Steps towards incorporating geomorphic considerations in farm and catchment management plans in the Waimatā Catchment, Aotearoa New Zealand

Harvey K[1], Brierley G[1], Easton L[2], Watson L[2], Tunnicliffe J[1]

1 The University of Auckland, 23 Symonds Street, Auckland, Aotearoa New Zealand 1010. Email: khar251@aucklanduni.ac.nz

2. Waimatā Catchment Management Group, Gisborne, Aotearoa New Zealand 3437

Key Points

- Recurrent accumulations of logs on beaches at Gisborne attest to highly connected linkages 'From the Mountains to the Sea'. Typical of many systems in Aotearoa, terraces constrain accommodation space along short, steep rivers in Waimatā Catchment. This induces efficient conveyance of flow, sediment and logs to the coast. The trunk stream acts like a flume (a vertically adjusting throughput zone), with laterally adjusting transfer zones along some tributaries.
- Indices of connectivity and applications of the CASCADE sediment transfer model identify geomorphic hotspots (primary sediment sources and areas subject to significant reworking)
- Sediment flux management scenarios (reafforestation, riparian vegetation management, wetland (re)construction) highlight implications for proactive, precautionary and strategic plans which tackle issues at source while addressing concerns for off-site impacts (i.e. treatment response).
- Effective management practices link targeted farm management plans within a coherent catchment plan.

Abstract

Recurrent log accumulations on beaches reflect the inherent connectivity of drainage pathways from the Mountains to the Sea on the East Cape of Aotearoa. This study brings together results from field investigations, landscape mapping and modelling analyses to derive geomorphic understandings that support co-development of scenarios to scope restoration initiatives with members of the Waimatā Catchment Group. High sediment yields from headwater reaches, and efficient sediment delivery pathways, create sedimentation issues in lower reaches of the Waimatā Catchment. Overall, this river behaves like a flume, efficiently conveying flow, sediment, and logs through terrace-confined reaches. Connectivity modelling shows how land use influences the potential for sediment generation and transport, with high connectivity in steep slope and low vegetated areas and low connectivity in low slope or densely forested reaches. Options for management of sediment 'hotspots' identified using a Connectivity Index are developed using the CASCADE Toolbox.

Keywords

Sediment flux, Geomorphology, Connectivity, Farm plan, Catchment plan

Introduction

Managing sediment flux at the catchment scale is an integral component of geomorphologically-informed approaches to river management. Failure to incorporate such understandings results in recurrent (mis)applications of reactive measures which are ineffective in environmental, economic and socio-cultural terms. Proactive and precautionary management plans strategically address issues at source, applying process-based solutions that 'work with the river' to minimize negative off-site impacts of disrupted sediment regimes (e.g. Brierley and Fryirs, 2009; Wohl et al., 2015). Analysis of landscape connectivity – the effectiveness and efficiency with which flow and sediments are transferred through river systems – is key to such investigations (Bracken et al., 2015; Brierley et al., 2006; Fryirs, 2013). Anthropogenic modifications to patterns and rates of sediment storage and transfer have profound implications for river management (Poeppl et al., 2020; Tunnicliffe et al., 2018).

In Aotearoa New Zealand, short and steep rivers result in highly connected systems that efficiently carry materials 'From the Mountains to the Sea' (*Ki Uta ki Tai*; Brierley et al., 2019; Harmsworth and Awatere, 2013). As on-the-ground management applications are largely applied at the farm scale, integrating farm plans in a coherent catchment plan is critical to addressing sediment management problems, especially concerns for geomorphic hotspots (Czuba & Foufoula-Georgiou, 2015). In sediment-overloaded systems, strategic measures target the primary areas from which sediments are derived (i.e. managing at source), developing practices that reduce sediment inputs or retard rates of sediment movement as required. Effective catchment-scale plans carefully consider treatment responses (Schmidt et al., 1998), minimizing negative consequences of offsite impacts and legacy effects.

As a result of its weak lithology, landuse change and frequent high rainfall, river systems on the East Cape of New Zealand have some of the highest sediment yields per unit area in the world (Hicks et al., 1996). Recurrent accumulations of logs on beaches at Gisborne in recent decades attest to sensitive landscape responses to storm events under altered landuse conditions (forestry management, sheep and beef farming; Marden, 2012). Typical of many systems in Aotearoa, the constraints imposed upon accommodation space by terrace confinement result in efficient conveyance of flow, sediment, and logs to the coast. The trunk stream acts like a flume (a vertically adjusting throughput zone), with local instances of laterally adjusting transfer zones (especially along tributaries) (cf., Brierley and Fryirs, 2000). Throughput zones are characterised by single thread, low sinuosity, stable channels with extensive bedrock outcrops, sand sheets, occasional pools and discontinuous floodplain pockets. The bedrock channel and associated pools may be exposed after floods, only to be re-covered by transient sediment pulse materials. Transfer reaches are single thread channels within a narrow but winding valley. Sediment stores on the inside of bends (point bars, point benches and sand sheets) are recurrently reworked, balancing sediment inputs and outputs over time (Brierley and Fryirs, 200).

Ongoing concerns for sedimentation issues in the Waimatā Catchment have prompted significant community interest in restoration initiatives, including the Waimatā Catchment Restoration Project and Waikereru Ecosanctuary. GIS and sediment routing models can help to characterise and quantify sediment sources, transport pathways and the potential magnitude and spatiotemporal distribution of responses of fluvial geomorphic processes to anthropogenic disturbances (e.g. Borselli et al., 2008; Heckmann et al., 2015; Schmitt et al., 2018; Tangi et al., 2019). In this study we use indices of connectivity (Borselli et al., 2008) and outline applications of the CASCADE sediment transfer model (Tangi et al., 2019) to identify sediment hotspots, defined as reaches with a high potential for change in sediment storage over time. This helps to prioritise areas with the greatest potential for mitigating accentuated sediment transfer. We then demonstrate some of the key mechanisms and pathways of sediment transfer evident in landuse scenarios, including forest removal, vegetation regeneration and wetland construction to provide some insights into how best to manage sediment flux in this system.

Study Site

The Waimatā River is located on the East Coast of New Zealand's North Island. The river drains approximately 370 km^2 of hill-country. Before discharging into Poverty Bay, the Waimatā joins the Taruheru River in the Gisborne CBD forming the shortest river in the Southern Hemisphere, the Turanganui River (Forbes et al., 2018). The 20 km, short but steep river flows through sheep and beef country. Weak underlying geology comprises uplifted mudstones and sandstones (Figure 1). Mud volcanoes, earthflows and gully erosion reflect strongly fractured and faulted rocks, including smectic claystones (Mazengarb and Speden, 2000). Tectonic and climatic factors have generated flights of terraces along the river (Marden, 2012).

