist successfully.



(a) The structure prevents the area behind it being inundated. (b) The removal of the structure allows more space for the river to flow and slow the flow. (c) Conceptual diagram of cascading consequences and impact of structures on flow and sediment dynamics. 1: Structure no. 13 was built in the left bank. 2: Influence of the structure caused increased erosion of the opposite bank. 3: Another structural intervention was built to protect the right bank from erosion.

Reference: Tolentino, P. L. M., Williams, R. D., & Hurst, M. D. (2024). Cascading consequences of structural interventions in a tropical wandering gravel-bed river. *River Research and Applications*.

Full paper access: https://doi.org/10.1002/rra.4362

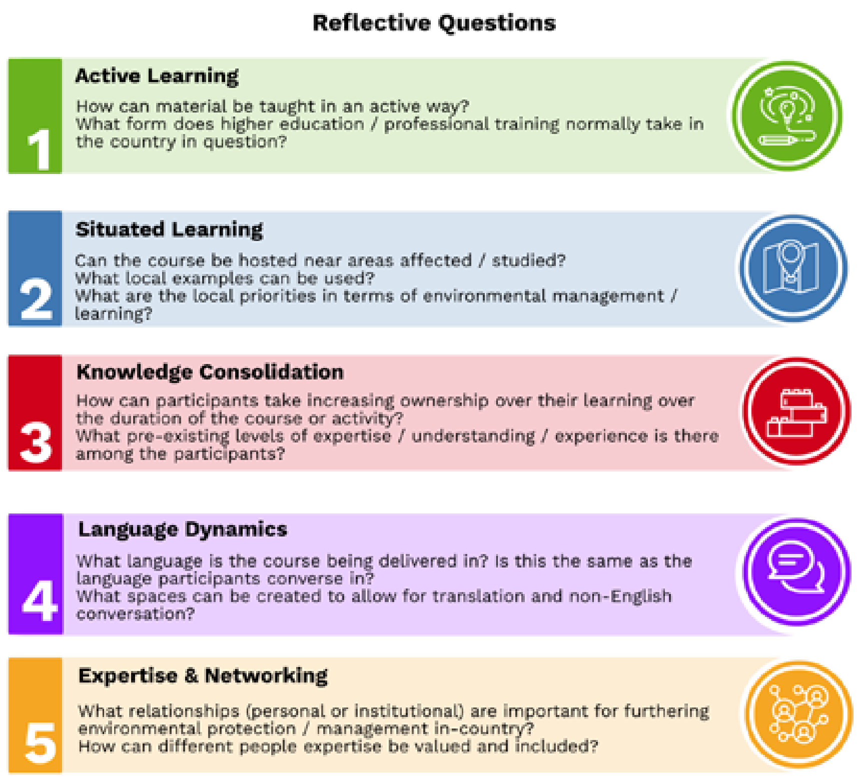
FROM LEARNING TO ACTION: CO-CREATING SUSTAINABLE, GEOMORPHOLOGICALLY-INFORMED RIVER FUTURES

OVERVIEW

Research outputs from the Catchment Project build upon one another to provide a coherent package of geomorphic insights into Philippine river catchments. Together, they provide a foundation to understand diversity and variability, underpinned with process-based understandings. Contemporary river management needs to merge insights derived from analyses of digital data with field-based interpretations. The project advocates for an equitable approach to river management by promoting a community of practitioners. Through bridging geomorphic insights with sustainability goals, we highlight the need for inclusive, knowledge-driven decision making through co-creation and collaboration.

DELIVERING CAPACITY STRENGTHENING COURSES IN RIVER MANAGEMENT

Capacity strengthening activities – be that in the form of courses, workshops or seminars – equip river management practitioners with skills to produce and use digital analyses of river catchments, and to interpret field observations. Instructors need to work with participants to co-produce knowledge, rather than assuming epistemic authority and imposing externally-derived knowledge. Reflexive and adaptable practices before, during and after each activity can be guided using the questions shown below.

