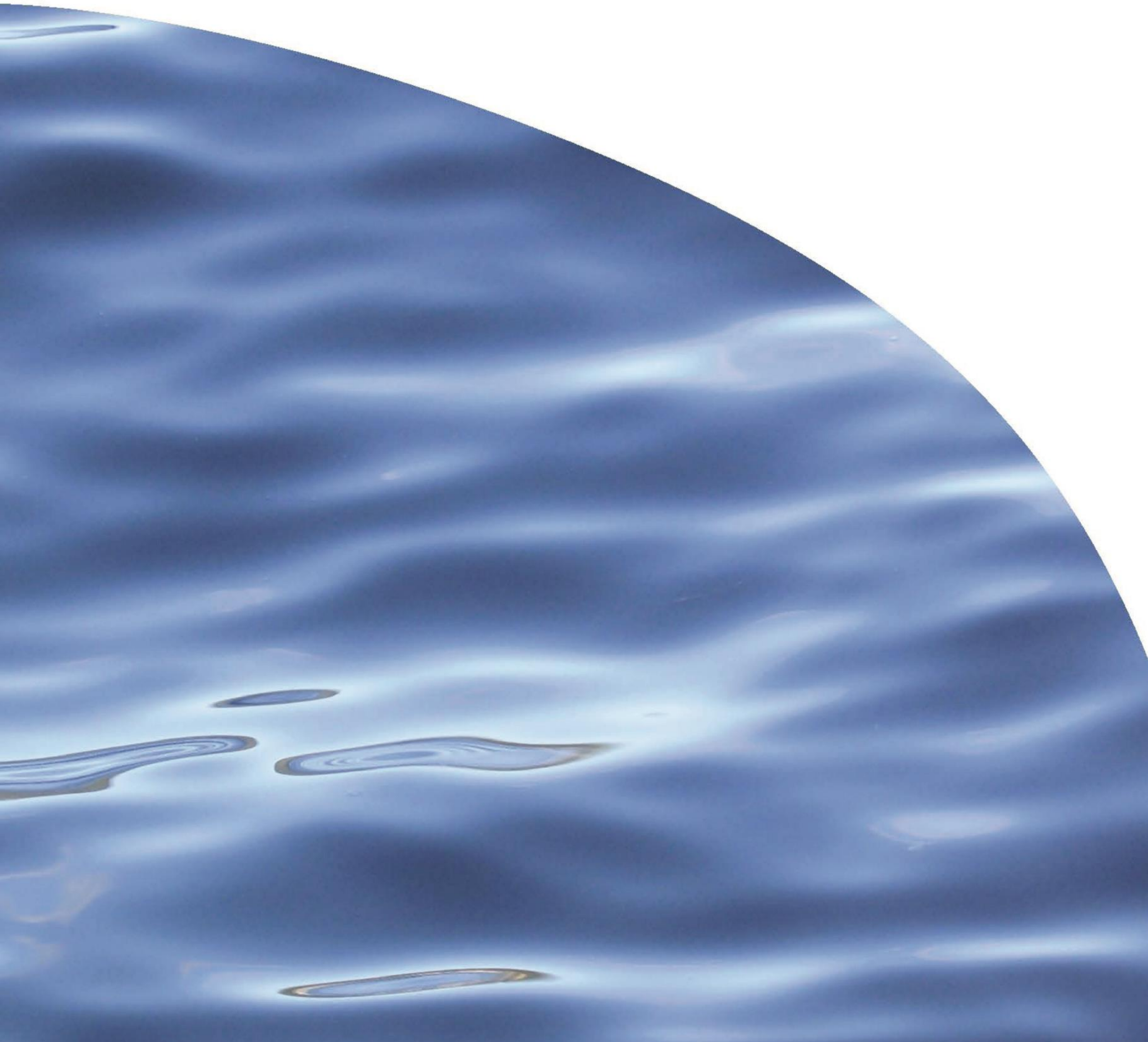
REPORT NO. 3179

# POTENTIAL INDICATORS OF RIVER HABITAT MODIFICATION FOR NATIONAL MONITORING



# POTENTIAL INDICATORS OF RIVER HABITAT MODIFICATION FOR NATIONAL MONITORING

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ISSUE DATE: 24 July 2018

RECOMMENDED CITATION: Holmes R, Fuller I, Death R 2018. Potential river habitat modification indicators for national monitoring. Prepared for Ministry for the Environment. Cawthron Report No. 3179. 24 p. plus appendices.

# EXECUTIVE SUMMARY

New Zealand currently does not monitor and report at a national scale on the environmental pressure represented by physical river habitat modification. This report is the first step towards developing physical River Habitat Modification Indicators (RHMI) that are suitable for national monitoring and reporting.

A workshop was convened on 2 March 2018 with water managers and relevant experts to determine a candidate list of RHMI that are suitable for national monitoring and reporting in New Zealand. We combined the workshop outputs with consideration of monitoring initiatives elsewhere, to recommend the following five indicators that will be suitable for initiating a national monitoring and reporting programme for river habitat modification:

1. riparian vegetation type
2. presence of channel engineering
3. presence of stopbanks
4. river planform measurements
5. presence of potential fish passage barriers.

The riparian vegetation type RHMI can be applied immediately using existing data in the Land Cover Database. The fish passage barrier RHMI could also be applied, to a limited extent across the country, within a relatively short time frame following collation of existing regional council records.

Applying the segment-scale channel engineering, stopbanking and channel planform RHMI will require the development of an aerial imagery processing methodology and an appropriate sampling regime. We suggest using a randomised, representative sampling approach to ensure cost-effective use of monitoring resources when applying the suggested segment-scale RHMI.

To bring New Zealand's river monitoring programme in line with countries like the United Kingdom, United States and Australia, we suggest developing a site-specific habitat modification assessment to complement the existing Rapid Habitat Assessment (RHA) protocol. The RHA is already widely applied at State of Environment river monitoring sites and results can be scaled to inform site, (sub)catchment, regional and national reporting.

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# 1. INTRODUCTION

Physical river habitat is a dynamic template upon which hydraulic and physicochemical regimes define biological communities. Globally, physical river habitats have been extensively modified to enhance navigation, drain land for agriculture and protect people, property and infrastructure from flooding (Poff & Ward 1990; Maddock 1999). Common river habitat modification actions include: removing or manipulating riparian vegetation, stopbanking, channel straightening, bed lowering, bank reinforcing, gravel extraction, bridging, culverting and damming (Maddock 1999). All these actions affect river processes and ecology. River modification often results in a simplified habitat template which, in turn, can reduce biodiversity and the provision of ecosystem services (Schoof 1980; Peipoch 2015; Death et al. 2015).