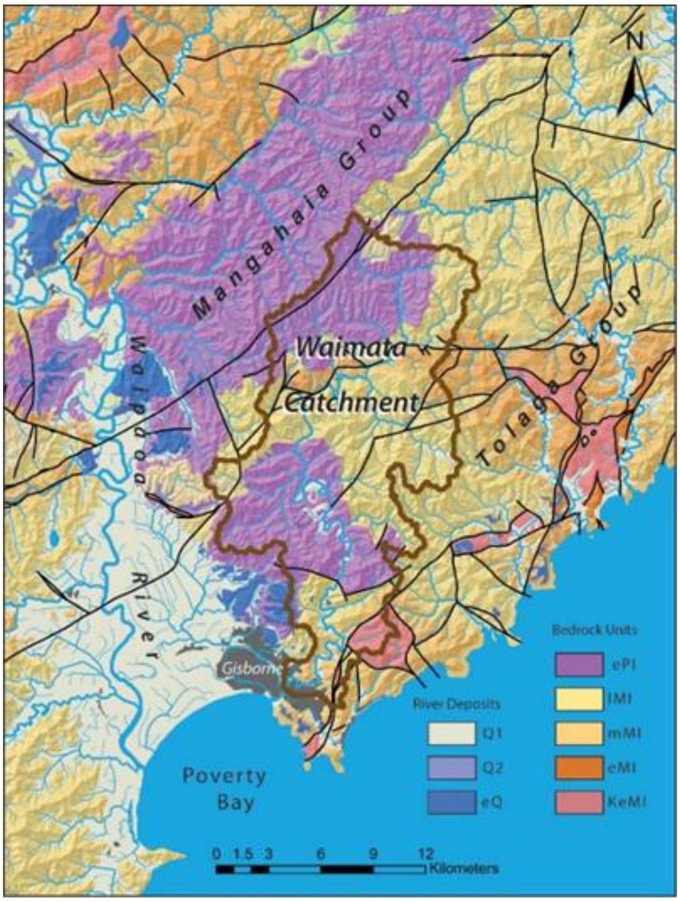


Figure 1. The geology of the Waimatā consists primarily of Early to Late Miocene Tolaga Group (eMI, mMI and lMI) units, which are unconformably overlain by the latest Miocene to Early Pliocene Mangahaia Group (Pmz). The bulk of the Tolaga Group comprises massive and thinly bedded mudstones, generally weak to moderately hard. The Mangahaia Group consists chiefly of sandstone and siltstone. There are some small outcrops of undifferentiated melange (KeMI), and numerous deposits of older alluvial fill along the main valley (Q1) (Mazengard and Speden, 2000).

Methodology

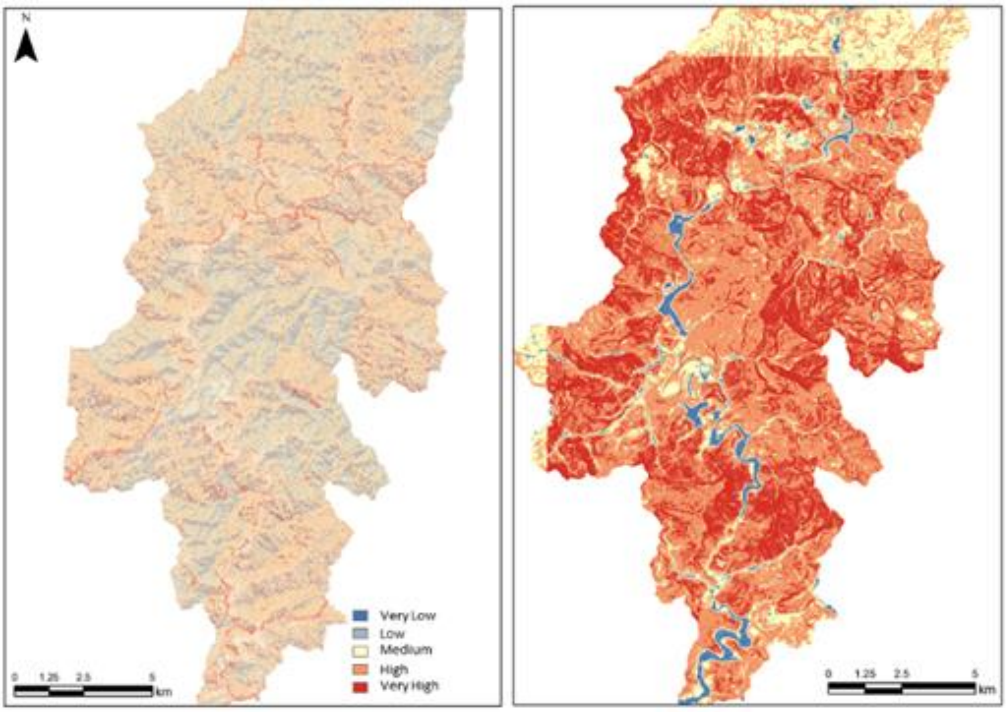
Recent LiDAR surveys of the Gisborne District (GDC, 2019) have yielded a high-resolution (1 m) bare-earth model of the study area. This enables us to clearly resolve details of, for instance, hillslope dissection and channel configuration, even under tree canopy. By contrast, the Geographix (LINZ, 2014) 8 m DEM commonly used for landscape analysis in New Zealand is a more generalised representation of topography interpolated from 20 m contours and may not resolve some of the finer-scale details of the drainage network.

Steps outlined in Borselli et al. (2008) were followed to create indices of connectivity for several landuse scenarios outlined in Harvey (2021):A Business as Usual (BAU) scenario involving; forestry removal, and two regeneration scenarios involving erosion control, retiring sections of forestry and agriculture, conversion to native forest, revegetation of riparian strips, and use of constructed wetlands as barriers. The algorithm uses layers of geological and land-cover information to assign the relative transport potential from hillslopes to river channels in different land-use or land-cover settings. We used the LUCAS (2018) land use layer and NZ Road Centrelines (Topo, 1:50k) from Koordinates to define these. Systematic analysis of bed material size underpinned modelling applications.

The three scenarios were considered in the CASCADE analysis, identifying dominant sediment sources and transfer patterns, and by comparing sediment input values to simulate changes to the land use categories (Tangi et al., 2019). The CASCADE model requires field data inputs including grain size data (D16, D50 and D84) and Manning's n as well as GIS derived inputs including, channel width, and discharge. External sediment generation was estimated following Cave (2019) and scaled according to Larsden et al. (2010) forestry removal regime calculations (see Harvey, 2021).