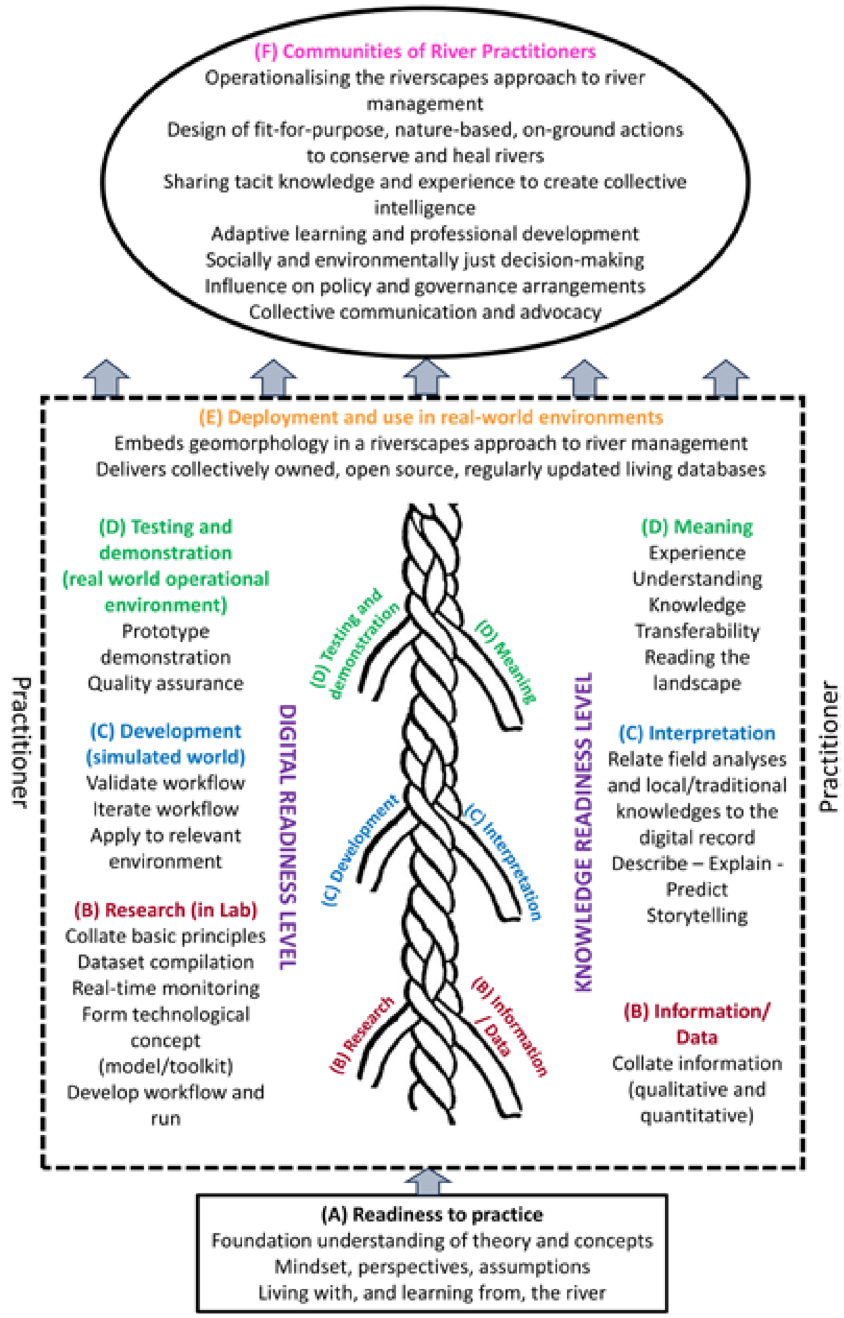


Reference: Mitchell, D., Laurie, E. W., Williams, R. D., Fryirs, K. A., Brierley, G. J., & Tolentino, P.L.M. (2024). Developing an equitable agenda for international capacity strengthening courses: Environmental pedagogies and knowledge co-production in the Philippines. *Journal of Geography in Higher Education.* 48(2), 281–311.

Full paper access: https://doi.org/10.1080/03098265.2023.2235668

DEVELOPING COMMUNITIES OF RIVER PRACTITIONERS

Communities of River Practitioners (CoRPs) are required to address concerns for digital and knowledge readiness in the design and uptake of a geoethical approach to geomorphologically-informed river management. The framework below outlines the pathway to practitioner readiness in river management, integrating knowledge, digital tools, and real-world application. CoRPs work collaboratively to develop and implement nature-based solutions that conserve and restore rivers. The journey to readiness to practice begins with foundational knowledge and perspectives (A), progressing through research (B), development (C), and real-world testing (D), before reaching full-scale deployment (E). This process weaves scientific data, digital tools, and local knowledge for a holistic understanding. By embedding geomorphology, adaptive learning, and socially just decision-making, this approach empowers river practitioners to shape policy, drive sustainable action, and advocate for healthier rivers.