In developed and populous nations, like the United Kingdom, river habitat modification is so widespread that managers describe natural rivers as a rare phenomenon (Maddock 1999). Yet in New Zealand, owing partly to our relatively short industrialised history, extensive tracts of unmodified rivers exist, particularly within our national parks. Nevertheless, almost all rivers in low-elevation flat-land areas have been modified to some extent to accommodate agriculture—with more intensive channel engineering occurring in our towns and cities (Figure 1).

Figure 1. Two examples of river habitat modification; (left) bed lowering and bank contouring for land drainage and erosion prevention (respectively) in an agricultural catchment, and (right) bed lowering and concrete bank reinforcing to protect urban properties from floods.

National monitoring for various aspects of water quality and quantity are in place within New Zealand as part of State of the Environment (SoE) reporting (MfE 2017). In addition, large research programmes are ongoing within the water quality and quantity domains, for example, NIWA's Sustainable Water Allocation Programme (C01X1004). However, there is currently no national-scale reporting on physical aspects of river habitat modification. The Ministry for Environment (MfE) recognises this as a deficiency within its national reporting programme for river environments.

## 1.1. Project scope

The present report is the first step towards developing physical River Habitat Modification Indicators (RHMI) that are suitable for national monitoring and reporting. An important focus of this project is to identify practical RHMI that can be used to start a habitat modification monitoring programme within the next few years, rather than indicators that could take five or more years to develop and implement. Specifically, in this report we:

1. briefly review river habitat modification monitoring in New Zealand and overseas
2. detail the outcomes of an expert workshop held to determine potential RHMI
3. suggest RHMI that are suitable for national-scale reporting and provide guidance on the initial steps required to apply them.

## 1.2. The importance of scale when monitoring river habitat

Before determining how to measure river habitat modification, it is useful to consider the concept of rivers as a continuum of nested spatiotemporal scales (Figure 2). The nested-scale concept provides a framework for considering how anthropogenic pressures can be matched with RHMI at an appropriate scale. For example, river stopbanking (for flood protection) occurs for kilometres along entire river segments. Therefore, reach-scale measurements of stopbanking will be unsuitable, unless they are undertaken in a manner that is representative of the wider river segment(s). Throughout this report we will refer to the river-scale framework when evaluating potential RHMIs.

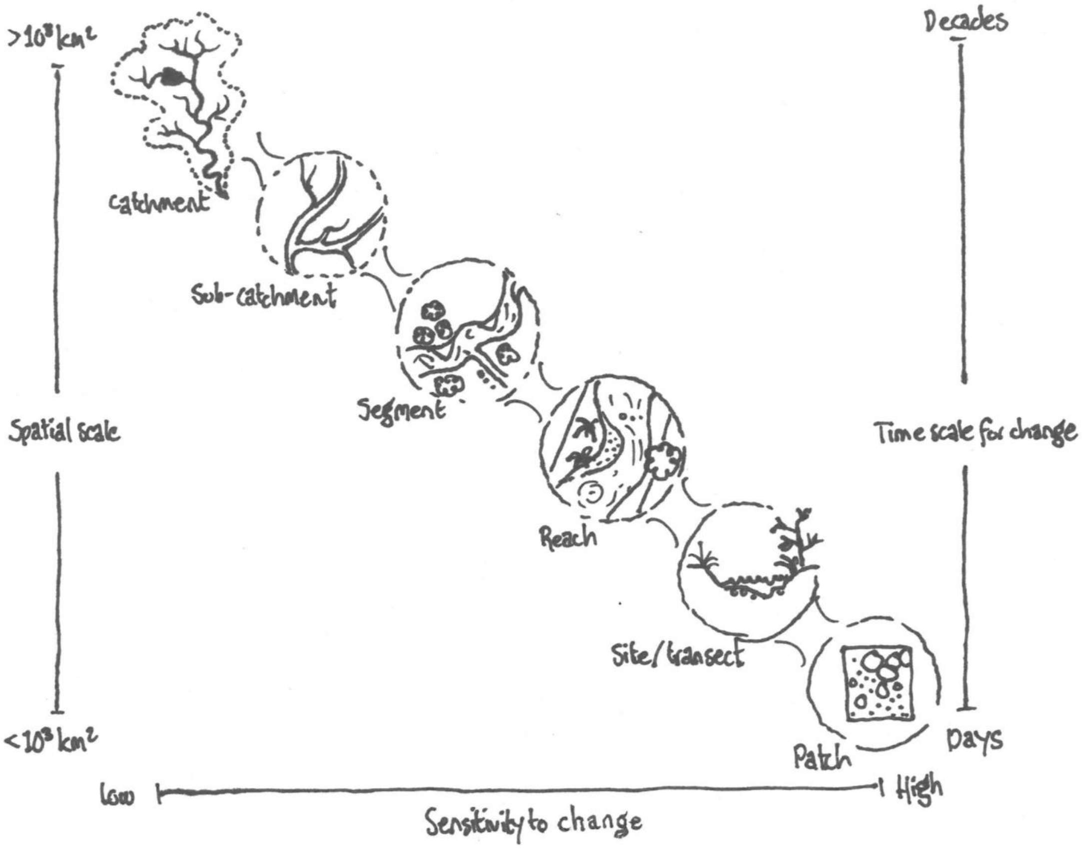


Figure 2. A functional classification of river habitat by spatiotemporal scale, adapted from Maddock (1999).

## 1.3. Physical river habitat monitoring in New Zealand

Below we briefly summarise New Zealand monitoring efforts that are relevant to physical river habitat modification. We focus on monitoring in non-tidal rivers and streams. We have not included water quality, sediment chemistry, or flow-related assessments because determining indicators related to these aspects of river ecosystems is outside the scope of this report. We focus on the physical form of the river because river morphology sets the physical template for which lotic processes operate.

### Patch-scale habitat monitoring

Attributes of streambed patches, such as substrate composition and benthic algal biomass, are measured regularly by water managers using established river bed assessment protocols (e.g. Wolman 1954; Biggs & Kilroy 2000). However, these measurements are generally undertaken at numerous locations within a mesohabitat (usually a riffle or a run), with the results being aggregated to indicate the streambed habitat state at the reach-scale. To date, there have been no attempts to consolidate patch-scale habitat measurements for reporting at the national scale, although run-scale assessments of deposited sediment have been used to develop predictive models (see below).