Results and Discussion

The Borselli algorithm indicates high sediment connectivity values in the Waimatā DEM (Figure 2). High/very high connectivity values are associated with steep sloped ridges and hillslopes. High/moderate connectivity values are more prominent in areas of partial confinement, whereas low/very low values are found almost exclusively on low slope floodplain areas. There are some notable contrasts between results from the LiDAR (1 m) DEM and the 8 m dataset. The lower resolution raster does not resolve many of the obstacles to connectivity, and has many smooth, planar facets that the algorithm interprets to be highly connected components of the landscape. This has important implications for any broadscale application of this tool, highlighting the algorithm's sensitivity to relatively fine-scale features and textures in the landscape.



Connectivity Descriptor	8m Pixel range	1m Pixel range
Very Low	-4.5 to -2	-7 to -1
Low	-2 to 0	-1 to 0
Medium	0 to 3	0 to 5
High	3 to 4.5	5 to 10
Very High	5.5 +	10 +

Figure 2. Sediment connectivity maps for the Waimatā Catchment. Left depicts 1m and right the8m resolution DEM inputs. Table lists delineating connectivity thresholds.

The influence of changing land use on connectivity was appraised for three scenarios (Figure 4). The BAU land use scenario highlights the influence of forest harvesting on sediment erosion and transport. Removing vegetation decreases slope stability resulting in increased sediment generation. Given high hillslope-channel coupling, sediments are readily transferred to the channel and flushed downstream in this highly connected catchment, other than areas of retained native bush. The regeneration and wetland examples produced similar results at the catchment scale. Areas converted from farmland to native bush show a change from moderate/high connectivity to low connectivity. Low connectivity is further promoted by the introduction of buffer zones as areas for sediment deposition between the hillslope and channel decoupling the system.

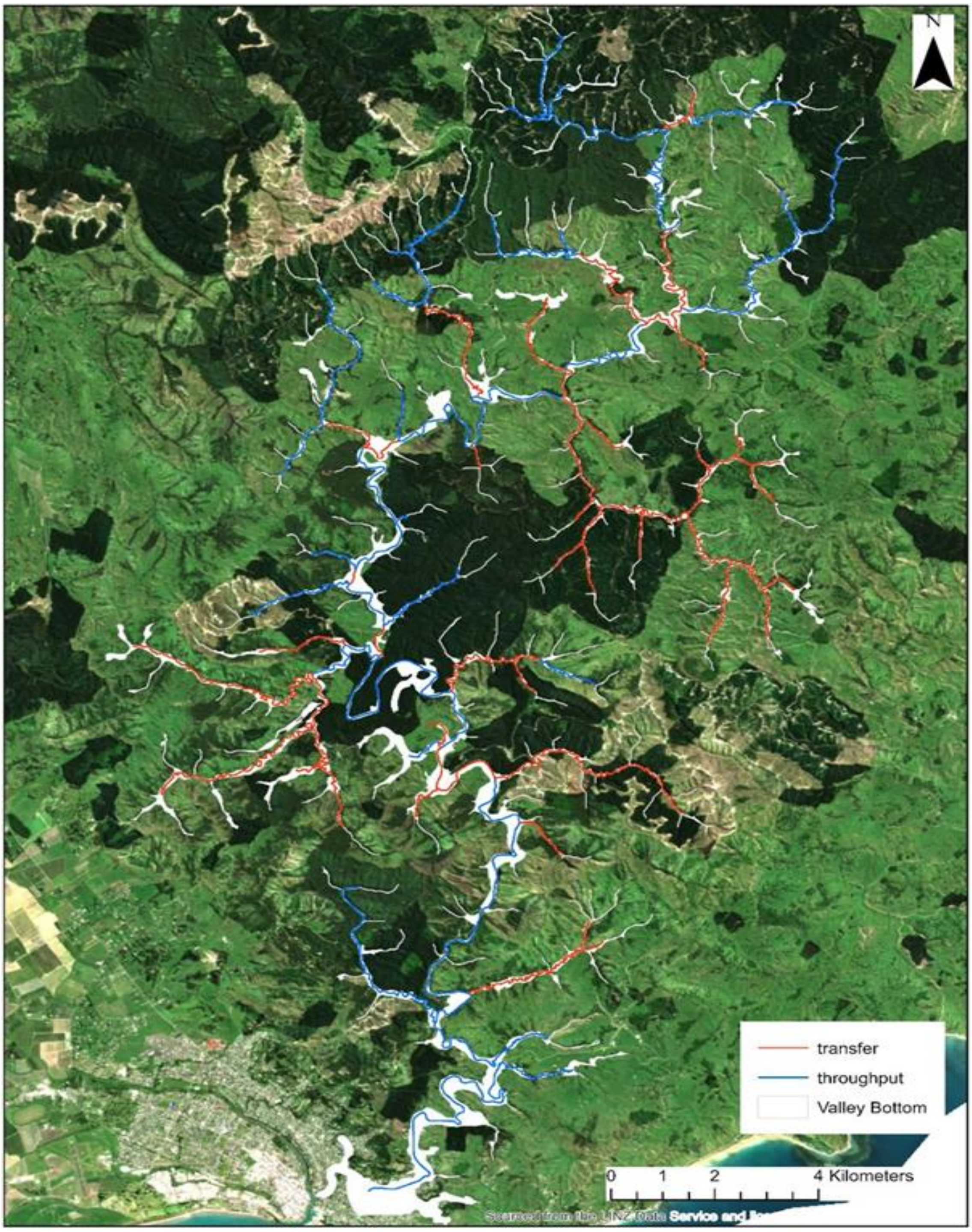


Figure 3. Transfer and throughput zones in the Waimatā Catchment overlayed on a map showing valley confinement.

A case study application of CASCADE further highlights these relationships (Figure 5), showing how a deforested area with high sediment generation can propagate sediment input downstream.

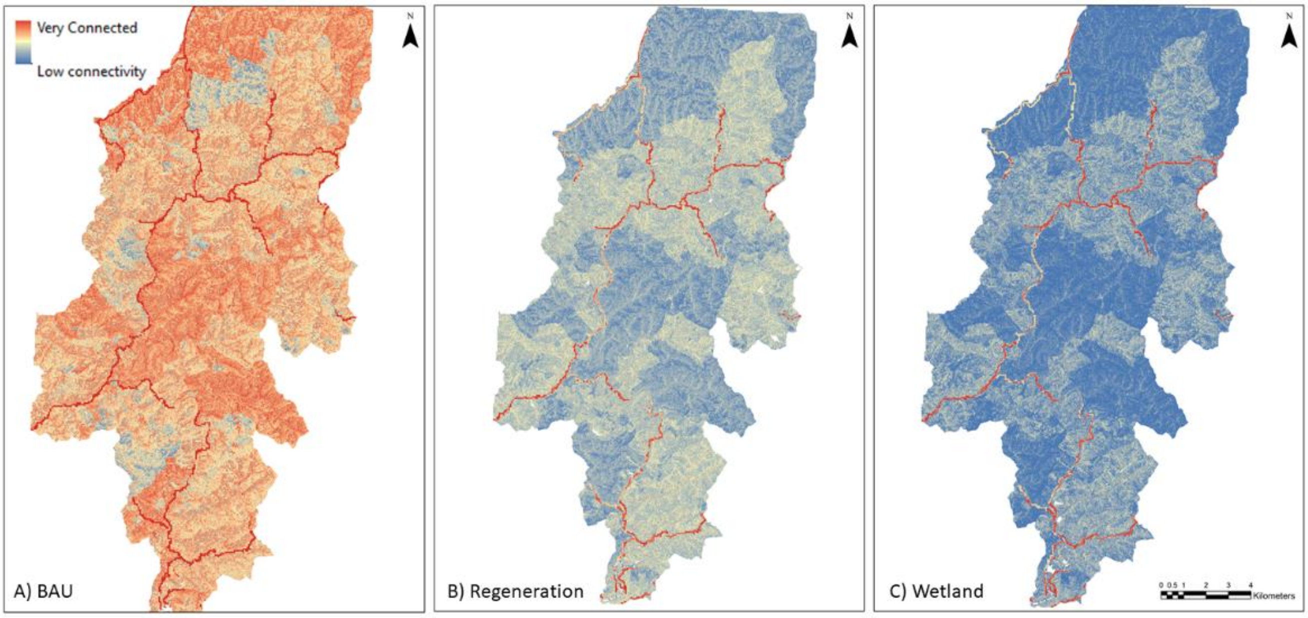


Figure 4. Connectivity indices following land use scenarios outlined in Harvey (2021).

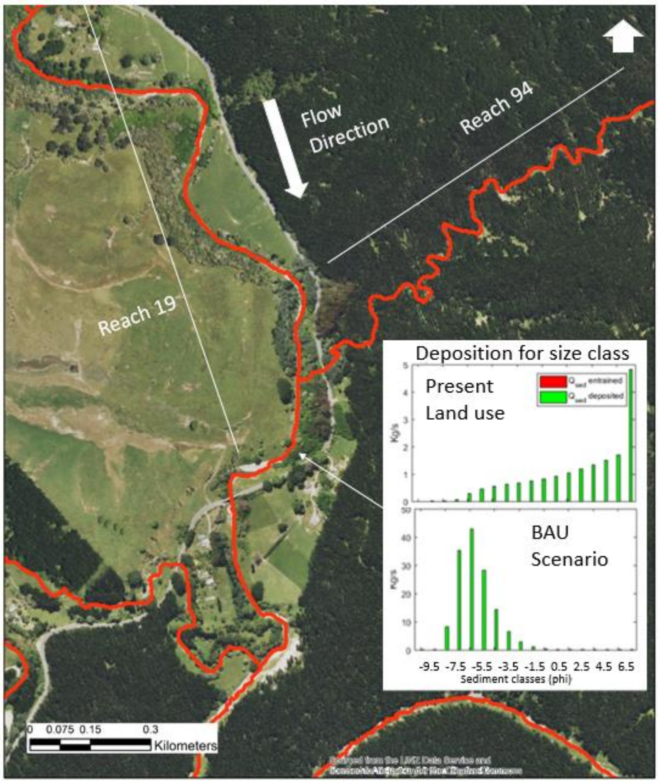


Figure 5. CASCADE Toolbox example, showing the influence of removing forest.

The impact of using wetlands as buffer zones (scenario C) is shown in Figure 6. Placing wetlands in areas with a slope low enough to accumulate sediment, with a highly connected hillslope upstream, reduces connectivity from moderate/low in the regeneration scenario to low/very low in the wetland example. A combination of reforestation and wetland generation provides the most effective method to disconnect sediment supply.

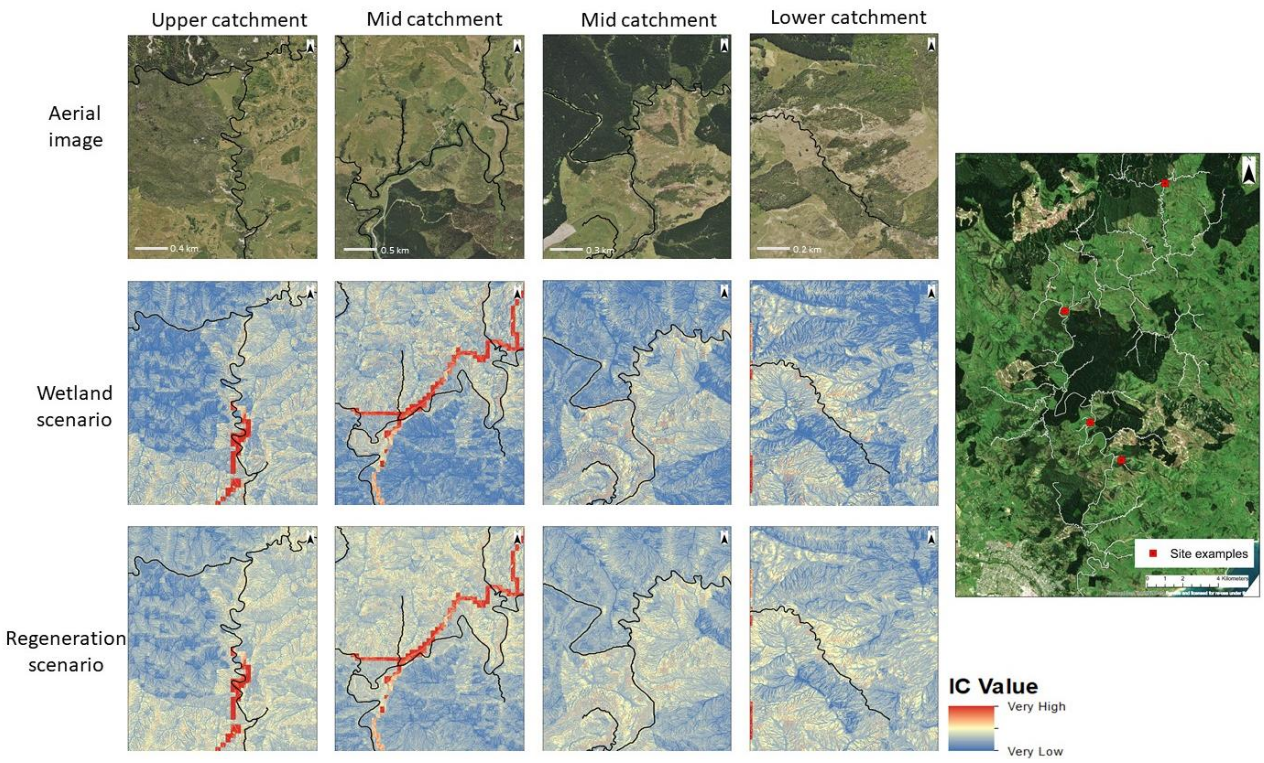


Figure 6. Site examples of wetland generation with locations of where sites were analysed.

Management implications

Modelling analysis of connectivity relationships can support Waimatā Catchment Group to directly relate farm management plans to a coherent catchment action plan. Precautionary and strategic approaches to management of sediment flux link targeted farm management plans within a coherent catchment management plan, carefully tackling issues at source while addressing concerns for off-site impacts (i.e. treatment response). Proactive management in the upper catchment is required to mitigate issues in lower reaches of this highly connected catchment. Critically, geomorphologically informed rehabilitation strategies link catchment-scale connectivity scenarios outlined here with targeted farm management plans that incorporate local knowledge. A farm plan is a tool that is used by landowners to help identify on-farm environmental risks and develop a programme to manage those risks in relation to the goals and aspirations of the landowner and the type of farming operation. Farm plans are structured using several modules including soils, freshwater, nutrient resources, waste management, biodiversity and climate change. The management plan outlines a set of actions that the landowner will undertake if changes are necessary in their farming operation. For example, erosion control measures may be applied to stabilise the land and reduce sediment contamination in nearby waterways. Findings from this study emphasise the importance of such measures in light of the flume like behaviour of the Waimatā River. Differentiation of transfer and throughput reaches provides process-based insight to support management of potential hotspot zones of river change. Increasing vegetation cover and creating buffer zones (wetlands) will promote sediment retention and decrease hillslope-channel coupling. Root stabilisation and increased throughfall interception will decrease connectivity and reduce erosion potential. Farm plans are related to catchment management plans as they include and provide details of resources and environmental risks to freshwater throughout the catchment. In the Waimatā Catchment, concerns for sedimentation are directly tied to management of water quality issues, especially E. coli. Proactive management at sites is sought on the one hand, while concern for collective impacts (scaling-up) is required on the other.

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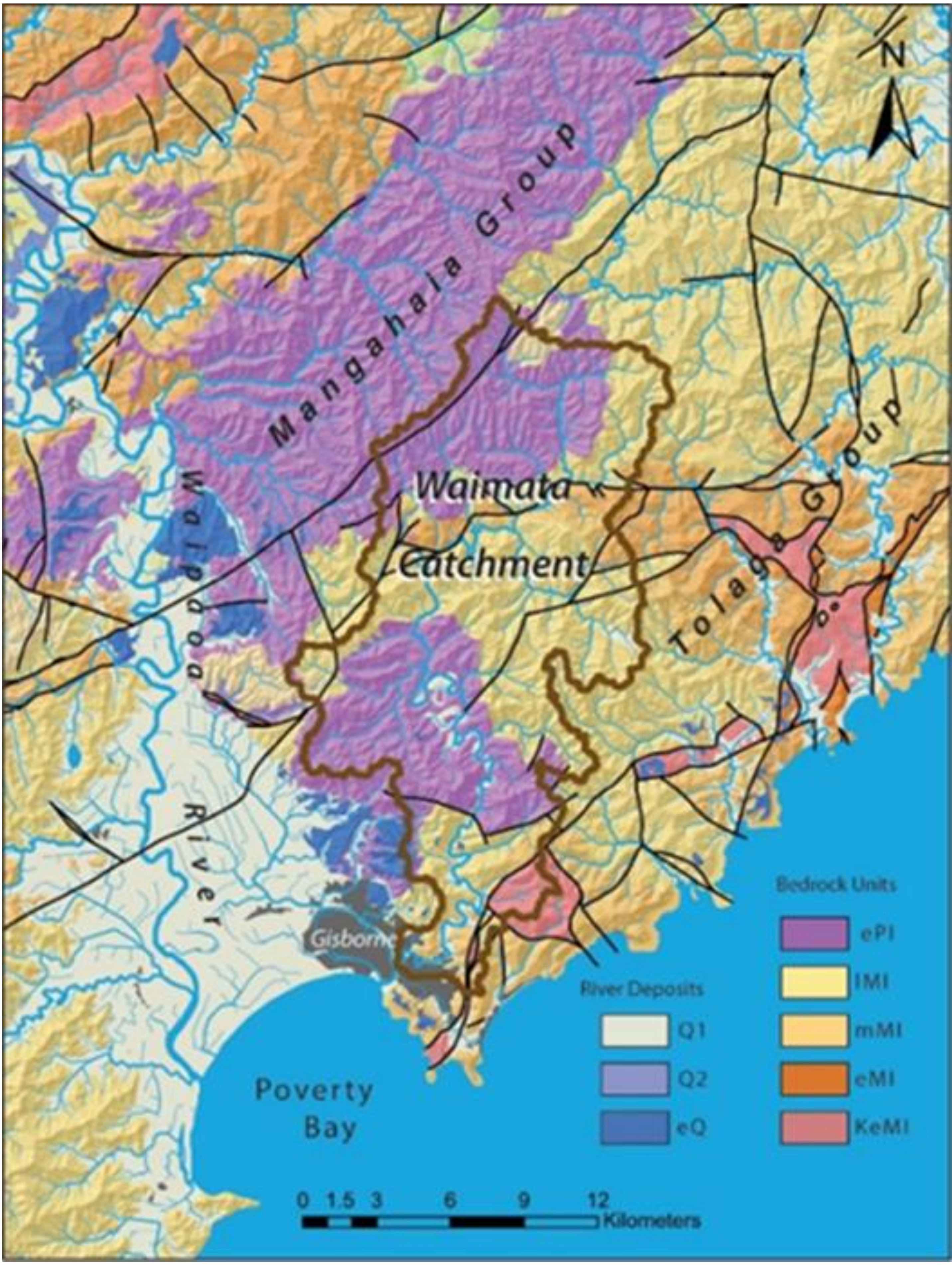
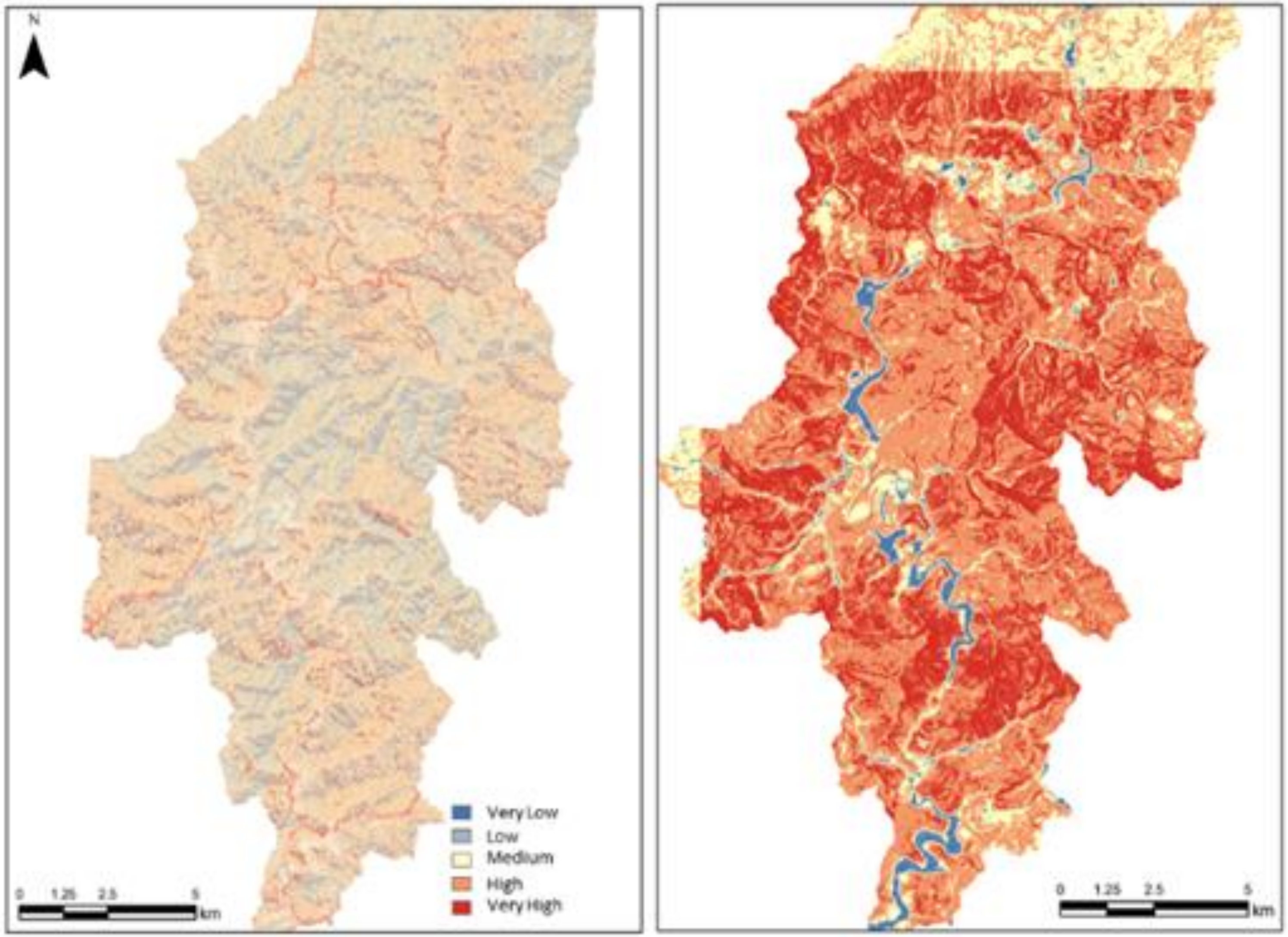