Reference: Brierley, G., Fryirs, K., Williams, R., Boothroyd, R., andTolentino, P. L. (2025). Practitioner Readiness: Developing Communities of River Practitioners (CoRPs) to Deliver Proactive Management Practices That Work With the River. *WIREs Water*, 12(2), e70021.

Full paper access: https://doi.org/10.1002/wat2.70021

RETHINKING RIVER MANAGEMENT: KEY ISSUES & SOLUTIONS

1. Work with, not against, rivers

Issue: Misguided perceptions that rivers need to be controlled.

Problem: Traditional river management focuses on controlling rivers (e.g., excessive dredging, channelisation) rather than understanding and adapting to their natural dynamics.

Consequences: Short-term interventions lead to long-term river instability and high long-term costs.

Solutions:

- Shift from command and control to nature-based solutions (e.g., floodplain and catchment restoration, conserving river width, green-gray solutions).
- Recognise that rivers are living systems that are dynamic, ever-changing systems rather than fixed entities.

Key Message: *Rivers are not problems to fix, but systems to work with.*

2. Respect river diversity

Issue: One-size-fits-all strategies that ignore river differences create bigger problems.

Problem: Many river management strategies ignore differences in geography, ecology, and hydrology.

Consequences: Generic solutions cause unintended damage to infrastructure and river health.

Solutions:

- Recognise each river's unique characteristics; some rivers naturally shift, others remain stable.
- Develop land use plans that give rivers space to move, where appropriate.
- Develop place-based management strategies rather than universal solutions.

Key Message: *Each river is unique, respect its natural diversity.*

3. Manage rivers holistically

Issue: Fragmented, isolated interventions by different agencies often 'work against' each other.

Problem: Flood control, floodplain land use, quarrying, dams and conservation are often handled in isolation, leading to unintended consequences.

Consequences: Solutions in one area create unintended problems elsewhere (e.g., river channelisation funnels water downstream, which can increase downstream flooding).

Solutions:

- Adopt catchment-scale thinking which considers upstream and downstream impacts.
- Integrate geomorphology, ecology, hydrology, and community knowledge into decision-making.
- Assess conditions and measure effectiveness of strategies in master plans.

Key Message: *A river is a connected system; what happens upstream affects downstream.*

4. Plan for the future, not just for disasters

Issue: Reactive, crisis-driven river management is ineffective and costs more.

Problem: Crisis effect – people act only after disasters strike leading to repeated damage and high costs.

Consequences: Loss of life and infrastructure damage, significant economic losses; failure to learn from experiences.

Solutions:

- Invest in proactive planning using geomorphic assessments, predictive tools, and long-term strategies.
- Shift funding from disaster recovery to risk reduction.
- Make use of living databases to track and analyse river changes over time.

Key Message: Spending on prevention not only saves lives and money but reduces the cycle of repeated damage.

5. Engage local communities in decision-making

Issue: Top-down, expert-only approaches fail to engender sustainable outcomes.

Problem: Local communities are often excluded from river management decisions.

Consequences: Missed opportunities to incorporate valuable local insights.

Solutions:

- Engage communities as partners.
- Co-create solutions with communities rather than dictating policies.

Key Message: *Communities are not just stakeholders, they are knowledge holders.*

6. Avoid short-term fixes that cause long-term harm

Issue: Solving today's problem, creating tomorrow's crisis.

Problem: Many interventions (e.g., dams, bank erosion protection structures, land use changes) ignore cumulative, cascading effects.

Consequences: Increased erosion, habitat destruction, and large magnitude floods over time.

Solutions:

- Use future scenario modelling to predict long-term river changes.
- Prioritise sustainable interventions that balance economic, environmental and social needs.
- Practice adaptive management that minimises cascading consequences.

Key Message: *Think beyond today, plan for tomorrow's river.*

7. Strengthen practitioner readiness

Issue: River management requires adaptive and collaborative expertise.

Problem: Many practitioners rely on rigid, top-down approaches instead of embracing diverse learning methods.

Consequences: Limited capacity to implement holistic, nature-based solutions effectively.

Solutions:

- Develop river management champions.
- Develop practitioners who drive change and share knowledge.
- Promote professional development, peer-to-peer learning and interdisciplinary collaboration.

Key Message: *Building capacity means embracing collaboration and continuous learning.*

Funding has been from:

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