#### Reach-scale habitat monitoring

All regional councils assess reach scale physical stream habitat quality to some degree. There are a range of protocols used to assess reach-scale physical river habitat condition (e.g. Harding et al. 2009). Some of the more intensive habitat assessment protocols explicitly include river habitat modification components (e.g. Harding et al. 2009; Quinn 2009; Holmes & Hayes 2011). However, these have only been applied on a project basis and therefore existing data are of little use for national scale reporting. The Stream Ecological Evaluation (SEV) protocol also contains habitat modification components, and has been applied more widely by some regional councils (principally in Auckland and trialled in Hawke's Bay and Wellington). However, its application is largely limited to urban streams (Storey et al. 2011).

Recently, a series of projects have been undertaken to develop standardised protocols for assessing physical stream habitat at the reach scale. The Rapid Habitat Assessment (RHA) protocol was an outcome of this process (Clapcott 2015). This protocol focuses on assessing the *state* of instream physical habitat. The RHA deliberately omits any assessment of instream habitat pressures (such as riparian habitat modification) to avoid confusion between cause and effect when assigning an instream habitat quality score to a reach. With the exception of the creation of national deposited fine sediment cover models, which is discussed below, to date, there have been no attempts to consolidate reach-scale physical habitat survey data at the national scale.

Standardised run-scale assessments of deposited fine sediment cover (Clapcott et al. 2011) have been widely applied across New Zealand. These data have been used alongside reach-scale assessment of streambed substrate composition from the Freshwater Fisheries Database to determine fine sediment levels across New Zealand. Deposited fine sediment reference conditions were modelled for all stream segments in the digital river network (River Environment Classification v1; REC) based on environmental variables from the Freshwater Ecosystems of New Zealand database (including land use, climate, geology, morphology and topography as described in Leathwick et al. (2011)). The observed levels of deposited fine sediment cover were then compared to modelled reference conditions. The difference between observed conditions and modelled reference conditions indicates how streambeds have been modified by land use-derived sediment at a national scale (Clapcott et al. 2011).

### Segment-scale habitat monitoring

There are currently no standardised protocols for assessing segment-scale river habitat modification that are used extensively in New Zealand. However, there have been several detailed investigations into the effects of habitat modification on segment-scale river channel morphology. A common theme of these studies is assessing how the diversity and extent of reach-scale habitat features, such as mesohabitats (e.g. runs, riffles and pools), side braids and hydraulically connected off-channel habitat changes in response to management actions. These investigations are based on planform river models constructed from aerial photos (Fuller et al. 2013) or Digital Elevation Models (DEMs) created using ground survey or LiDAR (Light Detection and Ranging, pulsed laser remote sensing) (e.g. Fuller & Basher 2013; Fuller & Death 2018), or more recently, photogrammetry (e.g. Javernick et al. 2015). There is currently no national reporting on segment-scale river habitat condition.

### Sub-catchment and catchment-scale habitat monitoring

The Department of Conservation's (DOC) Waterways of National Importance (WONI) initiative is perhaps the best example of an established catchment-scale national assessment of river habitat quality in New Zealand. The WONI ranks river sub-catchments and catchments based on their natural heritage values. 'Natural heritage' includes both the diversity of geological form (and process) as well as indigenous biota (Chadderton et al. 2004).

The WONI assessment includes a 'pressures' component which rates a catchment or sub-catchment based on the occurrence of seven attributes. These include:

1. percentage natural land cover (in the upstream catchment)
2. urbanisation
3. land use intensity
4. fish passage (downstream)
5. downstream dam effects
6. exotic fish
7. point source pollution.

Data for these attributes have been assembled for river segments across the country using the Land Cover Database, the Freshwater Fish Database and regional council consent databases (Chadderton et al. 2004).

## 1.4. Physical river habitat monitoring overseas

Below we briefly summarise three examples of national-scale monitoring programmes for river habitat modification overseas that could provide useful templates for a New Zealand programme.

### 1.4.1. United Kingdom

Catalysed by the European Union Water Framework Directive 2000, monitoring of river habitat modification has occurred across the United Kingdom (Raven et al. 2000). Habitat modification reporting is based on data gathered using a standardised 500-m stream and river survey protocol. This protocol has been extensively applied using a stratified, randomised design to gather representative data at the national scale from a variety of river types, as well as from 'minimally disturbed' reference sites. The information relevant to habitat modification includes a mix of measurements and subjective assessments on the degree of channel and bank modification, bank profile and riparian vegetation. In addition, the presence of artificial features such as weirs and culverts is also recorded. Survey information is combined into a Habitat Modification Score; these scores are binned into five habitat modification classes from 1 being near pristine to 5 being severely modified. Scores are reported on at the national scale using colour-coded maps and through a range of technical documents and scientific publications (Raven et al. 2000).

### 1.4.2. United States of America

In the United States, the National Rivers and Streams Assessment is a collaborative programme between the Environmental Protection Agency (US EPA) and multiple state entities and Native American tribes. A standardised river habitat assessment protocol, with a focus on river habitat state rather than habitat modification, is applied throughout the country (US EPA 2016). As in the United Kingdom, this protocol is applied using a stratified representative sampling approach. Four components of the assessment protocol measure aspects of river habitat modification. These include streambed excess fine sediments, in-stream fish habitat, riparian vegetation and riparian disturbance. The first three indicators are interpreted based on an observed vs. expected reference condition approach.

The riparian disturbance component of the protocol is the most direct measurement of habitat modification. For this parameter, riparian areas are scored based on the presence (or absence) of 11 types of anthropogenic influence (within 50 m of each river edge). Examples of anthropogenic influence types include: the presence of roads, pavements and cleared lots, buildings, pastures and rangeland, row crops, dams and logging or mining operations. River reaches are given a riparian condition score contingent on a set of rules about the frequency and extent of these human activities along a sample reach.

### 1.4.3. Australia

The AUSRIVAS program includes both water quality and physical river habitat assessment components. The physical habitat component is based on data collected using a nationally standardised protocol that was closely modelled on the US EPA stream habitat assessment method. The program uses an observed vs expected reference condition approach to assess the degree of physical habitat alteration (Parsons et al. 2004). In addition to the AUSRIVAS programme, the Sustainable Rivers Audit is an ecosystem health assessment that is applied to the entire Murray-Darling river system—which drains about a seventh of Australia. Within this programme there is a strong focus on floodplain habitats and vegetation. In the most recent application of the Sustainable Rivers Audit, extensive LiDAR surveys were used to determine the quality of riparian vegetation and extent of floodplain wetland areas. The area of land adjacent to rivers that is inundated during a rain event with a 100-year return period was used to delineate floodplain area (MDBA 2012).

# 2. RIVER HABITAT MODIFICATION INDICATORS WORKSHOP

On 2 March 2018 a one-day workshop was convened with water managers and relevant experts at Environment House, Ministry for the Environment, Wellington, to determine a candidate list of RHMI that are suitable for national monitoring in New Zealand. The specific goals of the workshop were to:

1. determine a list of data criteria to assess the suitability of RHMI for national monitoring and reporting
2. determine a 'long list' of potential RHMI
3. assess the long list of potential RHMI against the agreed data criteria to determine a short list of the most suitable indicators.

The workshop built on knowledge generated at the large-river habitat assessment workshop that was held two years previously by DOC in conjunction with Massey University's Innovative River Solutions group. Many of the attendees at the MfE-hosted habitat modification indicators workshop also attended the previous DOC-led workshop (including the authors of this report). The breadth of expertise present at the workshop included spatial database management, statistics, instream ecology, fluvial geomorphology, floodplain ecology and waterbody management for Maori values. The workshop agenda and list of attendees are provided in Appendix 1. After presentations from each workshop attendee, a 'strawman' proposed set of data criteria was put forward to the group. This was critiqued to create the list shown in Appendix 2. The remainder of the workshop focused on harvesting the knowledge present in the room to create a 'long list' of potential RHMI, this is shown in Appendix 3.

There was not enough time during the workshop to assess the proposed indicators against all the data criteria (workshop goal 3). This was done after the workshop by the lead author of this report. To allow the systematic assessment of each individual potential RHMI, an Excel spreadsheet matrix was created with data criteria listed along the top and the potential RHMI listed vertically. The matrix was then populated by assigning each RHMI a 'yes or no' or a 'low, moderate or high' subjective rating for each column. After undertaking this process, we assigned numerical values to each RHMI rating (i.e. a 1 for a yes, 0 for a no and a 1, 0.5 or 0 for a high, moderate and low rating, respectively). Scores for each RHMI (row) were then summed and normalised to a 0-1 scale before ranking in numerical order. We used the ranked list, as well as our own professional opinion and knowledge shared during the workshop, to determine six RHMI that would be suitable for national monitoring. The completed matrix and the suggested 'top six' RHMI were then emailed to all the workshop attendees. They were asked for their opinion on how the matrix had been populated. They were also asked to supply their own preferred short list of RHMI. Among those that responded, there was general agreement on five RHMI discussed below (Appendix 4).

## 2.1. Five habitat modification indicators suitable for national reporting

For each of the RHMI below, we briefly introduce what the RHMI measures and then detail its data requirements. We have determined the data requirements based on our opinion of the most parsimonious reporting metric available. Where appropriate, we note if workshop attendees have suggested that a RHMI would be best represented by multiple component metrics.

### *2.1.1. Riparian vegetation type*

Typically, the vegetation in floodplains and riparian areas is the first aspect of a river to be modified when a catchment is developed. Riparian vegetation has a direct influence on fundamental aspects of river health, including food web dynamics and physicochemical water conditions (Gregory et al. 1991). Riparian areas are periodically flooded during high flow events. During these periods the riparian area, and the vegetation within it, essentially become part of a river, where effective channel-floodplain connectivity is permitted, which serves an important function contributing to biophysical flux. Furthermore, riparian vegetation is also an important architect of river channel form. For example, riparian trees supply large wood to a river which creates mesohabitat diversity. In addition, the composition of riparian vegetation strongly influences bank erosion processes (Broadmeadow & Nisbet 2004), depending upon bank structure.

#### Obtaining and reporting data

Two options were discussed at the workshop for monitoring riparian vegetation type: 1) use existing national spatial database information and 2) assess georeferenced aerial imagery using spatial mapping software (e.g. GIS).

At the sub-catchment level, existing Land Cover Database layers could be used to determine vegetation type in land parcels adjacent to river reaches. However, it must be acknowledged that the most recent version of the Land Cover Database was compiled using imagery from 2012. In some waterway segments, the vegetation type over an area will have changed substantially since then. Because any non-native vegetation in the riparian area represents a modified river ecosystem, the initial ‘current state’ assessment would be of interest to determine the relative amount of unmodified riparian area across New Zealand. In addition to the Land Cover Database, the Freshwater Ecosystems of New Zealand (FENZ) database has a layer that predicts segment-scale riparian shading (percent). Although, this *SegShade* layer is calculated from Land Cover Database v1.0, the algorithm could be modified and applied to the most recent land cover data available to determine the presence of relatively mature riparian vegetation. The base data are assembled and ready to apply, meaning a version of this RHMI could be applied next financial year.

Cataloguing riparian vegetation features using aerial imagery and spatial mapping software will provide more reliable and detailed information than interrogating the Land Cover Database. This is because aerial imagery will be up to date and of higher resolution, which will allow the assessment of reach-scale features. Aerial imagery assessments should be targeted at the river segment scale (i.e. at least 1-kilometre river lengths) and should be applied using a representative sampling approach (see Section 3.2 for some discussion on potential sampling regimes). Coarse vegetation categories that can be clearly identified on aerial imagery could be used to inventory the degree of riparian vegetation modification. For example, separate categories for pasture, mature native trees, willows and exotic trees may be suitable (see Holmes et al. (2013) for methodology to create GIS-based riparian habitat information from orthorectified aerial imagery). The Land Information New Zealand (LINZ) data service maintains recent orthorectified areal photographs for about 95% of the country. Aerial imagery coupled with image recognition software may be a feasible approach to mapping some vegetation categories (Yang 2007), although a substantial feasibility project would be required before this approach could be applied. In the short term, anybody with spatial mapping software experience will be able to annotate coarse-scale vegetation features on georeferenced areal imagery with minimal training. Once annotated with GIS, the spatial extent of different riparian vegetation features could be used to report on the degree of riparian vegetation modification.

Ideally, the ‘functional width’ of a riparian area would be defined before assessing riparian features. Defining the width of a riparian area allows the extent of any habitat modification to be put into context, for example, as a percentage of the total riparian area. However, functional riparian width is notoriously difficult to determine because it depends on multiple variables including flow regimes, geology, local topography and vegetation (Gregory et al. 1991; Clinton et al. 2009). Ilhardt et al. (2000) capture the challenge of determining riparian areas in their definition:

> Riparian areas are three-dimensional ecotones of interaction that include terrestrial and aquatic ecosystems, that extend down into the groundwater, up above the canopy, outward across the floodplain, up the near-slopes that drain to the water, laterally into the terrestrial ecosystem, and along the water course at a variable width.

The Murray-Darling Basin Authority used LiDAR-derived DEMs to define the extent of floodplain / riparian areas for inclusion in a vegetation mapping survey. The ‘Near riparian area’ and ‘floodplain’ survey sample frames were defined as the area within 50 m of bank-full and areas that would be inundated during a 1 in 100-year flow event, respectively (MDBA 2012). However, defining riparian areas at a national scale using LiDAR-derived DEMs may be prohibitively expensive in New Zealand. An alternative pragmatic approach would be to determine a set of generic rules to ascribe nominal riparian areas (or widths) which define where information is collected. For example, 60-m riparian widths on each bank for rivers > 6 m wide (at base flow) and 30 m widths for rivers < 6 m wide. Alternatively, or in addition, cut-off points for nominal widths could be based on flow statistics, such as the coefficient of the flow variation (flow-CV), which indicates the frequency that a river inundates its riparian area. These data can be extracted from the REC database.

### 2.1.2. Channel engineering

Directly modifying rivers by armouring banks (e.g. with rock riprap) and installing bank protection structures (such as rock or cable groynes) are obvious examples of river habitat modifications that exert constraints on channel shape, size and diversity, as well as limiting channel-floodplain connectivity. These actions alter the channel at the sites where they are installed and affect channel morphology within the wider river segment by changing the way the river interacts with its boundary, simplifying channel form and reducing habitat diversity at reach and segment scales. These interventions alter erosion and sediment transport dynamics in the channel corridor (Surian & Rinaldi 2003; Fuller & Basher 2013; Massey & Biron 2016).

#### Obtaining and reporting data

During the workshop, two processes were identified for obtaining data regarding the location and extent of channel engineering works—through regional council work permits and by analysing aerial imagery. All regional councils have records of work permits issued for undertaking bank protection measures. Collating these data at the national level is likely to be a substantial task but would enable the development of a national channel engineering spatial database layer. In areas where work permit data may be incomplete, the locations of channel engineering works could be obtained by scrutinising aerial imagery and recording their presence (or absence) using spatial mapping software (at least in areas where vegetative cover is minimal). Both methods of data collation would ideally work together.

Once channel engineering location data are collated, they could be reported on simply as the number and / or length, and type of bank protection structures per kilometre of stream. Over time, more sophisticated indices should be developed that indicate the degree of modification by accounting for the intensity of channel alterations. For example, banks armoured with inter-planted rock riprap could be rated less modified (i.e. more accommodating of diversity in form and function) than banks armoured with concrete.

### 2.1.3. Stopbanks (permitted flood plain)

The extent of a river's floodplain is often constrained by stopbanks to protect farmland or dwellings from inundation. Stopbanks are large earth mounds that run parallel with a river and contain it during a flood or a 'specific design flow'; for example, a river flow with a 100-year return period (annual recurrence interval, ARI, or a 1% average exceedance probability, AEP). In addition to stopbanks, flood gates are also used to prevent land from being inundated. Stopbanks, when placed close to the channel, modify river morphology by effectively constraining the channel so that it adopts a more single-thread form with reduced lateral activity to protect the integrity of the stopbank (Figure 3). In addition, overly-confining a river during large floods modifies sediment transport and erosion dynamics during major channel forming events. This leads to further changes to low-flow channel morphology (Fuller, 2007, 2008; Fuller & Basher 2013; Fuller et al. 2013).


Figure 3 The Waimea River (Tasman District) before (upper, 1947) and after (lower, 1973) stopbanks were instated showing the simplification of channel form after flood protection infrastructure.

**Obtaining and reporting data**

The workshop attendees identified that stopbanking data could be collected in the same manner as channel engineering data (i.e. collating regional council work permit records and / or through scrutinising aerial photographs). Indeed, channel engineering often proceeds in conjunction with stopbank works as engineers seek to maintain the integrity of flood protection infrastructure. Once collated, a simple way of reporting these data is by the length of river affected. Displaying these data spatially on maps would be an appropriate method of reporting.

Although still useful for national scale reporting, cataloguing stopbanks simply by their presence or absence would omit a lot of information on the *degree* of pressure they place on river ecosystems. Stopbanks affect floodplain connectivity to varying degrees, depending on how close they are to the low-flow channel and by how high they are. In addition, a river's flow regime influences how often a river will connect with its floodplain under natural conditions and, therefore, the degree of potential impact that stopbanks can have (Fuller et al. 2013). For example, spring-fed rivers (by definition) have simple U-shaped channels and stable flow regimes. Stopbanks will have a relatively minor effect on these rivers when compared to naturally wandering or braided rivers that have highly variable flows and frequent and dynamic interactions with their floodplains (when left unconstrained).

Determining the extent of information required to inform an accurate floodplain modification or connectivity index could be a focus for further work. A permitted flood plain *vs.* natural flood plain index should be achievable at a national scale based on aerial imagery. For example, the area and / or width of the permitted or active floodplain (that between the stopbanks) can be reported with reference to the natural floodplain at a segment scale. LiDAR-derived DEMs of valley floors provide an excellent resource for this purpose. Fuller & Death (2014, 2018) have used this metric as part of habitat quality index (HQI) assessments.

### *2.1.4. Channel planform*

Various human actions within a catchment such as forest clearance, land use, flow modification, and channel engineering combine to alter river channel form (Grabowski et al. 2014). There are well-established systems for defining river channel type and for tracking channel form changes in response to management (e.g. Brierley & Fryirs (2005) 'River Styles'). These systems rely heavily on categorising planform river channel measurements (i.e. channel morphology as viewed from above), and recent work provides a scheme of channel nomenclature based on valley-floor confinement, planform, and sediment type (Fryirs & Brierley in review) to classify river type at a reach / segment scale. Channel cross-sectional information is also a key component for assessing channel morphology. However, collecting channel cross-sectional data at a national scale is likely to be prohibitively expensive because it requires intensive instream field measurements, although regional councils generally routinely measure channel cross-sections on a c. 5-year rotation at a small subset of rivers. In principle these data would be available at a national level for all managed rivers, but the volume of data would be significant. For this report, we focus on planform measurements because these have realistic data requirements for developing national scale RHMI. In the longer term we recommend incorporation of cross-section data, which could be trialled within a region in the first place.

### Obtaining and reporting data

The key river planform measures suggested through the workshopping process included sinuosity, channel type, degree of braiding and wetted, or active channel area (within a standardised flow range). All these measurements can be determined using georeferenced aerial imagery and spatial mapping software (Fuller et al. 2014, 2018). Death et al. (in review) report a habitat quality index (HQI) as a meaningful protocol to determine change in habitat condition over time, in relation to a reference condition. Repeat measurements of the same parameters at reach and segment scales will permit tracking of change in habitat condition over time. River channel type is best defined using the protocol described by Fryirs and Brierley (in review). Sinuosity is measured as a ratio between channel length over straight line valley length between two points (e.g. start and end of a reach or segment). A braiding index is calculated by measuring the total length of mid-channel bars in a reach / segment, multiplying by two and dividing by length of reach / segment in which the bars occur. These metrics are described in most river morphology textbooks (e.g. Fryirs & Brierley 2013).

An observed (current state) vs. reference condition approach needs to be taken to frame river planform channel measurements as indicators of habitat modification. The reference planform state of a river can be:

1. benchmarked empirically though analysis of historical aerial photographs (Fuller et al. 2014)
2. modelled based on catchment characteristics (i.e. geology, catchment area, precipitation and slope)
3. compared to minimally disturbed reference catchments that have similar catchment-scale conditions.

Historic aerial photographs will provide the most robust benchmarking method. We suggest that, initially, planform channel measurements should be applied within the spatial extent of historic aerial photographs taken over the period c. 1940 to the present (Fuller et al. 2014; Fuller & Death 2018; Death et al. in review). Archive aerial photographs are held by regional councils and becoming increasingly available via http://retrolens.nz/map/, which provides an historical imagery resource derived from records of the organisations that make up the Local Government Geospatial Alliance (LGGA) and is made available under the Local Government Official Information and Meetings Act 1987. However, to our knowledge, historical aerial imagery has not been compiled into datasets suitable for analysis with spatial mapping software at a national level. Therefore, collation of these data will be required before this approach is feasible.

The channel form of many rivers will have been modified from catchment development undertaken prior to the 1940s. Nevertheless, referencing current-day planform channel measurements to this period will still provide a useful comparison to 'minimally or moderately disturbed' conditions and will be useful for determining the trajectory of river channel evolution at various sites (see Fuller et al. 2014).

#### *2.1.5. Fish passage barriers*

Modifying rivers by installing dams, pipes, culverts, weirs and other structures can impede or prevent fish passage (Franklin et al. 2018). These structures are in place, even in headwater areas of catchments, mainly for roading infrastructure (e.g. to facilitate forestry access). Currently, some regional councils are inventorying fish passage barriers (programmes exist in the Hawke's Bay, Tasman and Wellington regions). However, assessing fish passage obstruction is problematic because many barriers present a challenge to migration only during certain flows. For example, fish may easily surmount an obstacle during high flows but not during low flows. Furthermore, some catchments, or areas within catchments, may naturally lack fish species that require passage over an obstacle (McDowall 2010). In addition, because fish diversity is strongly linked with elevation and distance from the coast (Jowett & Richardson 1996), fish passage barriers near the coast have a disproportionally large effect on fish community structure when compared to barriers in headwater streams. An Envirolink Tools project (C01X1609) is currently underway to determine a standardised protocol for assessing the degree of fish passage challenge presented by an instream barrier.

**Obtaining and reporting data**

Given the difficulties with determining the *degree* of barrier that a potential fish passage obstacle presents, we suggest that the presence or absence of any structure that could be a fish passage barrier is the most robust and appropriate RHMI for national scale reporting. Data for large dams have already been compiled as a layer in the LINZ spatial database (see: layer dam_cl.). However, locating smaller structures would require compiling regional council records. These data exist for some regions but further data collection would be required to complete a national-scale database. Reporting could be based on the number of potential fish passage barriers per kilometre within river sub-catchments or within catchments. Because data on fish passage barriers are limited in extent, reporting on the areas that lack any information of fish passage barriers will be necessary.

### *2.1.6. Other outcomes of the workshop*

In addition to the outputs discussed above, the workshopping process generated some interesting discussion points that should be considered before developing a RHMI programme.

#### Pressure-state-impact indicators

New Zealand's environmental reporting is based on a pressure-state-impact framework. This framework is a subset of the more commonly used 'drivers-pressure-state-impact-response' framework. Pressures include the natural or human influences on the environment that can explain changes in the state of an environment. The state of the environment covers the physical, chemical, and biological characteristics of the environment and how these characteristics are changing. Impacts are the ecological, economic, social, and cultural consequences of changes in the state of the environment (MfE 2014).

The issue of whether a RHMI is a measure of a pressure, state or impact was discussed in the workshop. The distinction can be confusing because it depends on what aspect of river ecology is being considered. For example, macrophytes can fit into all three pressure-state-impact categories. They can be an impact because their abundance is affected by increased light or nutrients from land use, a state of the instream environment, or a pressure on instream ecology if they reach nuisance levels. In addition, if the floodplain, riparian zone and instream area are all considered to be inseparable parts of ‘a river’, by viewing a catchment as a single riverscape, this makes it hard to assign indicators into pressure or state boxes. Despite the difficulties with defining a potential RHMI within the pressure-state-impact framework, as long as the indicator in question is a measure of a pressure *or* a state then it will potentially be suitable. This is because a state measure can be made into a pressure indicator if it is defined by the degree of deviation from pristine reference conditions (i.e. using an observed vs. expected reference condition approach).

#### Values-based habitat modification indicators

Another key issue that emerged from the workshop was that indicators could be selected using a values-based framework, rather than a set of data criteria that essentially relate to the practicality of application at a national scale. After assessing each individual indicator on the ‘long list’ (Appendix 3), it became apparent that all the suggested RHMI measure aspects of rivers which are linked to multiple values and ecosystem services. This is perhaps unsurprising because they are all measures of river structure—the habitat template upon which all aspects of river processes and ecology play out.

Generally, river structures and processes occurring at larger scales affect a more diverse range of values (Maddock 1999). Therefore, picking RHMI that measure processes at the river-segment-scale (or greater) will ensure that the river feature being monitored is linked to a broad range of instream values. For example, nested within the processes that shape the sinuosity of a river will be processes that affect biodiversity, mahinga kai, aesthetics and much more. So, measuring sinuosity will provide some information about all of these values, whereas, measuring residual pool depth (which is affected by sinuosity) will only provide information on a subset of the values that are linked to sinuosity. In part, this line of reasoning is the justification for why most of our suggested RHMI are applied at the segment-scale. The trade-off is that finer-scale indicators are likely to provide more reliable and detailed information about the values that they are linked with.

# 3. SUMMARY AND RECOMMENDATIONS

New Zealand currently lacks a river habitat modification monitoring programme. By contrast, river modification is monitored in the United States, the United Kingdom and Australia at a national scale. By workshopping expert opinion and considering monitoring initiatives elsewhere, we recommend that the following five RHMI are suitable for national monitoring and reporting:

1. riparian vegetation type
2. presence of channel engineering
3. presence of stopbanks
4. river planform measurements
5. presence of potential fish passage barriers.

The riparian vegetation type RHMI can be applied immediately using existing spatial databases. The fish passage barrier RHMI could also be applied, to a limited extent across the country, within a relatively short time frame following collation of existing regional council records (Table 1). The fish passage pressure attribute in the WONI database will provide a useful starting point for assembling these data.

Applying the channel engineering, stopbanking and channel planform RHMI will require processing a substantial amount of aerial imagery within spatial mapping software (e.g. GIS) (Table 1). However, all of these RHMI, including a more detailed analysis of riparian vegetation types, could be done using the same set of orthorectified aerial imagery (at the same time). Nevertheless, before any imagery can be analysed, a data processing methodology and an appropriate sampling regime needs to be developed.

Table 1. Suggested river habitat modification indicators for national monitoring and the indicative time scale for their potential application.

| **Habitat modification indicator** | **Timescale for application and required steps** |
|---|---|
| Riparian vegetation type | Immediately using existing spatial databases. |
| Presence of channel engineering | Within the next five years, following the development of data processing methodology and collation of existing council records. |
| Presence of stopbanks | Within the next five years, following the development of data processing methodology, collation of existing council records and analysis of aerial imagery. |
| River planform measurements | Within the next five years, following the development of data processing methodology, collation of historic and contemporary aerial imagery and analysis. |
| Presence of potential fish passage barriers | Within the next five years following collation of existing council records and analysis of aerial imagery. Application will be limited in its spatial extent. |

Once these five indicators are developed and applied, the results could be interpreted using a multimetric index approach; for example, by assigning relative-to-reference condition scores to each attribute and combining the scores by weighted averaging. This is analogous to the approach taken by Raven (2000). However, at present the framework for such an index cannot be defined until the assumptions of the various components are detailed and the scale at which they are applied is determined.

## 3.1. Habitat modification monitoring sample regime

We suggest developing a randomised, representative sampling approach to ensure cost-effective use of monitoring resources when applying the suggested segment-scale RHMI (Raven et al. 1998). The design of the sample frame should account for location (where data are feasible to collect), the river type and catchment land use. For example, a river planform monitoring programme will first need to determine where baseline historic aerial photographs have been taken. The Land Cover Database and FENZ could be used to stratify sample sites by habitat pressures (such as % urban land cover), as well as river attributes such as flow-CV and predicted wetted width, which could be used to determine river type. Furthermore, the sample frame should have substantial overlap with existing SoE monitoring sites. This would future-proof the monitoring programme for incorporating reach-scale habitat measures that are undertaken as part of routine regional council monitoring (such as deposited fine sediment cover assessments). In addition, in time, some overlap between RHMI sites and the SoE monitoring sites will enable the links between river habitat modification (pressures) and instream state to be investigated.

## 3.2. Developing a (rapid) river habitat modification assessment protocol

Regional council field staff collect reach-scale instream habitat data at SoE river monitoring sites using the RHA. We suggest developing a habitat modification assessment component to add to the existing RHA protocol. This would bring New Zealand in line with river monitoring programmes in the United States, United Kingdom and Australia where river habitat monitoring is a well-established part of national reporting.

The main constraint for applying a river habitat modification protocol in New Zealand would be the time it takes council field staff to carry out the monitoring. During the creation of the RHA, the feedback from field staff was that river surveys must be (very) rapid to apply, in the order of 10–20 minutes, to be feasible (Clapcott et al. 2015). This means that a habitat modification protocol would need to be based on visual estimates (e.g. percentage cover estimates) and / or a subjective scoring system. That is unless additional resourcing for river habitat surveying can be arranged. There are a range of subjective assessment protocols already well established and in use overseas (e.g. Raven et al. 1998). With input from regional councils, these could be adapted to create a rapid protocol to suit New Zealand conditions.

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# 4. APPENDICES

Appendix 1. The agenda for the MfE habitat modification indicators workshop and list of attendees.

| | | |
|---|---|---|
| 9:00am – 9:15 | Introductions | |
| 9:15 – 9:30 | Project scope overview and outline of anticipated workshop outputs | Robin Holmes |
| 9:30 – 9:45 | Update on the outcomes of the last DOC-led physical habitat indicators workshop and update on recent work with geomorphological indicators | Russell Death and Ian Fuller |
| 9:45 – 10:00 | Hawke's Bay RC habitat monitoring | Andy Hicks |
| 10:00 – 10:15 | Morning Tea | |
| 10:15 – 10:30 | Habitat modification and Iwi management | Mahina-a-rangi Baker |
| 10:30 – 10:45 | DOC requirements for Habitat modification indicators (*place-holder title*) | Natasha Petrove |
| 10:45 – 11:00 | Off-channel habitat / connectivity measurements (*place-holder title*) | Kevin Collier |
| 11:00 – 11:15 | Use of spatial data bases for assessing habitat modification | Eric Goodwin |
| 11:15 – 11:30 | Existing habitat assessment protocol overview | Joanne Clapcott |
| 11:30 – 12:00pm | Discuss the criteria required for indicators to be suitable for national reporting. Create a 'long list' of potential habitat modification indicators | Robin and then All |
| 12:00 – 12:30 | Lunch | |
| 12:30 – 2:45 | Go through the list of potential indicators and assess their suitability according to the defined criteria. | All |
| 2:45 – 3:00 | Afternoon tea | |
| 3:00 – 3:45 | Summary and capture of workshop outputs. Outline next steps. | All |

**Workshop attendees**:

| | |
|---|---|
| Robin Holmes | Cawthron Institute |
| Joanne Clapcott | Cawthron Institute |
| Eric Goodwin | Cawthron Institute |
| Russell Death | Massey University |
| Ian Fuller | Massey University |
| Kevin Collier | University of Waikato |
| Natasha Petrove | Department of Conservation |
| Michael Lake | Waikato Regional Council |
| Amanda Death | Greater Wellington Regional Council |
| Andy Hicks | Hawke’s Bay Regional Council |
| Lauren Long | Ministry for the Environment |
| Julie Percival | Ministry for the Environment |
| Baz Parker | Ministry for the Environment |
| Tom Pirie | StatsNZ |
| Mahina-a-rangi Baker | Independent consultant |

Appendix 2. List of data criteria to assess the suitability of potential indicators for national monitoring. Data criteria were determined at the MfE river habitat modification indicators workshop.

| | |
|---|---|
| Data overview | Data source? Institutional custodian of the data? |
| | Is this an aspect of physical / structural river habitat or is it an attribute / metric / indicator better suited to measure water quantity or water quality? |
| | Practically, how long will it take to start reporting results? |
| | Period to expect change overtime? |
| Most appropriate scale of measurement | Patch |
| | Site / reach |
| | Segment |
| | Sub-catchment |
| | Catchment |
| Data availability | Complete national dataset exists |
| | Partial dataset exists |
| | Some data exists but needs a substantial collation effort |
| | Collection protocol exists but needs further application |
| | Collection protocol needs further development |
| Statistical data attributes | Partial measure |
| | Indirect measure |
| | Measurement accuracy (high or moderate?) |
| | Consistency of data collection method |
| | Coherence with international methods |
| | Interpretability, is it easy for the public to understand? |
| What does it measure?<br><br>Benchmarking method | Ecosystem structure |
| | Ecosystem function |
| | River structure |
| | River process<br>Relative to reference |
| | Relative to a defined limit |
| | Relative to a desired state / function |
| Direct relevance to biota | Aquatic plants |
| | Macroinvertebrates |
| | Fish |
| | Riparian animals (birds, spiders etc) |
| Relevance to New Zealanders | (highly) relevant instream values |
| Ease of mitigation | If a problem is detected can management mitigate it easily? |

Appendix 3. The ‘long list’ of potential river habitat modification indicators determined at the MfE river habitat modification indicators workshop. Indicators are presented in the order that they were suggested at the workshop.

1. Riparian vegetation type (composition within a buffer)
2. Channelisation
3. Stopbanks and / or permitted flood plain
4. Meandering / sinuosity
5. Riprap / bank protection structures
6. Fish passes
7. Residual pool depth
8. Unaltered wild rivers
9. Fish passage barriers: presence / absence of instream structures
10. Fish passage barriers >3m
11. Dams
12. Degree of fish passage barrier effect
13. % Fine sediment cover
14. Substrate compaction
15. Substrate size composition
16. Bank composition
17. Riparian vegetation cover
18. Functional riparian width
19. Riparian pest species
20. Degree of riparian vegetation shading
21. Draping vegetation hanging over the water
22. Macrophytes (as habitat structure)
23. Macrophyte clearing
24. Bridging (including human use)
25. Degree of fencing
26. Stock access (heavy vs light vs avian)
27. Stock crossings
28. Stock damage to bank (pugging)
29. Presence of feed lots
30. Adjacent land-use
31. Adjacent land cover
32. Catchment land use
33. Catchment land cover
34. Effective imperviousness
35. Large wood
36. Rubbish
37. Contaminants - heavy metals, PAHs, etc
38. Flood plain connectivity
39. Connected wetland area
40. Channel straightening

41. Channel widening
42. Channel narrowing
43. Channel depth change (bed level change)
44. Channel incision/entrenchment
45. Water abstraction take
46. Bank re- battering/contouring
47. Bank undercutting
48. Bank stability
49. Degree of channel braiding (braiding index)
50. Bar area
51. Bar type
52. Channel rationalisation (island bisection etc)
53. Gravel extraction
54. Flood gates, tide gates, flow control structures, flood pumps
55. Piping / undergrounding
56. Water abstraction structures
57. Catchment hydrology modification
58. Storm water point source discharge
59. Human activity access (e.g. 4wd, swimming, tracks, trails, tow paths, horse trekking)
60. Human resource access (e.g. mahinga kai)
61. Human fishing structures (e.g. eel fishing, whitebaiting)

Appendix 4. Top six habitat modification indicators listed by individual workshop attendees in response to a follow-up email sent after the workshop.

Michael Lake, Waikato Regional Council:
1. Unaltered wild rivers
2. Meandering / sinuosity
3. Channelisation.
4. Riparian vegetation type
5. Fish passage barriers: presence/absence
6. Stop banks

Andy Hicks, Hawke's Bay Regional Council
1. Riparian vegetation type (composition within a buffer)
2. Channelisation
3. Stop banks and / or permitted flood plain
4. Meandering / sinuosity
5. Unaltered wild rivers
6. Catchment hydrology modification

Natasha Petrove, Department of Conservation (National office)
1. Riparian vegetation type (composition within a buffer)
2. Channelisation
3. Stop banks and / or permitted flood plain
4. Meandering / sinuosity
5. Channel engineering
6. Catchment hydrology modification

Kevin Collier, Waikato University
1. Riparian vegetation index - type, width, extent
2. Channel modification index – sinuosity / channelisation, bank structure
3. Dysconnectivity index (area / length disconnected) - stopbanks, floodgates / tide gates (there should be council layers for these), fish barriers Meandering / sinuosity
4. Drainage modification index - impervious area, tile drains (?not sure if data available), drainage ditches (roughly discernible on REC)Catchment hydrology modification
5. Flow modification index - abstraction (Doug Booker has a national layer I think), dams for hydropeaking, water transfers.

Ian Fuller and Russell Death, Massey University
1. Riparian vegetation type (composition within a buffer)
2. Channelisation including narrowing, widening, straightening
3. Stop banks and / or permitted flood plain
4. Meandering / sinuosity
5. Rip rap / bank protection structures