N
Mangahaia Group
Tolaga Group
Waimata
Catchment
Waipaoa
River
Gisborne
Poverty
Bay
Bedrock Units
ePl
lMl
mMl
eMl
KeMl
River Deposits
Q1
Q2
eQ
0 1.5 3 6 9 12
Kilometers



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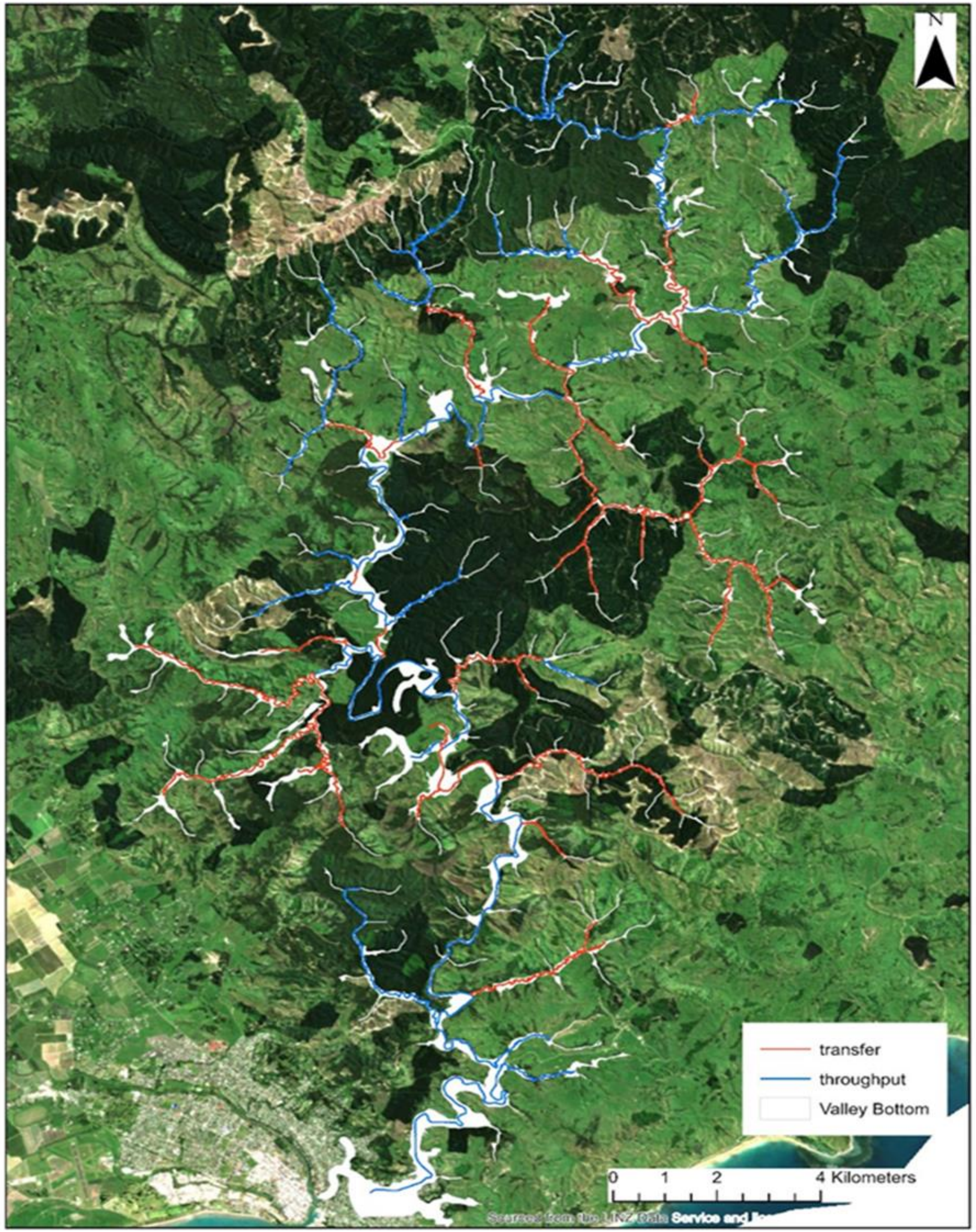
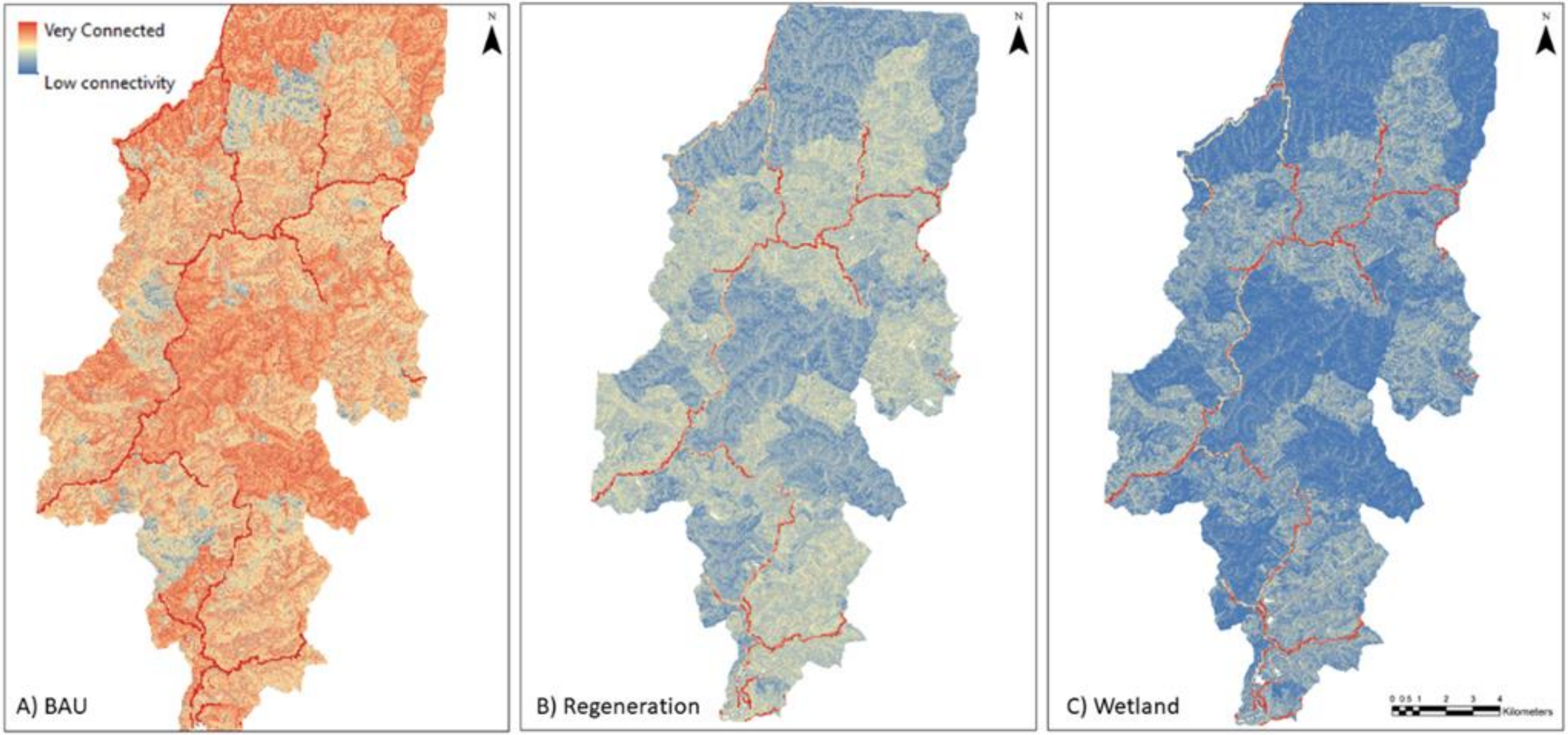
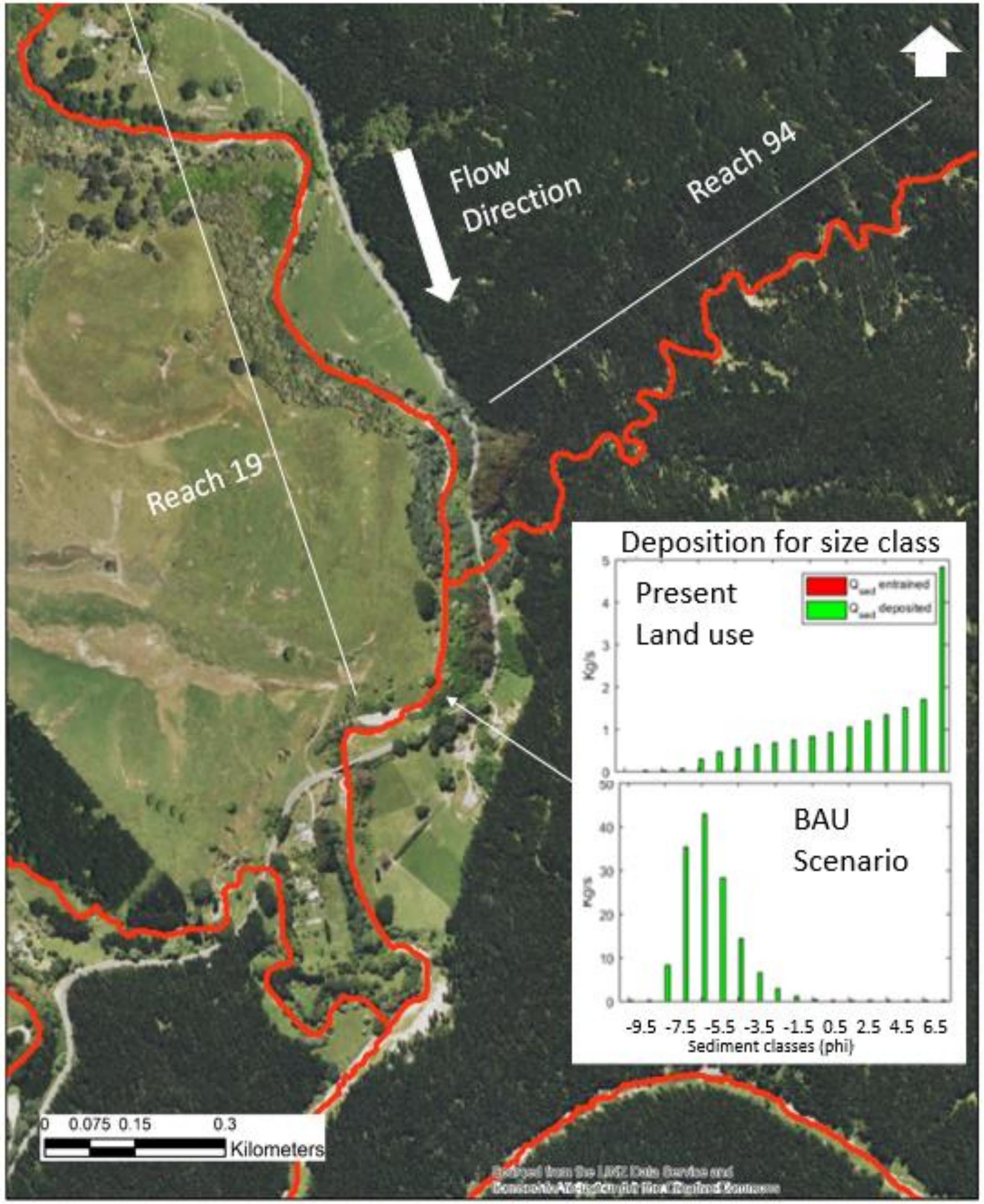
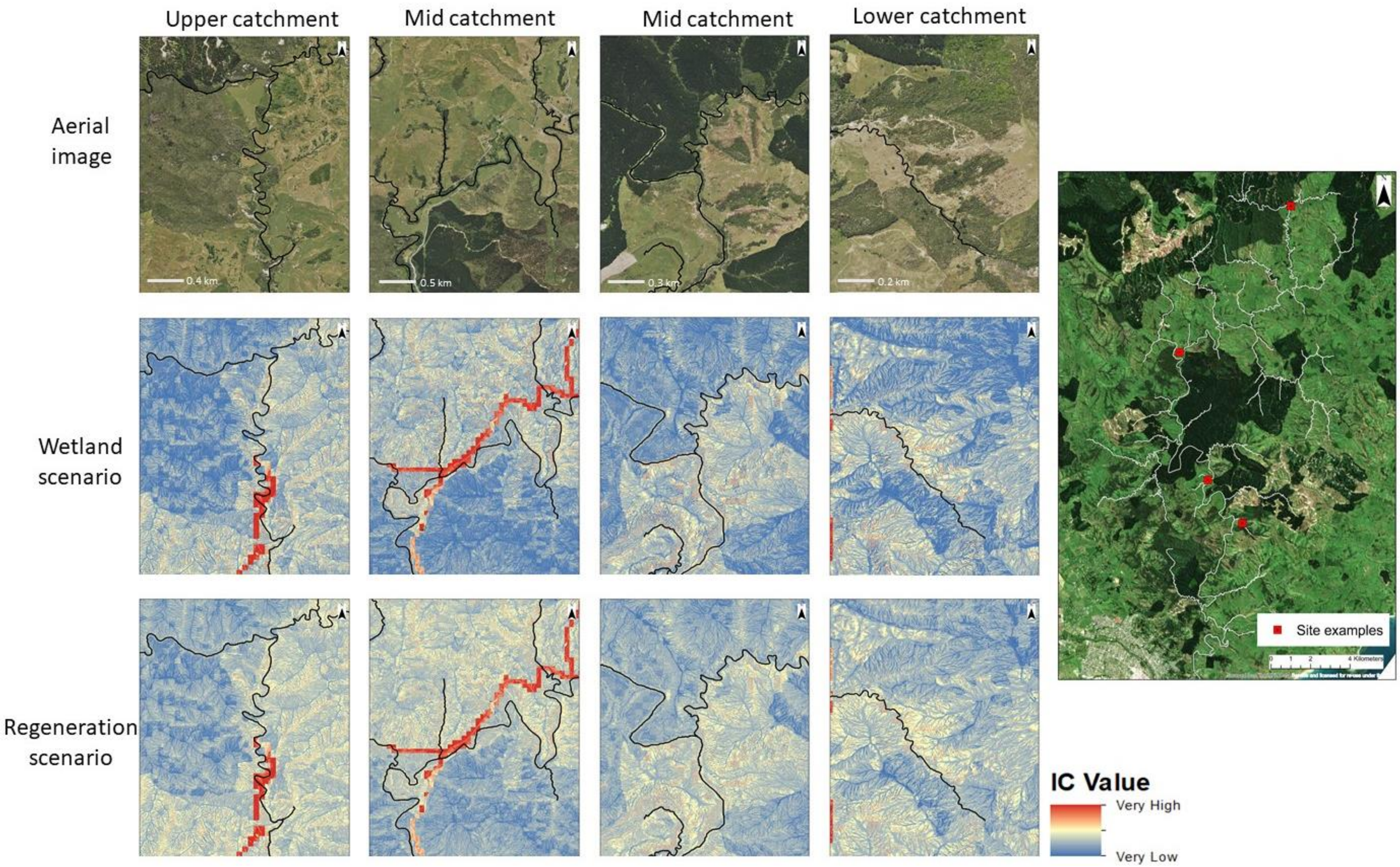

N
transfer
throughput
Valley Bottom
0 1 2 4 Kilometers


Very Connected
Low connectivity
N
A) BAU
N
B) Regeneration
N
C) Wetland
0 0.5 1 2 3 4
Kilometers


Flow Direction
Reach 94
Reach 19
Deposition for size class
Present Land use
BAU Scenario
Kg/s
Sediment classes (phi)
-9.5 -7.5 -5.5 -3.5 -1.5 0.5 2.5 4.5 6.5
0 0.075 0.15 0.3
Kilometers


Upper catchment
Mid catchment
Mid catchment
Lower catchment
Aerial image
Wetland scenario
Regeneration scenario
0.4 km
0.5 km
0.3 km
0.2 km
Site examples
IC Value
Very High
Very Low