# Stream Ecological Valuation (SEV): a method for assessing the ecological functions of Auckland streams

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Auckland Council
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# Stream Ecological Valuation (SEV): a method for assessing the ecological functions of Auckland streams

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# Preface

The first edition of the Stream Ecological Valuation (SEV) Technical Report (Rowe *et al*., 2006; Auckland Regional Council Technical Publication 302) was released in June 2006 and was followed by an updated second edition in January 2008 (Rowe *et al*., 2008). These reports were the result of a series of workshops at which an expert panel of freshwater ecologists sought to develop an ecosystem valuation system for Auckland streams. The reports provide the scientific background and reasoning behind the development of the SEV, together with a technical description of the variables and functions which are used in the SEV scoring system.

The widespread use of the SEV since its initial publication in 2006 has provided an abundance of SEV data and practical experience of the methodology, and much feedback has been received (both positive and negative) raising many issues and questions. During 2010, the former Auckland Regional Council reconvened the expert panel to review the SEV and consider the feedback received.

The panel recognised the sound scientific basis of the SEV method, but saw opportunities to resolve some redundancy and duplication issues within the method and also to address variables or functions that were not performing as well as anticipated. The result is this report, describing a revised SEV that is simpler and more efficient to carry out, yet has not lost any important information. In conjunction with the review, we have also produced an illustrated User's Guide that provides practical and photographic guidance to carrying out an SEV (Neale *et al*., 2011).

Contents

# 1 Executive Summary

This report details the technical background of the Stream Ecological Valuation (SEV), a method for quantifying the values of streams based on the performance of their key ecological functions. The SEV was developed to quantify the ecological value of streams in a consistent manner to inform resource management decisions. Historically, such assessments have been inconsistent and therefore of varying, but often limited, value for reliably assessing the ecological value of the resource. Hence, the requirement for a standard approach for assessing the ecological value of streams was recognised and provided the stimulus for the development of the SEV.

The first version of the SEV was released in 2006 following a series of workshops during which the method was developed by a panel of freshwater scientists. Subsequently, the SEV has been used extensively for a wide variety of purposes and as a result, a large amount of data and experience has accrued. Therefore in late 2010, five years after the original release, it was considered timely and appropriate to utilise this data and experience to inform a review the SEV method. The review was primarily achieved by two workshops of the SEV expert panel, which resulted in an update of the supporting materials.

The review focussed on resolving performance issues, including reducing duplication and redundancy, improving the practical guidance for undertaking SEV assessments and promoting consistency amongst the SEV supporting materials. This has resulted in a series of changes to the SEV method; the number of functions has been reduced from 16 to 14 and the number of variables from 31 to 28. The functions and variables are described in detail, together with the scoring method for each one. The supporting materials have been supplemented by an illustrated user's guide designed to be used in the field. As a result, the scope of this technical report has been narrowed to focus on the technical and scientific background of the SEV.

The revised SEV methodology consists of the 14 most important functions that were identified by the expert panel. The functions fall into four broad categories; hydraulic (four functions), biogeochemical (five functions), habitat provision (two functions) and biodiversity (three functions). The SEV method assesses the performance of each function compared with reference conditions, and provides a framework to compile, interpret and report the results in a numeric scoring system.

The performance of the revised 14-function methodology was tested at 19 sites, first to assess the practicalities of the revisions and second to compare the results obtained with those from the original 16-function version. The testing indicated that the revised SEV performs in a similar way to the original version, but with a greater discrimination among sites. This was an important result, indicating the revision of the method has not resulted in the loss of any important information, and gives us confidence that overall SEV scores from the two methods can be related to each other.

The report concludes with a chapter on the current and anticipated uses of the SEV, which include ecological monitoring programmes, catchment and stream restoration planning, as a scientific research tool and deriving environmental compensation ratios. These examples are provided for illustration and do not represent an exhaustive or comprehensive list of uses for the SEV.

# 2 Introduction

Systems for quantifying the values of ecosystems have been developed for many different ecosystem types in response to the widespread loss and degradation of ecological functions. Typically the main objective is to account for the loss of function due to a particular human activity or development, so that an equivalent gain in ecological function can be achieved in another place. However, the systems for quantifying ecological functions and values can also be applied for a variety of other purposes, such as catchment planning or state of the environment monitoring.

The Stream Ecological Valuation (Rowe *et al*. 2006, 2008) was derived from a method applied to wetlands by the US Environmental Protection Agency and US Army Corps of Engineers (e.g., Brinson 1993; Smith *et al*. 1995; Sudol 1996, Brinson & Rheinhardt 1996). The method was being used to underpin environmental compensation for wetland restoration, as described above. It was adapted from US wetlands to Auckland streams by a team of eight stream scientists with experience of Auckland streams and different areas of expertise in stream ecology. The team was assembled from two Crown Research Institutes (NIWA & Landcare), Massey University, