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SEV applicability to Waikato Regional Council Freshwater Ecosystem Services project

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SEV applicability to Waikato Regional Council Freshwater Ecosystem Services Project

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Executive Summary

Streamlined Environmental Ltd (SEL) investigated the applicability of the Stream Ecological Valuation (SEV) methodology as a semi-quantitative framework from which to derive functional scores of Freshwater Ecosystem Services (FWES) using the Waikato Regional Council's (WRC) State of the Environment (SOE) monitoring data. This proof-of-concept was designed to assist WRC in meeting two key Phase 3 objectives of the FWES project:

1. Examine trends in the levels of ecosystem services over time for sampled waterbodies using the existing WRC SOE data; and
2. Extrapolate the levels of ecosystem services in 1 above across a number of scales including reach, catchment, region, and as applicable.

The proof-of-concept process was comprised of three main steps:

i. Create Proxy SEV scores using WRC SOE data, derived primarily from data collected for the Regional Ecological Monitoring of Streams (REMS) programme;
ii. Derive Functional scores and align to FWES as defined by the Millennium Ecosystem Assessment (MEA) categories and used in Phases 1 and 2 of the FWES project; and
iii. Explore regional scalability of Proxy SEV/Functional FWES scores, i.e. from reach to subcatchment and/or watershed scales across the Waikato region.

A review and data gap analysis of existing WRC SOE REMS data was undertaken to identify a range of stream sites covering a diversity of land uses, including reference sites whose data would be used to derive 'potential scores' in the absence of human impacts, i.e. the maximum FWES value for a given stream type.

The REMS data used for this proof of concept was from nine wadeable streams (2nd - 4th order), collected post 2005 following a review of the REMS programme (Collier 2005). The six 'current state' sites included:

1. Piakoiti Stream (high-intensity agricultural land use; sampling site #751_10);
2. Waitomo Stream (low-intensity agricultural land use; sampling site #1253_8);
3. Mangawhero Stream tributary (low-intensity agricultural land use; sampling site #490_22);
4. Mangauika Stream Ag. (low-intensity agricultural land use; sampling site #477_5);
5. Bankwood Stream (urban stream in Hamilton City; sampling site #47_2); and
6. Wainui Stream (restoration site with native reforested riparian areas; sampling site #1172_6).

Three reference streams with predominantly native forested catchments were used as the 'potential' sites and included:

7. Milnes Stream (Hunua Ranges; sampling site #3104_1)
8. Mangatu Stream (Coromandel Peninsula; sampling site #474_2); and

9. Mangauika Stream Ref. (Mount Pirongia; sampling site #477_14).

A data harmonisation process was developed and applied whereby REMS data were translated into appropriate corresponding values required for input into the SEV calculator spreadsheet. A sensitivity analysis of data gaps and/or limitations was carried out concurrently.

As the SEV calculator was originally developed for streams in the Auckland region, specifically in regard to the macroinvertebrate community composition and distribution, the calculator spreadsheet was edited and data from Auckland reference sites was replaced with data from Waikato reference streams. Similarly, the fish data usually entered as an Index of Biotic Integrity (IBI) value, was substituted with the Waikato region fish IBI using quantile regressions (QIBI; Joy & Henderson 2007).

Overall, approximately 85 % of the 29 SEV variables were populated with the WRC SOE REMS data. Twenty-three variables were captured completely, two partially, and four could not be directly calculated using the WRC SOE REMS data. The significance of the data gaps is considered minor, however, as it is anticipated they can be address relatively easily. Recommended steps for populating gaps identified during the data harmonisation are described in detail by the Proxy SEV method developed by SEL.

Proxy SEV scores, including overall SEV, key function and subfunction scores, were successfully calculated for the six 'current state' non-reference stream sites, and the three reference 'potential state' streams. Proxy scores accurately reflected trends from poorest/worst to best/optimal ecosystem health across the sites. By using the SEV, our assessment is necessarily limited to streams and rivers, and other habitats which provide additional/different ecosystems services, such as wetlands, would require a different methodology.

A literature review revealed relatively few studies in which methods have been developed to quantify ecosystem services for freshwater ecosystems. A study of particular relevance by Logsdon and Chaubey (2013) described an example of how to value water ecosystem services specifically aligned to translating ecosystem "function" to ecosystem "services". They developed mathematical indices to represent selected provisional and regulatory ecosystem services using data outputs from a process-based model. Their aim was to develop indices that were not only comprehensive of the ecosystem *functions* that contributed to the ecosystem services, but were also applicable to any watershed, to enable comparison of ecosystem services between different watersheds – an outcome similarly desired by WRC. The algorithms used in the SEV method to describe ecosystem functions provide a comparable tool for linking ecosystem functions to ecosystem services. Emulating Logsdon and Chaubey's approach, we matched the SEV function 'Natural flow regime' to primary and secondary MEA ecosystem service classifications of divisions, groups and classes. Using this approach, it is possible to derive SEV-based algorithms for ecosystem services at different levels of detail and calculate measures of, or quantify of, FWES.

We investigated how the results of our combined methodologies could be applied over multiple spatial scales and mapped using GIS software. The REMS programme has been documenting the state and trend of ecological health in the region's streams since 1994. The sampling network is comprised of approximately 224 sites that effectively cover the major river catchments and zones throughout the Waikato region. Applying the described methods to existing WRC SOE REMS data presents an excellent opportunity to consistently and systematically value the FWES derived from 1^{st}-4^{th} order streams with different catchment land uses across the Waikato. These values could be plotted using GIS mapping software and displayed as 'heat-maps', similar to those used to represent indigenous biodiversity values of the Waikato region (Leathwick 2016).

This report presents a comprehensive analysis of the potential applicability of the SEV methodology as a quantitative approach for determining the state of a range of FWES across the Waikato region using readily available WRC SOE data. Our analysis illustrates that existing REMS data forms a strong basis for applying this method and that relatively minor modifications to existing methods could effectively address data gaps.

1. Introduction

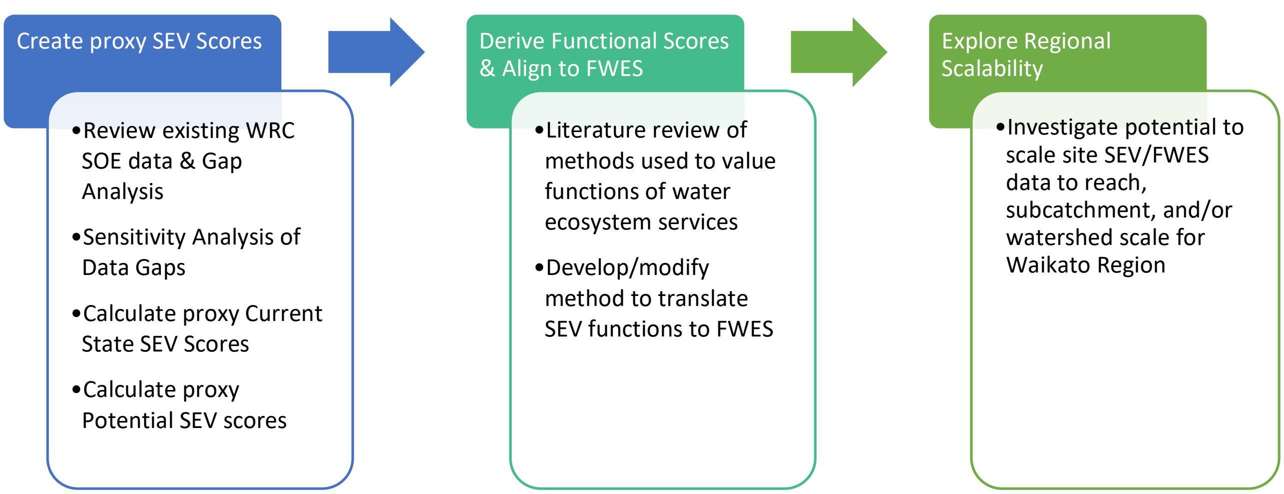
Phase 3 of the Waikato Regional Council's (WRC) Freshwater Ecosystem Services (FWES) project is focused on assessing temporal, reach, and Freshwater Management Unit (FMU) wide ecosystem services and values for selected freshwater ecosystems by applying modelling tools (or similar) to the WRC State of the Environment (SOE) monitoring data. Streamlined Environmental Ltd (SEL) proposed investigating the applicability of the Stream Ecological Valuation (SEV) methodology (Storey et al. 2011) as a semi-quantitative framework from which to derive functional scores of FWES using WRC's stream SOE monitoring data.

The specific objectives of Phase 3 of WRC's FWES project are to:

1. Examine trends in the levels of ecosystem services over time for sampled waterbodies using the existing WRC SOE data; and
2. Extrapolate the levels of ecosystem services in 1 above across a number of scales including reach, catchment, region, and as applicable.

Establishing consistent and robust numerically based descriptors of ecosystem services which can be used to characterise both the current and potential state of streams, for example, in the Waikato Region fundamentally underpins the Phase 3 objectives of the FWES project. Furthermore, to accurately quantify trends in FWES spatially and temporally, the data used requires an adequate level of detail and resolution, particularly regarding the Millennium Ecosystem Assessment (MEA) category of "Regulation and Maintenance", for which the ability to economically value relevant FWES is comparatively limited.

The following outlines the first steps in the process of aligning WRC SOE data and the SEV method to ultimately quantify FWES for a sample of monitored streams in the Waikato Region.



2. Methods

2.1 Review existing WRC data & Gap Analysis

2.1.1 Calculating Current State & Potential Proxy SEV scores

The purpose of this task was to derive SEV values describing the current state of a range of sites covering a diversity of land uses, with scores for reference sites being used to derive potential scores in the absence of human impacts. These values would then be used in testing our method for deriving functional scores aligned to FEWS.

We reviewed data previously collated by WRC staff relating to water quality, ecology, biogeochemistry, riparian areas and catchment land use derived from mandatory SOE monitoring of the water quality and ecological health of rivers and streams. The data used for this proof of concept was from nine wadeable streams (2^{nd} - 4^{th} order; exempting Waitomo which WRC considers non-wadeable) included in WRC's Regional Ecological Monitoring of Streams (REMS) programme and are typically surveyed every 1-3 years (Figure 1). The six 'current state' sites included:

1. Piakoiti Stream (high-intensity agricultural land use; sampling site #751_10);
2. Waitomo Stream (low-intensity agricultural land use; sampling site #1253_8);
3. Mangawhero Stream tributary (low-intensity agricultural land use; sampling site #490_22);
4. Mangauika Stream Ag. (low-intensity agricultural land use; sampling site #477_5);
5. Bankwood Stream (urban stream in Hamilton City; sampling site #47_2); and
6. Wainui Stream (restoration site with native reforested riparian areas; sampling site #1172_6).

Three reference streams with predominantly native forested catchments were used as the 'potential' sites and included:

7. Milnes Stream (Hunua Ranges; sampling site #3104_1)
8. Mangatu Stream (Coromandel Peninsula; sampling site #474_2); and
9. Mangauika Stream Ref. (Mount Pirongia; sampling site #477_14).

The following freshwater ecosystem characteristics are routinely monitored:

1. Instream and riparian habitat quality
    a. Qualitative Habitat Assessment (QHA) for hard-bottomed (HB) or soft-bottomed (SB) streams (Collier and Kelly 2005; Appendix 1)
    b. Rapid Habitat Assessment (RHA) (Clapcott 2011)
2. Macrophyte and periphyton (M&P) plant cover (Collier et al. 2014)
3. Macroinvertebrate community health (Collier and Kelly 2005)
4. Fish community health (David and Hamer 2010)

Figure 1. Location of the eight REMS sites used to calculate proxy SEV scores. Current state sites (black circles) 1=Piakoiti, 2=Waitomo, 3=Mangawhero, 4=Mangauika-Ag, 5=Bankwood,

6=Wainui, and reference/potential sites (white circles) 7=Milnes, 8=Mangatu, and 9=Mangauika-Ref.

A review of the REMS programme (Collier 2005) resulted in minor changes and improvements to the assessment methodologies, therefore only data collected post 2005 for the eight sites was considered in the proof of concept process. A detailed review of the data received was carried out, evaluating completeness and consistency between sites, and temporally within sites.

The data was subsequently translated into appropriate values for input into the SEV spreadsheet calculator and data gaps were identified. A sensitivity analysis of any identified data gaps was carried out concurrently. We calculated proxy values describing 'current state' SEV values (based on measured data from the six non-reference sites) and 'potential' SEV values (expected in the absence of anthropogenic impacts i.e. reference condition, based on measured data from the three reference sites).

The 'SEV calculator', an Excel workbook-spreadsheet, is widely used to semi-automate the calculations of the SEV variables and function scores. The calculator is relatively simple to use and limits the scope of errors in calculations as the complex algorithms and equations are 'set' in the template. The SEV calculator was developed for Auckland streams (as was the SEV method), and as such the equations are weighted against data from Auckland reference stream sites. To ensure the accuracy of the SEV scores for the Waikato stream sites, the SEV calculator was edited (with permission from Auckland Council) and data from Auckland reference sites was replaced with data from Waikato reference streams. Specifically:

i. **V_{MCI}** – Amended equation with the maximum, minimum, and range of Macroinvertebrate Community Index (MCI) scores for Waikato streams using WRC SOE REMS data from all sites monitored during the past 10 years (n=709);
ii. **V_{EPT}** – Amended the equation to use Waikato Ephemeroptera Plecoptera Trichoptera (EPT) taxa richness for soft-bottomed (n=20) and hard-bottomed (n=59) REMS streams (15.6 and 16.6, respectively); and
iii. **V_{INVERT}** – Amended taxa reference list using taxa found at more than 50 % of Waikato REMS reference streams. The soft-bottomed and hard-bottomed lists were combined to create one list as there were only four soft-bottomed reference sites.

The SEV method requires fish data to be entered as an Index of Biotic Integrity (IBI) value. Joy and Henderson (2007) developed a fish IBI using quantile regressions for the Waikato region (QIBI) which improves upon the original fish IBI developed for New Zealand fish fauna (Joy and Death 2004) through utilising more developed statistical methods. QIBI values were calculated for the eight sites using the revised methodology. The REMS fish data was used for Milnes, Mangawhero, Mangauika-Ref, Piakoiti and Wainui streams, while records from the Freshwater Fish Database (FFDB version 6.1) were used as surrogates for Mangatu, Mangauika-Ag, Waitomo, and Bankwood streams (Crow 2017).

2.2 Functional scores aligned to Freshwater Ecosystem Services (FWES)

A brief literature review of current quantitative methods used to evaluate ecosystem services (from waterbodies including marine environments), nationally and internationally, specifically aligned to translating ecosystem "function" to ecosystem "services" was carried out. The results of this review were then used to develop our approach for aligning the functional scores derived using the SEV with the MEA ecosystem services used in the Freshwater Ecosystem Services project. For consistency, we used the ecosystem services terminology as defined in (Olubode-Awosola 2017).

2.3 Scalability

We assessed how our approach, which is largely based on reach-scale measurements, could be applied over multiple spatial scales and how the resulting ecosystem services scores could be mapped using GIS software.

3. Results & Discussion

3.1 Existing WRC SOE REMS data & Gap Analysis

The REMS data received for the eight stream sites varied in its completeness and consistency between sites and years (from 2005 to 2019). It was therefore decided that the most recent data for all sites (2017-2019) would be used for this proof of concept.

Milnes, Mangatu, Mangauika, Mangawhero, Bankwood, Piakoiti and Wainui streams had complete records of instream and riparian habitat assessments, including data collected using the QHA Field Assessment Cover Form (referred to as QHA CoverPg herein), QHA Wadeable HB or SB form, and the RHA form, as well as M&P assessments from 2017 to 2019. Raw macroinvertebrate data were available for all sites. The data for Waitomo Stream was less consistent, however, due to the semi-wadeable conditions of the stream, with only near-complete records of instream and riparian habitat assessments and macroinvertebrate community composition provided for years 2016, 2018 and 2019. Across all sites a number of data points collected using the QHA CoverPg were missing, including surface velocity, cover of fine (< 1mm) detritus, and instream plant cover (filamentous algae, macrophytes, and mosses/liverworts). It is understood that these gaps are due to recent adjustments to the QHA assessment protocols. Where data from 2017-2019 year were missing, therefore, means (average) of the preceding 3 years of monitoring data were applied.

Overall, approximately 85% of the 29 SEV variables could be populated with the WRC SOE REMS data. A description of the SEV variable codes and descriptions is given in Table 1.

Twenty-three variables were captured completely, two partially, and four could not be directly calculated using the WRC SOE REMS data (Table 2).

Table 1. SEV variable codes and descriptions (summarised from Storey et al. 2011)

SEV variable codes	Description of variable
Vchann	Extent & type of channel modification
Vlining	Extent & type of channel lining + sediment load
Vpipe	Size & number of piped inflows to stream reach
Vbank	Floodplain connectivity
Vrough	Riparian zone vegetation condition
Vbarr	Extent & type of barriers to fish & invertebrate migration
Vchanshape	Extent & type of channel modification
Vshade	Proportion of the stream channel shaded
Vdod	Measure of dissolved oxygen demand & indicators of oxygen reducing processes
Vripar	Proportion of the riparian zone with intact woody vegetation
Vdecid	Measure of the permanence of vegetation shading stream channel
Vmacro	Extent & type of macrophyte cover
Vretain	Extent & type of channel modification & influence on instream retention
Vsurf	Substrate composition & abundance of surfaces suitable for biofilm colonisation and/or spawning for Godiidae fish species
Vripfilt	Measure of filtering activity of riparian zone
Vdepth	Measure of water depths
Vveloc	Measure of surface flow velocity
Vgalspwn	Extent of Galaxiidae spawning habitat i.e. near flat surface on banks inundated by small floods or spring tides
Vgalqual	Quality of Galaxiidae spawning habitat
Vgobspwn	Substrate composition & abundance of surfaces suitable for biofilm colonisation and/or spawning for Godiidae fish species
Vphyshab	Composite measure of physical habitat provision for fish & invertebrates based on standard protocols
Vwatqual	Measure of water quality maintenance based on oxygenation & low temperatures
Vimperv	Extent of upstream catchment imperviousness & flow control measures
Vfish	Calculated fish IBI scaled between 0 & 1
Vmci	Calculated MCI index scaled between 0 & 1
Vept	Calculated EPT taxa richness scaled between 0 & 1
Vinvert	Comparison of taxa richness with reference sites
Vripcond	Contribution of riparian vegetation of stream ecosystem
Vripconn	Proportion of stream channel where natural connections between riparian vegetation & stream banks/bed are not impeded

The outcome of the WRC SOE REMS data harmonisation with the SEV methodology to calculate Proxy SEV scores is summarised in Table 2.

Table 2. Comparison of WRC SOE REMS data with values required for input to the SEV calculator to determine proxy SEV scores

SEV Key function category	Sub function	Variable (code)	Captured by SOE monitoring	WRC SOE data collection method (colour denotes method source)	Description of method for proxy SEV scores
Multiple	Multi	Vdepth	Yes	Macrophyte & periphyton assessment	Use mean thalweg depths from maximum depth across 5 transects
Multiple	Multi	Vveloc	Yes	QHA CoverPg (pre 2005)	QHA CoverPg - Velocity measurement(s)
Multiple	Multi	Vveloc	No	No equivalent	Use online NZ River Maps modelled median flow data
Hydraulic	NFR	Vchann	Yes - partial	QHA Q5: Channel Alteration; QHA CoverPg	Convert rank scores to proportions + % cover wood + % cover macrophytes
Hydraulic	NFR	Vlining	Yes	QHA Q5: Channel Alteration; RHA Q1: Deposited sediment	Convert rank scores to proportions
Hydraulic	NFR	Vpipe	No	No equivalent	Use available GIS layers & maps
	Natural Flow Regime (NFR) score		**PARTIALLY**		
Hydraulic	FLE	Vbank	Yes	QHA Q5: Channel Alteration	Convert rank scores to proportions
Hydraulic	FLE	Vrough	Yes	RHA Q8: Bank vegetation; QHA CoverPg Fence	Convert rank scores to proportions AND check riparian fencing
	Floodplain effectiveness (FLE) score		**YES**		
Hydraulic	CSM	Vbarr	No	No equivalent	Use expert opinion and/or GIS maps
Connectivity for species migrations (CSM) score			**PARTIALLY**		
Hydraulic	CGW	Vchanshape	Yes - partial	As for Vchann	No data required - auto calculated in SEV calc spreadsheet
Hydraulic	CGW	Vlining	Yes	As for Vchann & Vchanshape	No data required - auto calculated in SEV calc spreadsheet
	Connectivity to ground water (CGW) score		**PARTIALLY**		
Hydraulic function mean score			**PARTIALLY**		

SEV Key function category	Sub function	Variable (code)	Captured by SOE monitoring	WRC SOE data collection method (colour denotes method source)	Description of method for proxy SEV scores
Biogeochemical	WTC	Vshade	Yes	Densiometer measurement; RHA Q10: Riparian shade	Densiometer measurement; Convert rank scores to SEV categories
Water temperature control (WTC) score			**YES**		
Biogeochemical	DOM	Vdod	Yes	RHA Q1: Deposited sediment; QHA CoverPg; RHA Q10: Riparian shade	Convert rank scores & proportions to SEV categories
Dissolved oxygen maintained (DOM) score			**YES**		
Biogeochemical	OMI	Vripar	Yes	RHA Q9: Riparian width	Convert rank scores to proportions
Biogeochemical	OMI	Vdecid	Yes	RHA Q10: Riparian shade	Convert rank scores to proportions
Organic matter input (OMI) score			**YES**		
	OMI	Vripar	Yes	RHA Q9: Riparian width	Convert rank scores to proportions
Biogeochemical	OMI	Vdecid	Yes	RHA Q10: Riparian shade	Convert rank scores to proportions
Organic matter input (OMI) score			**YES**		
	IPR	Vmacro	Yes	Macrophyte & periphyton assessment; QHA CoverPg	Align with macrophyte % cover data
Biogeochemical	IPR	Vretain	Yes	As for Vchann & Vchanshape & Vlining	No data required - auto calculated in SEV calc spreadsheet
Instream particle retention (IPR) score			**YES**		
	DOP	Vsurf	Yes	Macrophyte & periphyton assessment; QHA CoverPg	Use proportional data for: Coarse detritus + Large wood + Substrate composition + M&P assessment
Biogeochemical	DOP	Vripfilt	Yes	RHA Q8: Bank vegetation	Convert rank scores to proportions - RHA Q8
Decontamination of pollutants (DOP) score			**YES**		
Biogeochemical function mean score			**YES**		

SEV Key function category	Sub function	Variable (code)	Captured by SOE monitoring	WRC SOE data collection method (colour denotes method source)	Description of method for proxy SEV scores
Habitat provision	FSH	Vgalspwn	No	**No equivalent**	Data gap
Habitat provision	FSH	Vgalqual	Yes	**RHA Q10: Riparian shade; RHA Q8: Bank vegetation; QHA Q5: Channel alteration**	Convert RHA & QHA rank scores to SEV categories
Habitat provision	FSH	Vgobspwn	Yes	As for Vsurf	No data required - auto calculated in SEV calc spreadsheet
Fish spawning habitat (FSH) score			**PARTIALLY**		
Habitat provision	HAF	Vphyshab	Yes	**RHA Q2&4: Invertebrate & fish habitat diversity; RHA Q3&5: Invertebrate & fish habitat abundance; RHA Q6: Hydraulic heterogeneity; RHA Q10: Riparian shade; RHA Q8: Bank vegetation**	Convert RHA rank scores to SEV rank values x 2
Habitat provision	HAF	Vwatqual	Yes	**No equivalent**	GIS assessment of upstream catchment shading
Habitat provision	HAF	Vimperv	No	**No equivalent**	GIS assessment of upstream catchment imperviousness
Habitat for aquatic fauna (HAF) score			**YES**		
Habitat provision function mean score			**PARTIALLY**		
Biodiversity	FFI	Vfish	Yes	REMS Fish surveys	Input Waikato QIBI fish value
Fish fauna intact (FFI) score			**YES**		
Biodiversity	IFI	Vmci	Yes	REMS Macroinvertebrate sampling	Input macroinvertebrate data
Biodiversity	IFI	Vept	Yes	REMS Macroinvertebrate sampling	Input macroinvertebrate data
Biodiversity	IFI	Vinvert	Yes	REMS Macroinvertebrate sampling	Input macroinvertebrate data
Invertebrate fauna intact (IFI) score			**YES**		
	RVI	Vripcond	Yes	As for Vchann & Vchanshape & Vlining & Vretain	No data required - auto calculated in SEV calc spreadsheet
Biodiversity	RVI	Vripconn	Yes	**QHA Q5: Channel alteration**	Convert RHA rank scores to SEV proportional value
Riparian vegetation intact (RVI) score			**YES**		
Biodiversity function mean score			**YES**		
OVERALL PROXY SEV SCORE			**PARTIALLY**		

Details of the data gaps identified through the harmonisation process are summarised below (Table 3). The significance of these data gaps is considered minor given they can be addressed relatively easily. Recommendations have been given for comparatively simple methods to fill the majority of the data gaps. These methods were used in this proof of concept process to complete the calculation of sub-function, key function, and overall SEV scores.

Table 3. Summary of recommendations for data gaps identified during SEV:SOE data harmonisation sensitivity analysis

SEV function	Subfunctions	Variables	Assessment category gap	Recommendation
Hydraulic	NFR, CGW, IPR	Vchann, Vchanshape, Vretain	d. Natural channel, but evidence of channel incision from flood flows	**None**
	NFR, CGW, IPR	Vchann, Vchanshape, Vretain	f. Flow patterns affected by instream structure (e.g. ponding due to culvert, weir or unnatural debris)	Add assessment to QHA Field Cover Form
	NFR	Vpipe	a. b. c. Size and number of stormwater pipes or mole/tile drains	Use WRC GIS maps and/or LAWA, NZ River Maps, GoogleMaps
	CSM	Vbarr	a. b. c. Barriers to species migrations	Use WRC GIS maps and/or LAWA, NZ River Maps, GoogleMaps; expert advice
Habitat provision	FSH	Vgalspwn	Proportion of reach with floodplain suitable for Galaxiidae spawning	**None**. The *specifics* of suitable Galaxiidae spawning habitat is currently scientific data gap in NZ
	HAF	Vwatqual	Extent of the stream length upstream shaded by riparian vegetation	GIS assessment described by SEV method using WRC GIS maps and/or Topomap, LAWA, NZ River Maps, GoogleMaps
	HAF	Vimperv	Extent of catchment upstream covered by impervious surface + extent of flow control measures	GIS assessment described by SEV method using WRC GIS maps and/or Topomap, LAWA, NZ River Maps, GoogleMaps

The methodologies developed to populate each of the SEV variables required to calculate subfunction, key function, and overall SEV scores, are summarised in Table 4. Step-by-step instructions and detailed descriptions of the methods used to calculate proxy SEV scores using WRC SOE REMS data, or, where data gaps existed, alternative freely available sources of information, are given Section 6.1 and Table 11 (Appendix A).

Table 4. Summary of methods used to calculate proxy scores for each SEV variable

Variable (code)	WRC SOE data collection method	Description	Method summary
Vdepth	Macrophyte & periphyton assessment	Use mean thalweg depths from maximum depth across 5 transects	Add mean measurement data
Vveloc	QHA CoverPg (pre 2005)	QHA CoverPg - Velocity measurement(s)	Add mean measurement data
Vveloc	No equivalent	Use online NZ River Maps modelled median flow data	Use NZ River Maps online. Identify reach closest to monitoring location. Select median flow rate & divide by area of flow (wetted width x depth) to calculate velocity. check model accuracy against Wetted Width estimates. Refer https://shiny.niwa.co.nz/nzrivermaps/
Vchann	QHA Q5: Channel Alteration; QHA CoverPg	Convert rank scores to proportions + % cover wood + % cover macrophytes	If 1 match with assessment category, proportion =1 (QHA Q5), if 2 matches, proportion = 0.75 (QHA Q5) + 0.25 (QHA Macro/wood), if 3 matches, proportion = 0.4 + 0.3 + 0.3
Vlining	QHA Q5: Channel Alteration; RHA Q1: Deposited sediment	Convert rank scores to proportions	If 1 match with assessment category, proportion =1 (QHA Q5), if 2 matches, proportion = 0.8/0.5 (QHA Q5) + 0.2/0.5 (RHA Q1)
Vpipe	No equivalent	Use available GIS layers & maps	Use WRC GIS maps and/or LAWA, NZ River Maps, GoogleMaps
Vbank	QHA Q5: Channel Alteration	Convert rank scores to proportions	Match with assessment category, proportion =1 (QHA Q5) AND cross check with GIS maps
Vrough	RHA Q8: Bank vegetation; QHA CoverPg Fence	Convert rank scores to proportions AND check riparian fencing	If 1 match with assessment category, proportion =1 (RHA Q8), if 2 matches, proportion = 0.5 + 0.5 (e.g. RHA Q8 score 8 & 2)
Vbarr	No equivalent	Use expert opinion and/or GIS maps	Use WRC GIS maps and/or LAWA, NZ River Maps, GoogleMaps
Vchanshape	As for Vchann	No data required - auto calculated in SEV calc spreadsheet	No additional data required - auto calculated in SEV calc spreadsheet
Vlining	As for Vchann & Vchanshape	No data required - auto calculated in SEV calc spreadsheet	No additional data required - auto calculated in SEV calc spreadsheet
Vshade	Densiometer measurement; RHA Q10: Riparian shade	Densiometer measurement; Convert rank scores to SEV categories	Use densiometer measurements (if available), or match with assessment category, SEV frequency value = RHA Q10 category x 10
Vdod	RHA Q1: Deposited sediment; QHA CoverPg; RHA Q10: Riparian shade	Convert rank scores & proportions to SEV categories	Match sediment (RHA Q1), shade (RHA Q10) & macrophyte cover (M&P assessment) scores to DOD status 1,2,3 or 4 and average
Vripar	RHA Q9: Riparian width	Convert rank scores to proportions	Match with assessment category, SEV proportion value = RHA Q9 score LB + RB /40
Vdecid	RHA Q10: Riparian shade	Convert rank scores to proportions	Match with assessment category, SEV proportion value = RHA Q10 score / 10 for x 10 transects

Variable (code)	WRC SOE data collection method	Description	Method summary
Vmacro	**Macrophyte & periphyton assessment; QHA CoverPg**	Align with macrophyte % cover data	Match with Macrophyte/periphyton assessment, if available; or align with QHA CoverPg Marophyte % cover = surface-reaching/emergent/bankside macrophytes
Vretain	As for Vchann & Vchanshape & Vlining	No data required - auto calculated in SEV calc spreadsheet	No additional data required - auto calculated in SEV calc spreadsheet
Vsurf	**Macrophyte & periphyton assessment; QHA CoverPg**	Use proportional data for: Coarse detritus + Large wood + Substrate composition + M&P assessment	Match with corresponding proportional assessments - divide #% by 10 and replicate across each x 10 transects for each category. Ensure 'Sum' matches original proportional number.
Vripfilt	**RHA Q8: Bank vegetation**	Convert rank scores to proportions - RHA Q8	Match with assessment category, proportion = 1 (RHA Q8)
Vgalspwn	**No equivalent**	**Data gap**	Data gap
Vgalqual	**RHA Q10: Riparian shade; RHA Q8: Bank vegetation; QHA Q5: Channel alteration**	Convert RHA & QHA rank scores to SEV categories	Consider riparian shade (RHA Q10), bank vegetation (RHA Q8), channel alteration (QHA Q5) & select most appropriate Vgalsqual score (1,2,3, or 4) for each then select the **mean**
Vgobspwn	As for Vsurf	No data required - auto calculated in SEV calc spreadsheet	No data required - auto calculated in SEV calc spreadsheet
Vphyshab	**RHA Q2&4: Invertebrate & fish habitat diversity; RHA Q3&5: Invertebrate & fish habitat abundance; RHA Q6: Hydraulic heterogeneity; RHA Q10: Riparian shade; RHA Q8: Bank vegetation**	Convert RHA rank scores to SEV rank values x 2	Match with corresponding assessment category, SEV rank value a. b. c. d. e. = RHA Q2&4 (mean), Q3&5 (mean), Q6, Q10, Q8 score **x 2**
Vwatqual	**No equivalent**	GIS assessment of upstream catchment shading	Follow GIS assessment described by SEV method using WRC GIS maps and/or Topomap, LAWA, NZ River Maps, GoogleMaps
Vimperv	**No equivalent**	GIS assessment of upstream catchment imperviousness	Follow GIS assessment described by SEV method using WRC GIS maps and/or Topomap, LAWA, NZ River Maps, GoogleMaps
Vfish	REMS Fish surveys	Input Waikato QIBI fish value	Calculate Waikato fish QIBI following appropriate methodology described by Joy & Henderson (2007) TR2007/23
Vmci	REMS Macroinvertebrate sampling	Input macroinvertebrate data	Macroinvertebrate presence/absence data used to calculate MCI score weighted against **Waikato MCI range**
Vept	REMS Macroinvertebrate sampling	Input macroinvertebrate data	Macroinvertebrate presence/absence data used to calculate EPT variables weighted against **Waikato SB & HB mean EPT taxa richness**
Vinvert	REMS Macroinvertebrate sampling	Input macroinvertebrate data	Macroinvertebrate presence/absence data compared to **Waikato reference site taxa list**

Variable (code)	WRC SOE data collection method	Description	Method summary
Vripcond	As for Vchann & Vchanshape & Vlining & Vretain	No data required - auto calculated in SEV calc spreadsheet	No data required - auto calculated in SEV calc spreadsheet
Vripconn	**QHA Q5: Channel alteration**	Convert RHA rank scores to SEV proportional value	Match with assessment category (QHA Q5, channel alteration) SEV proportion value = (QHA Q5 score x 5)/ 100

Two examples of the data harmonisation steps taken for calculating the variables V_{dod} and V_{shade} are given in Table 5. These examples demonstrate one of the more complex data synchronisations and one of the most straight forward, respectively.

Table 5. Data harmonisation steps taken to synchronise WRC SOE REMS data with the SEV score calculator. A complex (V_{dod}) and more straightforward (V_{shade}) example are given

Method	**SEV**	**WRC SOE REMS**	**WRC SOE REMS**	**WRC SOE REMS**	
SEV variable	**V_{dod} - Indicators of oxyegn reducing processes**				
Description of assessment categories	Select the **'Status'** category that best describes the indicators of oxygen reducing processes that are present in the test reach				Best
	Optimal = 1 - No anaerobic sediment, little or no macrophytes, high shade	**RHA Q1: Deposited sediment - Score 9-10**	**RHA Q10: Riparian shade -**	**Macrophyte & Periphyton: Total Cover <5%**	
	Sub-optimal = 2 - No anaerobic sediment, moderate macrophytes, moderate shade	**RHA Q1: Deposited sediment - Score 7-8**	**RHA Q10: Riparian shade -**	**Macrophyte & Periphyton: Total Cover 5-25%**	
	Marginal = 3 - minimal anaerobic sediment, dense macrophytes, low shade	**RHA Q1: Deposited sediment - Score 5-6**	**RHA Q10: Riparian shade -**	**Macrophyte & Periphyton: Total Cover 26-75%**	
	Poor = 4 - much anaerobic sediment, excessive macrophytes, no shade, surface scums	**RHA Q1: Deposited sediment - Score 1-5**	**RHA Q10: Riparian shade - Score 1-2**	**Macrophyte & Periphyton: Total Cover >75%**	Worst
Data harmonisation steps	Match sediment (RHA Q1), shade (RHA Q10), & macrophyte cover (M&P assessment) scores to DOD status (1,2,3 or 4), and caculate the mean				
Method	**SEV**	**WRC SOE REMS**			
SEV variable	**V_{shade}**				
Description of assessment categories	Enter **frequency** of assessment category for 10 cross sections along the surveyed reach (0-10)				Best
	a. Very high shading; shading from vegetation and topographical features > 90%	**RHA Q10: Riparian shade - Score 10**			
	b. High shading; shading from vegetation and topographical features 71 - 90%	**RHA Q10: Riparian shade - Score 8-9**			
	c. Moderate shading; shading from vegetation and topographical features 51 - 70%	**RHA Q10: Riparian shade - Score 6-7**			
	d. Low shading; shading from vegetation and topographical features 31 - 50%	**RHA Q10: Riparian shade - Score 5**			
	e. Very low shading; shading from vegetation and topographical features 11 - 30%	**RHA Q10: Riparian shade -Score 3-4**			
	f. No effective shading; shading from vegetation and topographical features < 10%	**RHA Q10: Riparian shade -Score 1-2**			Worst
Data harmonisation steps	Match with assessment category, SEV frequency value = RHA Q10 score x 10				

3.2 Proxy SEV Scores

Using the data harmonisation 'Proxy SEV' method described above, we successfully calculated proxy scores, including overall, key function and subfunction scores, for the six 'current state' non-reference stream sites, and the three reference 'potential state' streams (Table 6). Scores range between 0 to 1 (poorest/worst to best/optimal, respectively).

Table 6. Proxy SEV scores including key function, subfunction, and Overall SEV score. 'Current state' scores are given for Piakoiti, Mangawhero, Waitomo, Mangauika-Agricultural (Ag.), Bankwood, and Wainui streams. 'Potential state' scores are given for the three Waikato reference streams Milnes, Mangatu, and Mangauika-Reference (Ref.).

Stream site		Piakoiti	Manga-whero	Waitomo	Mangauika Ag.	Bankwood	Wainui	Milnes	Mangatu	Mangauika Ref.
Catchment land cover		High intensity ag.	Low intensity ag.	Low intensity ag.	Low intensity ag.	Urban	Restoration	Native forest reference	Native forest reference	Native forest reference
Function	**Code**									
Natural Flow Regime	NFR	0.15	0.20	0.13	0.49	0.20	0.50	0.97	0.97	0.97
Floodplain effectiveness	FLE	0.10	0.24	0.10	0.28	0.24	0.24	1.00	1.00	0.90
Connectivity for spp. migrations	CSM	1.00	1.00	1.00	1.00	0.30	1.00	1.00	1.00	1.00
Connectivity to ground water	CGW	0.62	0.81	0.49	0.82	0.81	0.85	0.95	0.95	0.95
Hydraulic function mean score		0.47	0.56	0.43	0.65	0.39	0.65	0.98	0.98	0.95
Water temperature control	WTC	0.20	0.60	0.00	0.60	0.20	0.80	0.80	0.60	0.80
Dissolved oxygen maintained	DOM	0.23	0.45	0.23	0.60	0.40	1.00	1.00	0.60	1.00
Organic matter input	OMI	0.15	0.13	0.14	0.13	0.18	0.23	1.00	0.80	0.75
Instream particle retention	IPR	0.32	0.36	0.32	0.60	0.48	0.60	0.90	0.90	0.90
Decontamination of pollutants	DOP	0.43	0.62	0.44	0.71	0.54	0.60	0.76	0.60	1.00
Biogeochemical function mean score		0.26	0.43	0.23	0.53	0.36	0.64	0.89	0.70	0.89
Fish spawning habitat	FSH	0.18	0.43	0.53	0.88	0.48	0.88	1.00	1.00	1.00
Habitat for aquatic fauna	HAF	0.34	0.53	0.39	0.78	0.41	0.81	0.98	0.82	0.98
Habitat provision mean score		0.26	0.48	0.46	0.83	0.44	0.84	0.99	0.91	0.99
Fish fauna intact	FFI	0.57	0.43	0.63	0.97	0.97	0.97	0.97	0.97	0.97
Invertebrate fauna intact	IFI	0.32	0.41	0.87	0.87	0.69	0.88	0.90	0.90	0.91
Riparian vegetation intact	RVI	0.05	0.12	0.05	0.39	0.27	0.42	1.00	0.80	0.60
Biodiversity function mean score		0.31	0.32	0.52	0.74	0.64	0.75	0.96	0.89	0.82
Overall mean SEV score		0.33	0.45	0.38	0.65	0.44	0.70	0.94	0.85	0.91

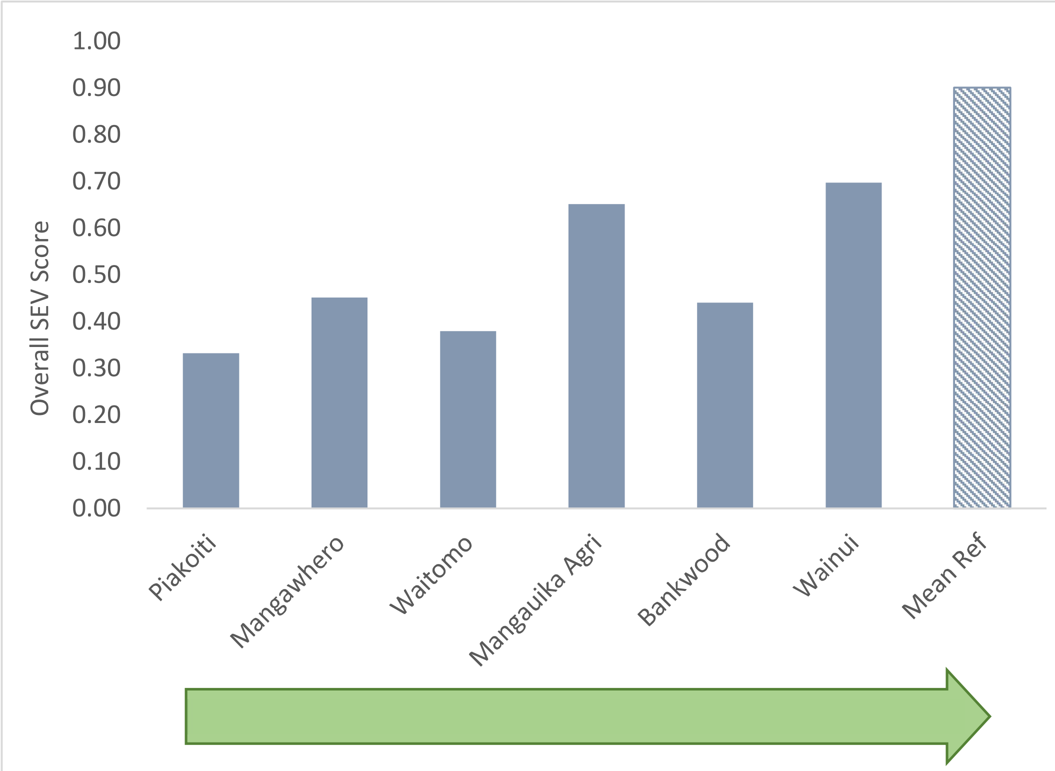


Figure 2. Overall SEV scores for the 'Current state' streams, and the mean SEV score for the three reference streams (Mean Ref), representing the 'Potential state'. Current State streams are ordered from those subjected to the highest land use pressures (intensive agriculture) to the lowest (restored riparian forest).

The overall proxy SEV scores for the assessed streams, with more to less impacted sites plotted from left to right (Figure 2), shows the trend we would expect in the ecological conditions of the streams selected for this data harmonisation process. This figure also highlights that the highest possible SEV score of **1** may not be realistically achievable in natural stream environments, and care must be taken when interpreting comparatively simplified numerical measures of the more complex realities of freshwater ecosystem health. For example, higher levels of sedimentation can arise due to naturally more erosive soil types in the catchment, rather than catchment land use and/or imperviousness alone.

The SEV variable scores for the eight streams are given in Table 7 and likewise scores range between 0 to 1 (poorest/worst to best/optimal, respectively).

Table 7. Calculated Proxy SEV variable scores. 'Current state' scores are given for Piakoiti, Mangawhero, Waitomo, Mangauika-Agriculture (Ag.), Bankwood, and Wainui streams. 'Potential' scores are given for the three Waikato reference streams Milnes, Mangatu, and Mangauika-Ref.

Stream site	Piakoiti	Mangawhero	Waitomo	Mangauika Ag.	Bankwood	Wainui	Milnes	Mangatu	Mangauika Ref.
Vchann	0.40	0.56	0.40	0.58	0.56	0.58	0.95	0.95	0.95
Vlining	0.70	0.90	0.50	0.96	0.90	1.00	1.00	1.00	1.00
Vpipe	0.30	0.30	0.30	0.70	0.30	0.70	1.00	1.00	1.00
Vbank	0.20	0.40	0.20	0.40	0.40	0.40	1.00	1.00	1.00
Vrough	0.50	0.60	0.50	0.70	0.60	0.60	1.00	1.00	0.90
Vbarr	1.00	1.00	1.00	1.00	0.30	1.00	1.00	1.00	1.00
Vchanshape	0.47	0.63	0.47	0.55	0.63	0.55	0.85	0.85	0.85
Vlining	0.70	0.90	0.50	0.96	0.90	1.00	1.00	1.00	1.00
Vshade	0.20	0.60	0.00	0.60	0.20	0.80	0.80	0.60	0.80
Vdod	0.23	0.45	0.23	0.60	0.40	1.00	1.00	0.60	1.00
Vripar	0.25	0.15	0.25	0.15	0.25	0.25	1.00	1.00	0.75
Vdecid	0.20	0.70	0.10	0.70	0.40	0.80	1.00	0.60	1.00
Vmacro	0.53	0.36	0.54	1.00	0.73	1.00	1.00	1.00	1.00
Vretain	0.32	0.48	0.32	0.60	0.48	0.60	0.90	0.90	0.90
Vsurf	0.65	0.84	0.69	0.82	0.48	0.59	0.51	0.39	0.99
Vripfilt	0.20	0.40	0.20	0.60	0.60	0.60	1.00	0.80	1.00
Vgalspwn	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Vgalqual	0.25	0.75	0.25	0.75	0.75	0.75	1.00	1.00	1.00
Vgobspwn	0.10	0.10	0.80	1.00	0.20	1.00	1.00	1.00	1.00
Vphyshab	0.32	0.61	0.42	0.93	0.66	0.95	1.00	0.91	1.00
Vwatqual	0.03	0.18	0.01	0.48	0.14	0.65	0.90	0.48	0.90
Vimperv	0.70	0.70	0.70	0.80	0.20	0.70	1.00	1.00	1.00
Vfish	0.57	0.43	0.63	0.97	0.97	0.97	0.97	0.97	0.97
Vmci	0.29	0.36	0.60	0.62	0.47	0.64	0.70	0.70	0.72
Vept	0.19	0.32	1.00	1.00	0.64	1.00	1.00	1.00	1.00
Vinvert	0.48	0.55	1.00	1.00	0.96	1.00	1.00	1.00	1.00
Vripcond	0.20	0.30	0.20	0.70	0.70	0.70	1.00	0.80	0.60
Vripconn	0.26	0.39	0.23	0.55	0.39	0.60	1.00	1.00	1.00

3.3 Functional scores aligned to Freshwater Ecosystem Services (FWES)

Based on our brief literature review, it appears that relatively few studies have developed methods to empirically quantify ecosystem services for freshwater ecosystems. For our study, the paper by Logsdon and Chaubey (2013) is of particular relevance. These authors developed mathematical indices to represent selected provisional and regulatory ecosystem services using the outputs of a process-based model. They considered the use of modelling as part of a data-driven approach necessary to build a fully comprehensive and holistic ecosystem services framework that is quantifiable. Their aim was to develop indices that were not only comprehensive of the ecosystem *functions* that contributed to the ecosystem services, but were also applicable to any watershed, to enable comparison of ecosystem services between different watersheds – an outcome similarly desired by WRC.

As an example, a **Freshwater provisioning algorithm (FWPI),** incorporating both quantity and quality of available water, was developed, as described in the formula below.

$$FWPI_t = \left(\frac{MF_t/MF_{EF}}{(MF_t/MF_{EF}) + (qne_t/n_t)}\right) \cdot \left(\frac{WQI_{avg,t}}{1+(e_t/n_t)}\right) \quad (1)$$

$$FWPI_t = (Q_t) \cdot FWPI_t \quad (2)$$

where:

MF = mean flow (m^3/s);

MF_{EF} = long term environmental flow requirements (m^3/s);

qne = number of times flow is less than environmental flow requirements in the time step;

WQI_{avg} = average water quality index (see equation 3 below);

e = number of times the WQI is less than 1 in the time step; and

n = number of unites in the time step.

A specific water quality variable was also developed:

$$WQI = \frac{\exp(w_1 + w_2 + \cdots + w_n)}{\exp[(w_1 \times (C_1/C_{1std})) + (w_2 \times (C_2/C_{2std})) + \cdots + (w_n \times (C_n/C_{nstd}))]} \quad (3)$$

where:

C_1, C_2…Cn = water quality constituents of concern (mg/L);

w_1, w_2…w_n = weights for water quality constituents of concern (summed to 1); and

std = standard criteria of water quality constituents of concern.

The FWPI is designed so that if environmental flow conditions are met throughout a particular time period, the quantity component (first set of parentheses) is equal to 1. This rule also applies to the water quality component. When both components = 1 (and hence FWPI = 1) this means the quantity of freshwater provisioning is equal to the total amount of water provided, indicating excellent freshwater provisioning services. If either component is less than 1, the FWPI will be less than 1, indicating a reduction in freshwater provisioning services. The authors undertook scenario testing in which concentrations of nitrogen (N) and phosphorus (P), as well as minimum flows, were considered in relation to ecological condition, calculated on an annual basis. Using this method, they demonstrated that water quality was impaired due to nutrients (validated with real data points for N and P) and that freshwater provisioning varied seasonally and temporally due to changes in reduced flows in drier season/years. "What if" scenarios could also be tested, comparing current and future potential land uses, to aid decision making and prioritise actions (Figure 3).

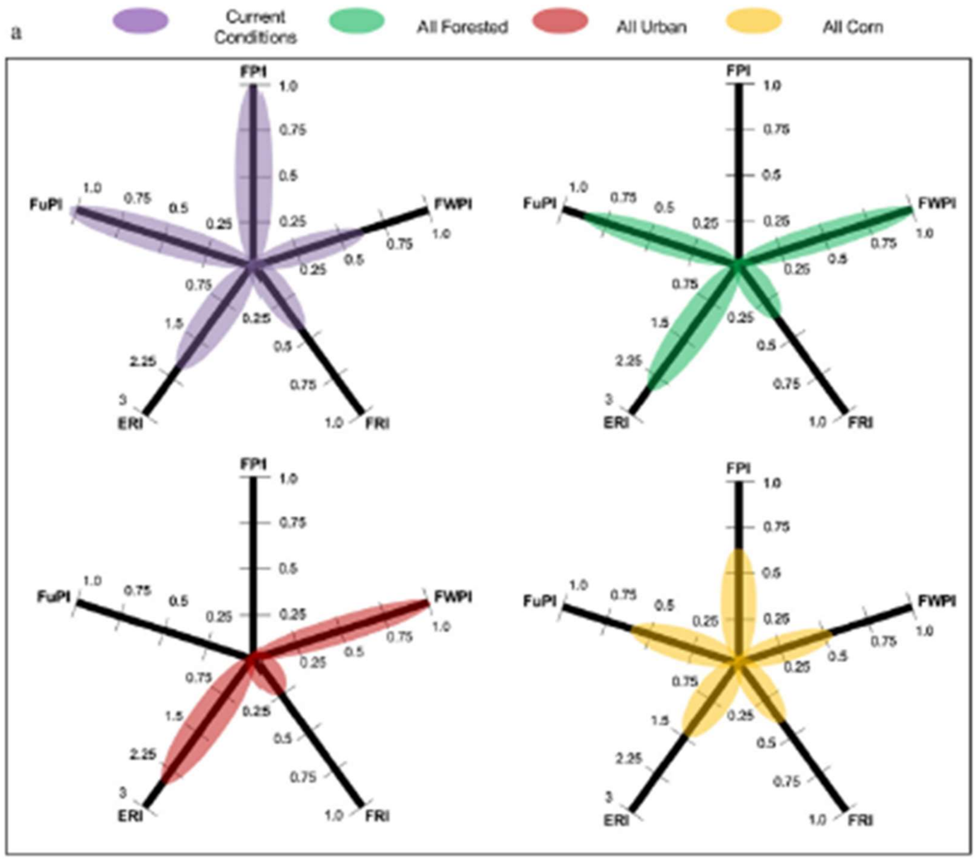


Figure 3. Spider plot of 5 ecosystem services under different land use scenarios. FPI (Food Provisioning Index), FWPI (Freshwater Provisioning Index), FRI (Flood Regulation Index), ERI (Erosion Regulation Index), and FuPI (Fuel Provisioning Index) (Source: Logsdon & Chaubey, 2013).

The algorithms used in the SEV method to describe ecosystem functions provide a comparable tool for linking ecosystem functions to ecosystem services. Using this approach, we have matched SEV functions to MEA ecosystem service classifications, divisions, groups and classes Table 8).

In this example, we have identified primary and secondary linkages between SEV functions and MEA ecosystem services. Further linkages to additional services could be derived. In our example, the SEV function 'Natural flow regime' (NFR) provides a quantitative measure of how well a stream mediates flows and hence contributes to the maintenance of the hydrological cycle and flow regime. The quantitative measurement includes measures of channel modification, channel lining and the presence, nature, and extent of instream piping. This same SEV function also contributes secondarily to the provision of surface water for drinking or non-drinking purposes. Thus, the algorithm for this single SEV function could contribute to an overall derived score for both regulating services and provisioning services for a stream reach. Using this approach, it is possible to derive SEV-based algorithms for ecosystem services at different levels of detail (Figure 4 and

Figure 5). In this case we have used a simple additive approach. These algorithms can then be applied to data collected for SEV assessments, to derive measures of ecosystem services (Table 9).

Table 8. SEV functions matched to Millennium Ecosystem Assessment (MEA) Ecosystem Service (ES) Classification, Division, Group and Class - as used in Olubode-Awosola (2017) (except red text)

SEV Functions	Function detail	Primary ES Classification	Primary ES Division	Primary ES Group	Primary ES Class	Secondary ES Category	Secondary ES Division	Secondary ES Group	Secondary ES Class	SEV algorithm[1]
Natural flow regime (NFR)	Maintenance of natural flow regime	Regulating services	Mediation of flows	Liquid flow	Hydrological cycle and water flow maintenance	Provisioning	Nutrition	Water	Surface water for drinking or non-drinking purposes	NFR = (2*Vchann + Vlining)/3 * Vpipe
Floodplain effectivenes (FPE)	Mitigation of flood flows through connection with floodplain	Regulating services	Mediation of flows	Liquid flow	Flood protection					FPE = Vbank * Vrough
Connectivity for natural species migrations (CSM)	Species migration	Regulating services	Maintenance of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection	Maintaining nursery populations and habitats	Provisioning	Nutrition	Biomass	Wild animals and their outputs	CSM = Vbarr
Natural connectivity to groundwater (CGW)	Interaction with groundwater	Regulating services	Maintenance of physical, chemical, biological conditions	Water conditions	Chemical condition of freshwaters	Provisioning	Materials (includes nutrition)	Water	Ground water for drinking or non-drinking purposes	CGW= (2*Vlining + Vchanshape)/3
Water temperature control (WTC)	Maintain cool water temperatures	Regulating services	Maintenance of physical, chemical, biological conditions	Water conditions	Chemical condition of freshwaters	Provisioning	Materials (includes nutrition)	Water	Surface water for drinking or non-drinking purposes	WTC = Vshade
Dissolved oxygen levels maintained (DOM)	Maintain oxygen levels	Regulating services	Maintenance of physical, chemical, biological conditions	Water conditions	Chemical condition of freshwaters	Provisioning	Materials (includes nutrition)	Water	Surface water for drinking or non-drinking purposes	DOM = Vdod
Organic matter input (OMI)	Provide organic matter from riparian zone	Regulating services	Mediation of waste, toxics and other nuisances	Mediation by ecosystem	Filtration/sequestration/storage/accumulation by micro-organisms, algae plants and animals	Provisioning	Materials (includes nutrition)	Biomass	Cycling of nutrients	OMI = (Vripar) * ((1 + Vdecid)/2)
In-stream particle retention (IPR)	Retain organic matter within stream	Regulating services	Mediation of waste, toxics and other nuisances	Mediation by ecosystem	Filtration/sequestration/storage/accumulation by micro-organisms, algae plants and animals	Provisioning	Materials (includes nutrition)	Biomass	Cycling of nutrients	IPR = IF(Vmacro < Vretain, then Vmacro, else Vretain)
Determinants of pollutants (DOP)	Process contaminants	Regulating services	Mediation of waste, toxics and other nuisances	Mediation by biota	Bioremediation by micro-organisms, algae, plants and animals	Regulating services	Maintenance of physical, chemical, biological conditions	Water conditions	Chemical condition of freshwaters	DOP = Average (Vsurf + Vripfilt)
Fish spawning habitat (FSH)	Provide spawning habitat for native fish	Regulating services	Maintenance of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection	Maintaining nursery populations and habitats	Provisioning	Nutrition	Biomass	Wild animals and their outputs	FSH = ((Vgalspwn * Vgalqual) + Vgobspwn)/2
Habitat for aquatic fauna (HAF)	Provide habitat for aquatic fauna	Regulating services	Maintenance of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection	Maintaining nursery populations and habitats	Provisioning	Nutrition	Biomass	Wild animals and their outputs	HAF = (((Vphyshab + Vwatqual)/2) + Vimper)/2
Fish fauna intact (FFI)	Fish fauna condition	Regulating services	Maintenance of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection	Maintaining nursery populations and habitats	Provisioning	Nutrition	Biomass	Wild animals and their outputs	FFI = Vfish
Invertebrate fauna intact (IFI)	Invertebrate fauna condition	Regulating services	Maintenance of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection	Maintaining nursery populations and habitats	Cultural Services	Spiritual, symbolic or other interactions with biota, ecosystems, and land/seascapes	Spiritual or emblematic	Symbolic	IFI = (Vmci + Vept + Vinvert)/3
Riparian vegetation intact (RVI)	Riparian vegetation functioning	Regulating services	Maintenance of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection	Maintaining integrity of land-water interface	Provisioning	Nutrition	Biomass	Wild plants, algae and their outputs	RVI = Vripcond * Vripconn

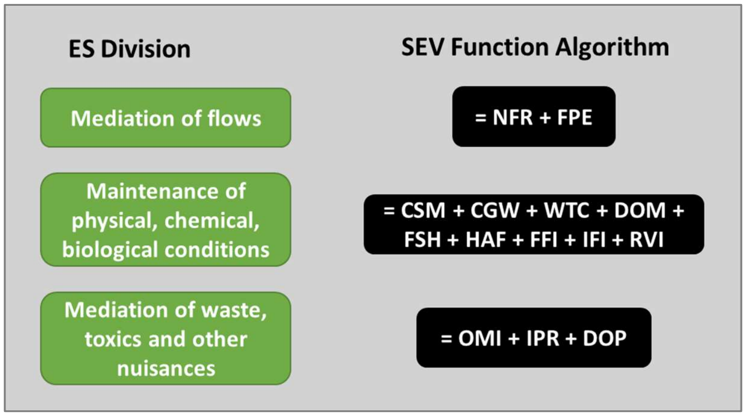


Figure 4. Algorithms based on SEV functions for quantifying regulating ecosystem services at the MEA <u>Division</u> level.

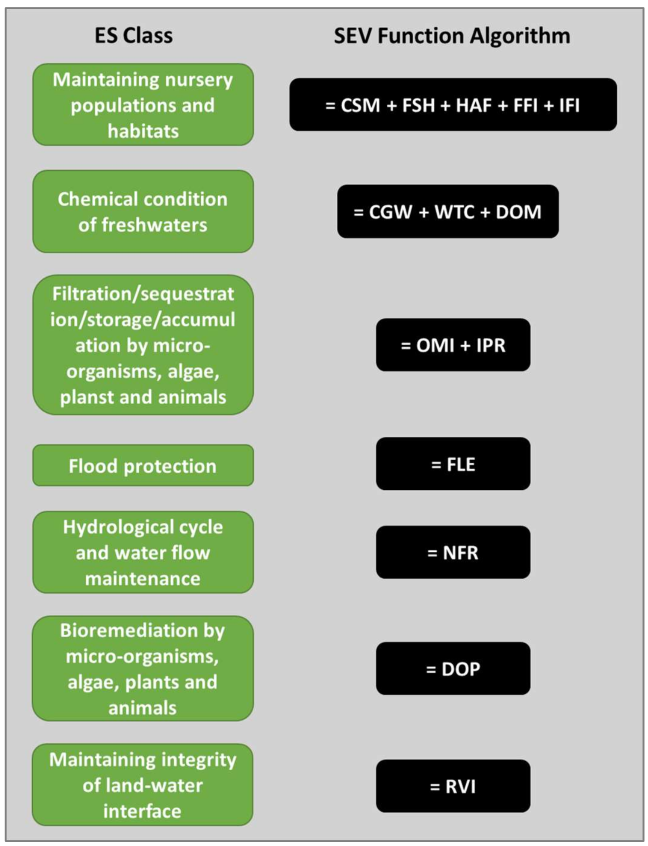


Figure 5. Algorithms based on SEV functions for quantifying regulating ecosystem services at the MEA <u>Class</u> level.

Table 9. Calculated 'Regulating Services' scores at Division and Class level, based on SEV algorithms. Ecosystem Service (ES) scores for Piakoiti, Mangawhero, Waitomo, Mangauika-Agriculture, Bankwood, and Wainui streams are based on 'Current State' SEV scores, while ES scores for Milnes, Mangatu, and Mangauika reference streams are based on calculated 'Potential' SEV scores.

Stream site		Piakoiti	Manga-whero	Waitomo	Mangauika-Ag.	Bankwood	Wainui	Milnes	Mangatu	Mangauika-Ref.
Catchment land cover		High intensity agriculture	Low intensity agriculture	Low intensity agriculture	Low intensity agriculture	Urban	Restoration	Native reference	Native reference	Native reference
ES Division	**Algorithms**									
Mediation of flows	NFR + FPE	0.13	0.22	0.12	0.39	0.22	0.37	0.98	0.98	0.93
Maintenance of physical, chemical, biological conditions	CSM + CGW + WTC + DOM + FSH + HAF + FFI + IFI + RVI	0.39	0.53	0.46	0.77	0.50	0.84	0.95	0.85	0.91
Mediation of waste, toxics and other nuisances	OMI + IPR + DOP	0.30	0.37	0.30	0.48	0.40	0.47	0.89	0.77	0.88
ES Class	**Algorithms**									
Hydrological cycle and water flow maintenance	NFR	0.15	0.20	0.13	0.49	0.20	0.50	0.97	0.97	0.97
Flood protection	FPE	0.10	0.24	0.10	0.28	0.24	0.24	1.00	1.00	0.90
Maintaining nursery populations and habitats	CSM + FSH + HAF + FFI + IFI	0.48	0.56	0.68	0.90	0.57	0.91	0.97	0.94	0.97
Chemical condition of freshwaters	CGW + WTC + DOM	0.35	0.62	0.24	0.67	0.47	0.88	0.92	0.72	0.92
Filtration/sequestration/storage/accumulation by micro-organisms, algae plants and animals	OMI + IPR	0.24	0.24	0.23	0.36	0.33	0.41	0.95	0.85	0.83
Bioremediation by micro-organisms, algae, plants and animals	DOP	0.43	0.62	0.44	0.71	0.54	0.60	0.76	0.60	1.00
Maintaining integrity of land-water interface	RVI	0.05	0.12	0.05	0.39	0.27	0.42	1.00	0.80	0.60

3.4 Link to scalability

WRC has been implementing its REMS programme annually since 1994, documenting the state and trend of ecological health in the region's streams as part of SOE monitoring. The sampling network comprises:

i. 50 long-term sites that have been sampled for 10 years or more (including 3 reference sites and 6 restoration sites where riparian management has been implemented);
ii. 180 random sites selected using a probability-based survey design to provide an unbiased estimate of the regional condition of wadeable streams on developed land (60 sites sampled once each year for 3 years, repeated every 3 years); and
iii. 25 reference sites in undeveloped (native forest) catchments to provide a baseline against which to measure change (sampled annually).

The REMS sites include wadeable hard-bottom streams with stony beds, and wadeable soft-bottom streams with beds dominated by sand and silt, making them perfectly suited to proxy assessments of FWES using the adapted SEV methodology. The 224 (approximate) sites effectively cover the major river catchments and zones in the Waikato region, as shown in Figure 6, reproduced from the WRC Technical Report 2014/46 (Pingram et al. 2016).

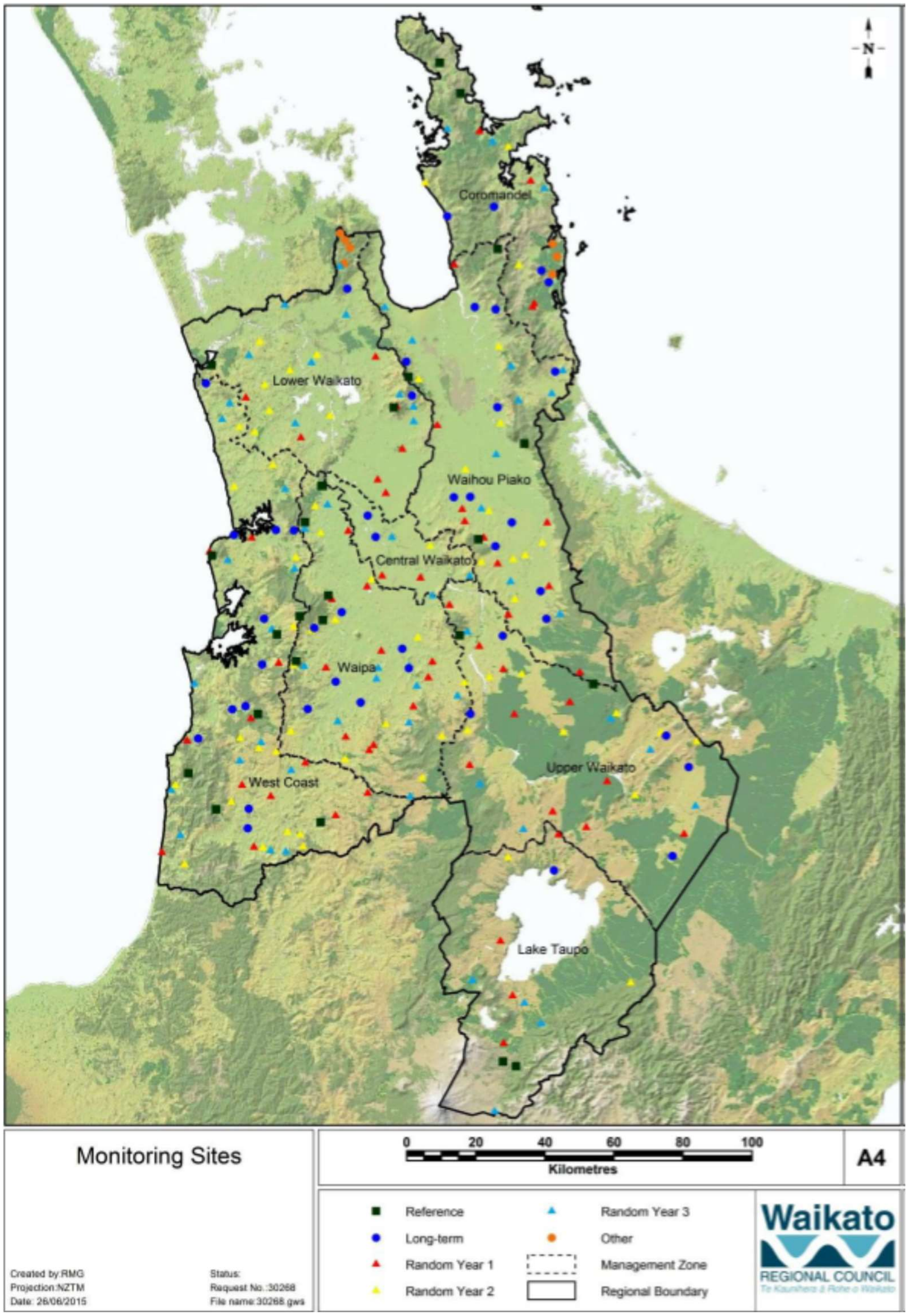


Figure 6. Location of REMS stream monitoring sites including those from the random network, reference sites, and long-term sites (source: Pingram et al. 2016)

This presents an excellent opportunity to consistently and systematically value the FWES derived from 1st to 4th order streams with different catchment land uses across the Waikato region. Furthermore, where gaps occur in areas of particular interest (e.g. land use intensification), SEV field assessments can be carried out at the stream sites. These supplementary SEVs could be carried out with little cost, particularly if the macroinvertebrate and fish community data can be obtained using modelled MCI sub-catchment scores and modelled fish QIBI scores. Typically, SEV assessments take between 2 and 4 hours to complete, depending on access to the stream.

Once proxy SEV and/or derived FWES-scores have been calculated for the regions SOE sites, these values could be plotted using GIS mapping software and displayed as 'heat-maps', similar to those used to represent indigenous biodiversity values of the Waikato region (Leathwick 2016). Figure 7 is a heat-map of the terrestrial and aquatic indigenous biodiversity values (ranked on a 0 to 1 scale) for the Central Waikato and Waipa River Zones, reproduced from the WRC Technical Report 2016/12 (Leathwick 2016). A similar mapping approach would align well with mapping FWES values as suggested in this report.

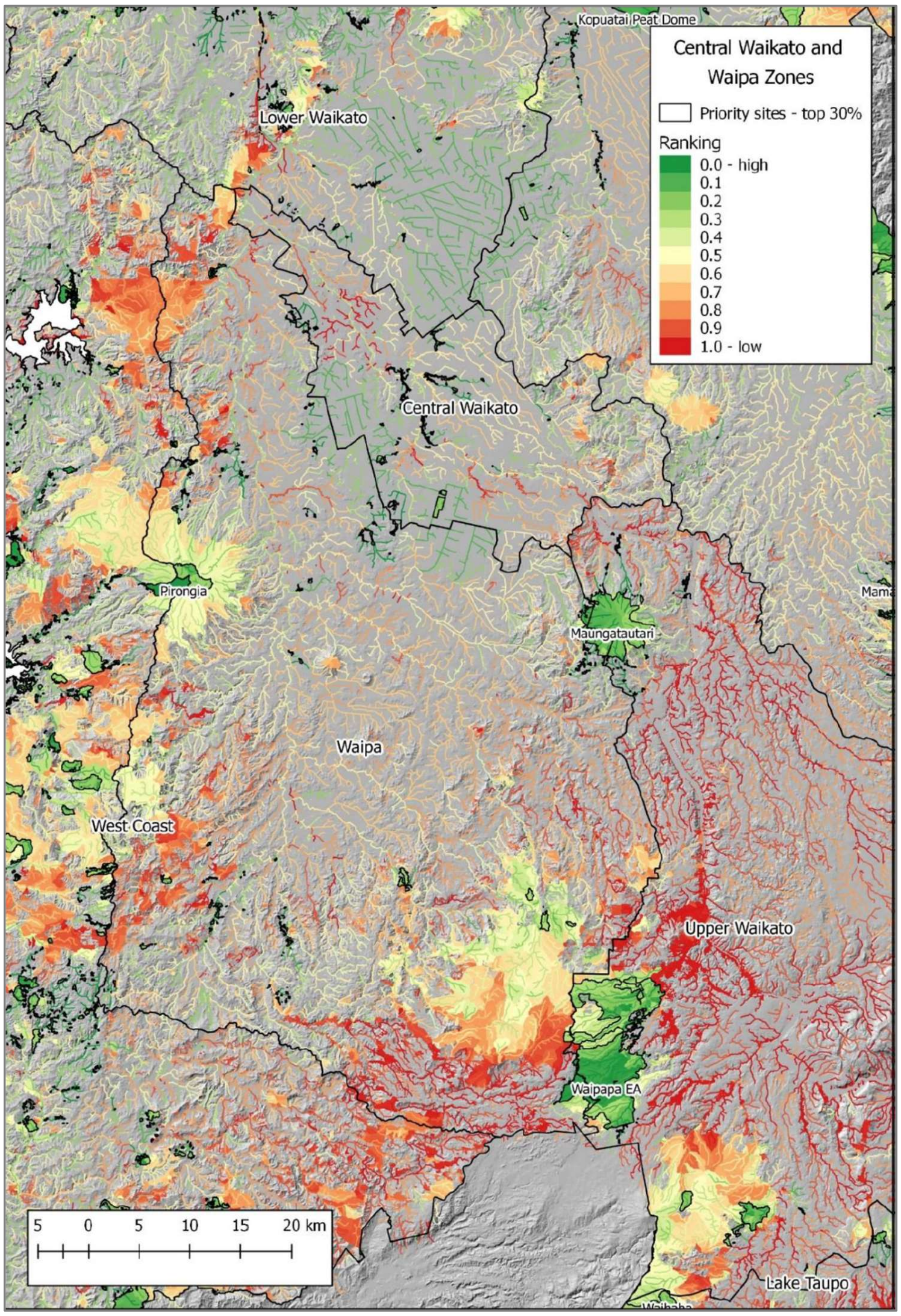


Figure 7. Terrestrial indigenous biodiversity priority sites for the Central Waikato and Waipa River Zones, overlaid across the continuous river ranking results (Source: Leathwick 2016)

4. Conclusions

This report presents a comprehensive analysis of the potential application of the SEV methodology as a quantitative approach for determining the state of a range of freshwater ecosystem services (FW ES) across the Waikato region using readily available WRC SOE data. Our analysis illustrates that existing SOE REMS data collected by WRC forms a strong basis for applying this method and that relatively minor modifications to existing methods could effectively address data gaps.

Using WRC GIS spatial layers, as well as freely available GIS maps (e.g. Topomap) and models (NZ River Maps), it is possible to consistently assess some of variables not captured by SOE monitoring data at the level of accuracy required for the SEV method. For example, the proportion of the upstream catchment that is shaded and the extent of impervious services, as well as stream flow velocities. Other variables, such as V_{pipe} (the number of pipe inputs to the assessment reach) and V_{barr} (barriers to fish migration) may be confidently assessed using GIS maps, alternative data sources (e.g. Fish Passage Assessment Tool, NIWA 2020[1]), and expert opinion in some instances (e.g. tile drains entering the watercourse within intensive agriculture) but not others (e.g. perched culverts affecting an stream flowing through agricultural land use). Other data gaps including $V_{galspwn}$ (proportion of reach with floodplain suitable for Galaxiidae spawning) and parts of V_{chann}/$V_{chanshape}$ (extent of channel modification) could be addressed through other measures or WRC data sources (e.g. stream bed gradient measurements made during fish monitoring for $V_{galspwn}$), or alternatively could be removed from the SEV proxy method with relatively minor adjustments to the related algorithms. Arguably, some aspects of the SEV assessment, such as 'evidence of channel incision from flood flows' may not be particularly relevant to valuing freshwater ecosystem services and could justifiably be removed. Moreover, where there is a lack of scientific consensus regarding how to measure an aspect of ecosystem health (e.g. Galaxiidae spawning habitat), removing these variables from the function scores seems warranted.

Our analysis has shown that the SEV method provides an effective means of deriving numeric measures for a range of MEA classified ecosystem services, encompassing regulatory, provisioning, and cultural services. The close alignment reflects the fact that the SEV method is itself focused on assessing functional attributes which reflect ecosystem processes. It is these ecosystem processes which ultimately provide the ecosystem services. By using the SEV, our assessment is necessarily limited to streams and rivers, and other habitats which provide additional/different ecosystems services, such as wetlands, would require a different methodology.

The ecosystem services of intermittent streams could be determined by utilising the SEV method that has been developed specifically for this stream type (Neale et al. 2016). The method itself is essentially the same as for perennial streams but requires the use of intermittent stream reference

[1] National Institute of Water and Atmospheric Research (NIWA) 2020. Fish Passage Assessment Tool and Citizen Science App: https://niwa.co.nz/freshwater/management-tools/fish-passage-assessment-tool accessed August 2020

sites and also specifies the flow conditions under which the SEV assessments should be undertaken in the field. The availability of existing available data on intermittent streams, however, is likely to limit the extent to which ecosystem services could be derived using this desktop analysis and field assessments to trial the complementary method are recommended.

Ecosystem metabolism (the combination of gross primary production, GPP, and ecosystem respiration, ER) is being increasingly used to assess stream health (Clapcott et al. 2016) and has been demonstrated as a good functional indicator of river health in the Waikato Region (Clapcott and Young 2008, Clapcott and Young 2009). The current SEV method doesn't include assessments of GPP or ER (although V_{DOD} does assess oxygen reducing processes) and therefore presents a data gap. A limited dataset of ecosystem metabolism values is available for streams within the Waikato Region (Clapcott and Doehring 2015), so further data would need to be collected to incorporate this measure into the broader ecosystem services framework. Given stream metabolism has been proposed as a numeric measure of ecosystem health under the revised National Policy Statement on Freshwater (STAG/MfE 2019), it is anticipated WRC will be looking to include this indicator in its SOE REMS programme and, as such, it should be possible to incorporate the associated FW ES values into this project.

Finally, while the detailed 'Proxy SEV' methodology provided in this report (along with the requisite Excel spreadsheets – SEV Data Analysis Spreadsheet v2.3 (2017)) will enable WRC to calculate Proxy SEV scores using the SOE REMS dataset as a desktop exercise, we recommend 'calibrating' the two field methods concurrently (the SEV and WRC's QHA/RHA/M&P/Fish assessments). Carrying out the assessments in streams representing a range of land uses (native forest, low and high intensity agriculture, peri-urban and urban streams), as well as topographical and climatic gradients across the region would provide a valuable 'snap-shot' of the FW ES of wadeable streams in the Waikato, while also testing the accuracy and appropriateness of the Proxy-SEV method as a quantitative measure of FW ES. Given the SEV was originally developed for streams in the Auckland region, and particularly for those impacted by, or threatened by the impact of, urban development, the 'calibration' process would additionally ensure the SEV method adequately and accurately assesses the ecosystem values, and analogous FWES, of streams throughout the Waikato region.

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6. Appendix A

6.1 Step-by-step instructions for calculating Proxy SEV scores using WRC SOE REMS data

1. Open 'REMS_to_SEV_Data_v1' excel workbook (SEV Data Analysis Spreadsheet v2.3 2017).
2. Select 'REMS QHA RHA' tab and copy across selected REMS stream and habitat assessment data for chosen sites. Refer to Table 10 below for a guide as to what data is required. You will need to clean up data, rearrange columns/rows and delete superfluous data accordingly. Transpose data when copying to the 'REMS QHA RHA' tab as shown in Table 10. Inconsistencies occur among recorded data throughout the years, so care is required to ensure relevant data is arranged in a consistent manner. For example, "large wood cover" has been assessed in four different ways over time, Large Wood (EW % cover), Large wood (% cover), Large Wood, and, Wood.
3. Collate REMS macroinvertebrate data for the chosen sites. Create a pivot table of the raw invertebrate data with 'Observable name' (taxa) as Row Labels and 'Sampling area name' (stream sites) as Column Labels, and 'Observation value' for the Values. Set Value Field Settings to 'Count of Observation Values'.
4. Copy presence/absence invertebrate data to the 'Invert Data' tab in the 'REMS_to_SEV_Data_v1' excel workbook.
5. Collate REMS fish population data for the chosen sites. Create a pivot table of the raw fish data with 'Observable name' (species) as Row Labels and 'Sampling area name' (stream sites) as Column Labels, and 'Observation value' for the Values. Set Value Field Settings to 'Count of Observation Values'.
6. Copy presence/absence fish data to the 'Fish Data' tab in the 'REMS_to_SEV_Data_v1' excel workbook.
7. Open 'FWES_SEV_calculator_v1' excel workbook.
8. Enter stream site data required into 'Functions' tab. Add "test/current state" sites first, followed by the "reference" sites.
9. Add data to individual tabs sequentially in the order they are presented and following the methods described in Table 11 (**page 35 – 41**). Anticipate some back-and-forth for deriving the proxy data and entering it into the 'FWES_SEV_calculator_v1' workbook.
10. Use GIS maps to predict/estimate/measure:
    a. Vimperv - Proportion of catchment with impervious surfaces, with or without treatment
    b. Vwatqual – Proportion of catchment upstream shaded
    c. Vpipe – number of pipe inputs
    d. Vbank - Movement of flood flows onto and across the floodplain (check for stop banks etc)
    e. Vbarr – barriers to fish migration in assessment reach
    f. Velocity – using NZ River Maps modelled estimates for median flow rates (https://shiny.niwa.co.nz/nzrivermaps/), divided by area of flow (wetted width x mean depth)

g. Distance to sea – using NZ River Maps (to be used in calculating QIBI fish scores)

h. Altitude – using Topomap http://www.topomap.co.nz/ (to be used in calculating QIBI fish scores)

11. Macroinvertebrate data – enter presence/absence (0/1) into spreadsheet using REMS monitoring data. Data is used for:

    a. Vmci – enter presence/absence (0/1)

    b. Vept – auto calculated

    c. Vinvert – enter presence/absence (0/1) for:

        i. Koura (Paranephrops planifrons)

        ii. Kakahi (Echyridella aucklandica, E. menziesii)

12. Fish data – enter QIBI scores for each stream site as per method using the Waikato QIBI.xls excel workbook. Use NZ River Maps to determine 'distance to sea' for each site

13. Once data entry is complete, return to 'Functions' tab and check there are values in every cell below each site (i.e. no zero values). If zero's are found, refer back to the relevant data tab and correct accordingly.

14. Summarise SEV scores for sub-functions and overall SEV score as presented in Table 6 (pg. 14).

Table 10. Recommended arrangement of WRC SOE REMS data to be used in populating proxy SEV scores

SEV functions	**Stream**	**Example**: Milnes
	Stream classification	Reference
	Catchment land use	Native forest
	Date/Time	20-Feb-19
Vveloc	**NZ River Maps Reach #**	3004247
Vfish	**Altitude m**	160
Vfish	**Distance from coast km**	87.1
	Cond. mS/m	12.4
	DO %	93.9
	DO mg/l	9.21
	Temp °C	15.7
	Turbidity	Clear
Vshade	**Channel shade %**	84.6
Vshade	**Canopy cover**	Significantly shaded
	Dominant riparian vegetation	Native forest
Vrough	**Fencing**	Complete both side
	Compaction (inorganic substrate)	Moderately packed
	Embeddedness covered by fine sediments	5-24%
	Measured Channel width m	5.12
Vveloc	**Measured Wetted width m**	2.36
Vdepth; Vveloc	**Measured Depth m**	0.32
Vveloc	**Discharge m3/s (median) modelled Q**	0.45
Vveloc	**Velocity m/s (calc. Q/area of flow)**	0.59
Vsurf	**bedrock %**	2
Vsurf	**boulder %**	
Vsurf	**clay %**	
Vsurf	**cobble %**	20
Vsurf	**large gravel %**	51
Vsurf	**sand %**	6
Vsurf	**silt %**	
Vsurf	**small gravel %**	21
Vsurf	**Large wood (EW % cover)**	2
Vsurf	**Fine (< 1mm) detritus (contractors) %**	
Vsurf	**Detritus (all) %**	
Vsurf	**Coarse detritus (% cover)**	10
Vsurf	**Large wood (% cover)**	2
	Macrophyte/periphyton assessment	**M&P**
	Below surface submerged; exotic %	0
	Below surface submerged; native %	0
Vmacro; Vchann; Vchanshape;	**Surface reaching submerged; exotic %**	0
Vretain; Vdod	**Surface reaching submerged; native %**	0
	Emergent; exotic %	0
	Emergent; native %	0
	Thin mat %	0.2
	Medium green mat %	0
	Medium light brown mat %	0
	Medium dark brown/black mat %	0
	Thick green/light brown mat %	0

	Thick dark brown/black mat %	0
	Short green filaments %	0
	Short brown/reddish filaments %	0
	Long green filaments %	0
	Long brown/reddish filaments %	0
	Submerged bryophytes %	0
	Submerged - bryophytes/iron floc %	0
	Other %	0
	Sampling method	QHA HB
	Wadeable (Yes/No)	Yes
	Riffles %	100
	Runs %	
	Macrophytes %	
	Edges %	
	Stones %	100
	Wood %	
	Rapid Habitat Assessment (RHA)	
Vlining; Vdod	RHA Q1: Deposited sediment	9
Vphyshab	RHA Q2: Invertebrate habitat diversity	10
Vphyshab	RHA Q3: Invertebrate habitat abundance	9
Vphyshab	RHA Q4: Fish cover diversity	9
Vphyshab	RHA Q5: Fish cover abundance	10
Vphyshab	RHA Q6: Hydraulic heterogeneity	8
	RHA Q7: Bank erosion	8
Vripfilt; Vphyshab; Vrough	RHA Q8: Bank vegetation	10
Vripar	RHA Q9: Riparian width	10
Vshade; Vdecid; Vphyshab; Vdod	RHA Q10: Riparian shade	10
	RHA Total score	93
	Qualitative Habitat assessment method	QHA HB
	HB: Habitat Assessment Sheet	
	HB Q1: Riparian Zone Width (Av. LB RB)	20
	HB Q1: Riparian Zone Width (LB) - Rank	20
	HB Q1: Riparian Zone Width (RB) - Rank	20
	HB Q2: Vegetative Protection (Av. LB RB)	19
	HB Q2: Vegetative Protection (LB) - Rank	19
	HB Q2: Vegetative Protection (RB) - Rank	19
	HB Q3: Bank Stability (Av. of LB & RB)	16
	HB Q3: Bank Stability (LB) - Rank	16
	HB Q3: Bank Stability (RB) - Rank	16
	HB Q4: Frequency of Riffle - Rank	16
Vchann; Vlining; Vbank	HB Q5: Channel Alteration - Rank	20
	HB Q6: Sediment Deposition - Rank	18
	HB Q7: Velocity/Depth Regime - Rank	15
	HB Q8: Abundance & Diversity of Habitat	19
	HB Q9: Periphyton - Rank	19
	HB Total Score - Rank	162
	SB Habitat Assess 2005+	
	SB Q1: Riparian Zone Width (av. LB RB)	
	SB Q1: Riparian Zone Width (LB)	
	SB Q1: Riparian Zone Width (RB)	
	SB Q2: Vegetative Protection (av. LB RB)	

Vchann; Vlining; Vbank	SB Q2: Vegetative Protection (LB) SB Q2: Vegetative Protection (RB) SB Q3: Bank Stability (av. of LB & RB) SB Q3: Bank Stability (LB) SB Q3: Bank Stability (RB) SB Q4: Channel Sinuosity SB Q5: Channel Alteration SB Q6: Sediment Deposition SB Q7: Pool Variability SB Q8: Abundance & Diversity of Habitat SB Q9: Periphyton - Rank SB total score	
	Calculations for proxy SEV data	
Vchann	QHA Q5	20
Vchann	M&P 25-75%	no
Vchann	Wood <5%	yes
Vimperv	GIS map assessment - u/s impervious surfaces	1
Vwatqual	GIS map assessment - u/s catch shade	1
Vbank	GIS map assessment - Score accurate?	Yes
Vbarr	GIS map assessment - barriers to migration in reach	1
Vpipe	GIS map assessment - point discharges	1
Vmacro	Surface reaching/emergent total	0
	Below surface total	0
	TOTAL	**0**
Vdod	Average of sediment, shade & macrophyte cover	1
Vripconn	Convert QHA Q5 to proportion	1
Vphyshab	**RHA Q2&4 - Mean habitat diversity x2**	**19**
Vphyshab	**RHA Q3&5 - Mean habitat abundance x2**	**19**
vsurf	**Proportional cover of substrates**	
Organic	Leaf litter	10
	Periphyton, submerged macrophytes	0.2
	Wood, roots, emergent & floating vege	0
Substrate size class (mm)	**SI/SA <2**	6
	SG 2-8	
	SMG 8-16	21
	MLG 16-32	
	LG 32-64	51
	SC 64-128	
	LC 128-256	20
	B >256	0
	Bedrock	2
	Sml Wood <50	
	Med Wood 50-100	
	Lrg Wood >100	2
	Total	102

Table 11. Description of detailed methodologies used to calculate proxy scores for each SEV variable

Variable Code	Method / Data source	Description			
V_{depth}	SEV	10 x cross sections w depth measurements @ 10%, 30%, 50%, 70% & 90% across from TRB to TRB. Contributes to vDOD (mean velocity/mean depth)			
	WRC SOE	**Macrophyte & Periphyton assessment**			
	Proxy SEV	**Method: Use mean thalweg depths (max depth x 5) recorded w macrophyte & periphyton assessment**			
V_{veloc}	SEV	10 x cross sections w velocity measured at swiftest point of flow. Contributes to vDOD			
	WRC SOE	**None**			
	Proxy SEV	**Method: Use NZ River Maps online. Identify reach closest to monitoring location. Select median flow rate & divide by area of flow (wetted width x depth) to calculate velocity. check model accuracy against Wetted Width estimates. Refer https://shiny.niwa.co.nz/nzrivermaps/**			
V_{pipe}	SEV	Size and number of stormwater pipes or mole/tile drains; 1=none	2=one <20cm diameter	3=several or >20cm diameter	
	WRC SOE	**None**	**None**	**None**	
	Proxy SEV	**Method: Use WRC GIS layers & maps and/or LAWA, NZ River Maps, GoogleMaps**			
V_{bank}	SEV	a. Movement of flood flows onto and across the floodplain is not restricted by any artificial structures or modifications.	b. Floodplain present, but connectivity to the full floodplain is restricted by modification, for example stop banks or urban development.	c. Floodplain present, but connectivity to floodplain reduced by channel incision or bank widening so that most flood flows are unlikely to reach the floodplain.	d. No hydrological connectivity with floodplain as all flows are likely to be artificially contained within the channel.
	WRC SOE	**QHA Q5: Channel Alteration Optimal Rank 16-20**	**QHA Q5: Channel Alteration Suboptimal Rank 11-15**	**QHA Q5: Channel Alteration Marginal Rank 6 -10**	**QHA Q5: Channel Alteration Marginal & Poor Rank 1 -5**
	Proxy SEV	**Method: Match with assessment category, proportion =1 (QHA Q5) AND cross check with GIS maps**			
V_{barr}	SEV	Barriers to fish migration **in assessment reach;** No=1	Partial=2	Total=3	
	WRC SOE	**None**	**None**	**None**	
	Proxy SEV	**Method: use expert opinion and/or WRC GIS maps and/or LAWA, NZ River Maps, GoogleMaps**			

Vdod	SEV	Status: **Optimal=1** - No anaerobic sediment, little or no macrophytes, high shade	**Sub-optimal=2** - No anaerobic sediment, moderate macrophytes, moderate shade	**Marginal=3** - minimal anaerobic sediment, dense macrophytes, low shade	**Poor=4** - much anaerobic sediment, excessive macrophytes, no shade, surface scums
	WRC SOE	**RHA Q1: Deposited sediment - Score 9-10**	**RHA Q1: Deposited sediment - Score 7-8**	**RHA Q1: Deposited sediment - Score 5-6**	**RHA Q1: Deposited sediment - Score 1-5**
	WRC SOE	**RHA Q10: Riparian shade - Score 8-10**	**RHA Q10: Riparian shade - Score 7-5**	**RHA Q10: Riparian shade - Score 3-4**	**RHA Q10: Riparian shade - Score 1-2**
	WRC SOE	**Macrophyte & Periphyton assessment: Total Cover <5%**	**Macrophyte & Periphyton assessment: Total Cover 5-25%**	**Macrophyte & Periphyton assessment: Total Cover 26-75%**	**Macrophyte & Periphyton assessment: Total Cover >75%**
	Proxy SEV	**Method: Match sediment (RHA Q1), shade (RHA Q10) & macrophyte cover (M&P assessment) scores to DOD status 1,2,3 or 4 and average**			
Vmacro	SEV	Proportion of transect covered by surface-reaching/emergent/bankside macrophytes, &/OR Submerged macrophytes			
	WRC SOE	**Macrophyte assessment: Surface reaching & Emergent; exotic % + native %**		**Macrophyte assessment: Below surface Submerged; exotic % + native %**	
	Proxy SEV	**Method: Match with Macrophyte/periphyton assessment, if available; or QHA CoverPg**			
Vgalspwn	SEV	Length of Galaxiidae spawning habitat, i.e. near-flat (slope<10°) (m) / length of reach = proportion of reach banks suitable for spawning = R			
	SEV	R > 0.25	R <0.25 & > 0.01	R <0.01	
	SEV weights	1	0.1 - 0.9	0	
	WRC SOE	**None**	**None**	**None**	
	Proxy SEV	**No method: Data gap**			
Vgalqual	SEV	Quality of fish spawning habitat (High=1)	Medium=2	Low=3	Unsuitable=4
	SEV	Under dense canopy >80% shade	Under moderate canopy 50-80% shade	Under partial canopy 10-50% shade	Under low canopy <10% shade
	SEV	Near flat bank <1° w heavy plant cover/leaf litter	Gently sloped bank 1-5° w moderate plant cover/leaf litter	Sloped bank 5-10° w sparce plant cover/leaf litter	Steep sloped bank >10° OR <10% plant cover/leaf litter
	WRC SOE	**RHA Q10: Riparian shade - Score 9-10**	**Score 6-8**	**Score 3-5**	**Score 1-2**
	WRC SOE	**RHA Q8: Bank vegetation - Score 9-10**	**Score 6-8**	**Score 3-5**	**Score 1-2**

	WRC SOE	**QHA Q5: Channel Alteration Optimal Rank 16-20**	**QHA Q5: Channel Alteration Suboptimal Rank 11-15**	**QHA Q5: Channel Alteration Marginal Rank 6 -10**	**QHA Q5: Channel Alteration Marginal & Poor Rank 1 -5**
	Proxy SEV	**Method: Consider riparian shade (RHA Q10), bank vegetation (RHA Q8), channel alteration (QHA Q5) & select most appropriate Vgalsqual score (1,2,3, or 4) for each, then select the mean**			
$V_{physhab}$	SEV a.	Aquatic habitat diversity: Optimal (score 16-20)	Aquatic habitat diversity: Suboptimal (score 11-15)	Aquatic habitat diversity: Marginal (score 6-10)	Aquatic habitat diversity: Poor (score 0-5)
	SEV b.	Aquatic habitat abundance: Optimal (score 16-20)	Aquatic habitat abundance: Suboptimal (score 11-15)	Aquatic habitat abundance: Marginal (score 6-10)	Aquatic habitat abundance: Poor (score 0-5)
	SEV c.	Hydraulic heterogeneity: Optimal (score 16-20)	Hydraulic heterogeneity: Suboptimal (score 11-15)	Hydraulic heterogeneity: Marginal (score 6-10)	Hydraulic heterogeneity: Poor (score 0-5)
	SEV d.	Channel shade: Optimal (score 16-20)	Channel shade: Suboptimal (score 11-15)	Channel shade: Marginal (score 6-10)	Channel shade: Poor (score 0-5)
	SEV e.	Riparian vege integrity: Optimal (score 16-20)	Riparian vege integrity: Suboptimal (score 11-15)	Riparian vege integrity: Marginal (score 6-10)	Riparian vege integrity: Poor (score 0-5)
	WRC SOE a.	**RHA Q2&4: Invertebrate & Fish habitat diversity - Score 9-10**	**RHA Q2&4: Invertebrate & Fish habitat diversity - Score 6-8**	**RHA Q2&4: Invertebrate & Fish habitat diversity - Score 3-5**	**RHA Q2&4: Invertebrate & Fish habitat diversity - Score 1-2**
	WRC SOE b.	**RHA Q3&5: Invertebrate & Fish habitat abundance - Score 9-10**	**RHA Q3&5: Invertebrate & Fish habitat abundance - Score 6-8**	**RHA Q3&5: Invertebrate & Fish habitat abundance - Score 3-5**	**RHA Q3&5: Invertebrate & Fish habitat abundance - Score 1-2**
	WRC SOE c.	**RHA Q6: Hydraulic heterogeneity - Score 9-10**	**RHA Q6: Hydraulic heterogeneity - Score 6-8**	**RHA Q6: Hydraulic heterogeneity - Score 3-5**	**RHA Q6: Hydraulic heterogeneity - Score 1-2**
	WRC SOE d.	**RHA Q10: Riparian shade - Score 9-10**	**RHA Q10: Riparian shade - Score 6-8**	**RHA Q10: Riparian shade - Score 3-5**	**RHA Q10: Riparian shade - Score 1-2**
	WRC SOE e.	**RHA Q8: Bank vegetation - Score 9-10**	**RHA Q8: Bank vegetation - Score 6-8**	**RHA Q8: Bank vegetation - Score 3-5**	**RHA Q8: Bank vegetation - Score 1-2**
		Method: Match with corresponding assessment category, SEV rank value a. b. c. d. e. = RHA Q2&4 (mean), Q3&5 (mean), Q6, Q10, Q8 score x 2			

$V_{watqual}$	SEV	Extent of upstream shading: Well shaded (>50% stream length u/s forested)	Extent of upstream shading: Partially shaded (<50% stream length u/s forested)	Extent of upstream shading: Minimally shaded (pasture w some riparian cover)	Extent of upstream shading: No upstream shade
	WRC SOE	**None**			
	Proxy SEV	**Method: Follow steps described by SEV method - use WRC GIS maps and/or Topomap, LAWA, NZ River Maps, GoogleMaps**			
V_{imperv}	SEV	Extent of catchment upstream covered by impervious surface + extent of flow control measures			
	SOE	**None**			
	Proxy SEV	**Method: Follow steps described by SEV method - use WRC GIS maps and/or Topomap, LAWA, NZ River Maps, GoogleMaps**			
V_{fish}	SEV	Fish community information requires the use of the fish IBI			
	SOE	**REMS fish surveys**			
	Proxy SEV	**Method: Follow steps described by IBI method**			
V_{mci}	SEV	Macroinvertebrate presence/absence data used to calculate MCI score			
		REMS macroinvertebrate sampling			
	Proxy SEV	**Method: Follow steps described by SEV method**			
V_{ept}	SEV	Macroinvertebrate presence/absence data used to calculate EPT variables			
		REMS macroinvertebrate sampling			
	Proxy SEV	**Method: Follow steps described by SEV method**			
V_{invert}	SEV	Macroinvertebrate presence/absence data compared to reference site taxa list			
		REMS macroinvertebrate sampling			
	Proxy SEV	**Method: Follow steps described by SEV method**			
$V_{ripcond}$	SEV	No data entry required			
		As for Vchann			
	Proxy SEV	**Method: Follow steps described by SEV method**			
$V_{ripconn}$	SEV	Connection between riparian zone & stream channel - Proportion of stream channel where stream channel NOT impeded (0 - 1)			
	WRC SOE	**QHA Q5: Channel Alteration Optimal Rank 16-20**	**QHA Q5: Channel Alteration Suboptimal Rank 11-15**	**QHA Q5: Channel Alteration Marginal Rank 6 -10**	**QHA Q5: Channel Alteration Marginal & Poor Rank 1 -5**
	Proxy SEV	**Method: Match with assessment category, SEV proportion value = (QHA Q5 score x 5)/ 100**			

V_{shade}	SEV	**a.** Very high shading; shading from vegetation and topographical features > 90%	**b.** High shading; shading from vegetation and topographical features 71 - 90%	**c.** Moderate shading; shading from vegetation and topographical features 51 - 70%	**d.** Low shading; shading from vegetation and topographical features 31 - 50%	**e.** Very low shading; shading from vegetation and topographical features 11 - 30%	**f.** No effective shading; shading from vegetation and topographical features < 10%	
	WRC SOE	**RHA Q10: Riparian shade - Score 10**	**RHA Q10: Riparian shade - Score 8-9**	**RHA Q10: Riparian shade - Score 6-7**	**RHA Q10: Riparian shade - Score 5**	**RHA Q10: Riparian shade -Score 3-4**	**RHA Q10: Riparian shade -Score 1-2**	
	Proxy	**Method: Use Densiometer measurements (if available), or match with assessment category, SEV frequency value = RHA Q10 category x 10**						
$V_{ripfilt}$	SEV	**Proportion of bank length with:** **a.** Very high filtering activity. Dense ground cover vegetation or thick organic litter layer under canopy; **AND** run-off into stream diffuse, with no defined drainage channels; **AND** width of buffer greater than 5x channel width.	**b.** High filtering activity. Dense ground cover vegetation or thick organic litter layer under canopy; **AND** run-off into stream diffuse, with only minor defined drainage channels, **AND/OR** width of buffer <5x channel width.	**c.** Moderate filtering activity. Uniform ground cover vegetation or abundant organic litter under canopy; **AND** run-off into stream mostly diffuse, with few defined drainage channels.	**d.** Low filtering activity. Patchy ground cover vegetation or little organic litter layer under canopy; **AND/OR** some run-off into stream in small defined drainage channels.	**e.** Very low filtering activity. Short (mown or grazed) vegetation, with high soil compaction; **AND/OR** run-off into stream mostly contained in small defined drainage channels.	**f.** No filtering activity; banks bare or impermeable.	
	WRC SOE	**RHA Q8: Bank vegetation - Score 10**	**RHA Q8: Bank vegetation - Score 8-9**	**RHA Q8: Bank vegetation - Score 6-7**	**RHA Q8: Bank vegetation - Score 4-5**	**RHA Q8: Bank vegetation - Score 2-3**	**RHA Q8: Bank vegetation - Score 1**	
	Proxy	**Method: match with assessment category, proportion = 1 (RHA Q8)**						
V_{chann} $V_{chanshape}$ V_{retain}	SEV	a. Natural channel with no modification	b. Natural channel, but flow patterns affected by reduction in roughness elements (e.g. logs, boulders).	c. Channel not straightened or deepened but upper banks widened to increase flood capacity.	d. Natural channel, but evidence of channel incision from flood flows	e. Natural channel shape but flow patterns affected by increase in roughness elements (e.g. excessive macrophytes).	f. Flow patterns affected by instream structure (e.g. ponding due to culvert, weir or unnatural debris).	g. Channel straightened and/or deepened
	WRC SOE	**QHA Q5: Channel Alteration - Optimal 16-20**	**REMS Large Wood < 5 % cover**	**QHA Q5: Channel Alteration - Sub to Optimal 11-15**	**None**	**Macrophyte & Periphyton: Total Cover 26-75%**	**None**	**QHA Q5: Channel Alteration - Marginal <8**
	Proxy SEV	**Method: If 1 match with assessment category, proportion =1 (QHA Q5), if 2 matches, proportion = 0.75 (QHA Q5) + 0.25 (QHA Macro/wood), if 3 matches, proportion = 0.4 + 0.3 + 0.3**						

V_{lining}	SEV	**a-i.** Natural channel with no modification - proportion = 0.8	**a-ii.** Natural channel with no modification - proportion = 0.5	**b.** Bed with unnatural loading of fine silt	**c.** Bank **OR** bed lined with **permeable** artificial lining (e.g. gabion baskets).	**d.** Bank **OR** bed lined with **impermeable** artificial lining (e.g. concrete).	**e.** Banks **AND** bed entirely lined with **permeable** artificial materials.	**f.** Banks **AND** bed entirely lined with **impermeable** artificial materials (e.g. culverts)			
	WRC SOE	**QHA Q5: Channel Alteration - Optimal 16-20**	**QHA Q5: Channel Alteration - Sub to Optimal 11-15**	**RHA Q1: Deposited sediment > 50%/ score < 3**	**QHA Q5: Channel Alteration - Marginal <8**	**QHA Q5: Channel Alteration - Poor 5**	**QHA Q5: Channel Alteration - Poor 2-4**	**QHA Q5: Channel Alteration - Poor 1**			
	Proxy	**Method: If 1 match with assessment category, proportion =1 (QHA Q5), if 2 matches, proportion = 0.8/0.5 (QHA Q5) + 0.2/0.5 (RHA Q1)**									
V_{surf}	SEV	Silt/sand (SI/SA <2 mm)	Small medium gravel (SMG 8-16 mm)	Large gravel (LG 32-64 mm)	Large cobble (LC 128-256 mm)	Boulder (> 256 mm)	Bedrock (BR)	Wood (LW > 100 mm)	Leaf litter - proportional cover	Periphyton, submerged macrophytes - proportional cover	Wood, roots, plus emergent and floating vegetation - proportional cover
	WRC SOE	**REMS substrate: clay + silt + sand + mud**	**REMS substrate: small gravel**	**REMS substrate: large gravel**	**REMS substrate: large cobble**	**REMS substrate: Boulder**	**REMS substrate: Bedrock**	**REMS Large Wood % cover**	**REMS Coarse detritus % cover**	**M&P assessment: Sum Periphyton + Submerged macrophyte % cover**	**Macrophyte assessment: SUM Surface reaching & Emergent; exotic % + native %**
	Proxy SEV	**Method: match with corresponding REMS substrate composition proportional assessments. Divide #% by 10 and replicate across each x 10 transects for each category. Ensure 'Sum' matches original proportional number.**									
V_{ripar}	SEV	Proportion of riparian zone covered in trees or bushes (20 m either side of stream)									
	WRC SOE	**RHA Q9: Riparian width - Score 10= >30 m**	**RHA Q9: Riparian width - Score 9=15 m**	**RHA Q9: Riparian width - Score 8=10 m**	**RHA Q9: Riparian width - Score 7=7 m**	**RHA Q9: Riparian width - Score 6=5 m**	**RHA Q9: Riparian width - Score 5=4 m**	**RHA Q9: Riparian width - Score 4=3 m**	**RHA Q9: Riparian width - Score 3=2 m**	**RHA Q9: Riparian width - Score 2=1 m**	**RHA Q9: Riparian width - Score 1=0 m**
	Proxy	**1.0**	**0.75**	**0.5**	**0.35**	**0.25**	**0.2**	**0.15**	**0.1**	**0.05**	**0**
		Method: Match RHA score to proportion as given above.									
V_{decid}	SEV	Proportion of canopy cover that is EVERGREEN i.e. permanent:									

SEV	1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1
WRC SOE	**RHA Q10: Riparian shade - Score 10**	**Score 9**	**Score 8**	**Score 7**	**Score 6**	**Score 5**	**Score 4**	**Score 3**	**Score 2**	**Score 1**
	Method: Match with assessment category, SEV frequency value = RHA Q10 score / 10 for x 10 transects									

V_{rough}	SEV	**a.** Mature native vege with diverse canopy and under-storey	**b.** Regen. native vege in late stage of suc-cession.	**c.** Natural diverse wetland vege on banks	**d.** Mature native trees but damaged under-storey	**e.** Mature exotic trees (e.g. willows or pine forest)	**f.** Low diversity regen bush with *stock excluded* **OR** tall exotic shrubs (> 2m)	**g.** Mature flax, long grasses and sedges	**h.** Low diversity regen bush with stock access **OR** Early stage restoration planting **OR** Short exotic shrubs (< 2m) **OR** Immature exotic forest	**i.** Mainly long grass (not grazed or mown)	**j.** Grazed wetlands	**k.** Mainly short grasses	**l.** Disturbed bare soil or artificial surfaces.
	WRC SOE	**RHA Q8: Bank vege - Score 10**	**RHA Q8: Bank vege - Score 9**	**RHA Q8: Bank vege - Score 8 (split prop. with g.)**	**RHA Q8: Bank vege - Score 7**	**RHA Q8: Bank vege - Score 6**	**RHA Q8: Bank vege - Score 5 IF STOCK excluded (refer QHA CoverPg Fence)**	**RHA Q8: Bank vege - Score 8 (split prop. with c.)**	**RHA Q8: Bank vege - Score 4 IF STOCK excluded (refer QHA CoverPg Fence)**	**RHA Q8: Bank vege - Score 3**	**RHA Q8: Bank vege - Score 2 (split prop. with k.)**	**RHA Q8: Bank vege - Score 2 (split prop. with j.)**	**RHA Q8: Bank vege - Score 1**
	Proxy SEV	**Method: If 1 match of assessment category, proportion =1 (RHA Q8), if 2 matches, proportion = 0.5 + 0.5 (e.g. RHA Q8 score 8 & 2)**											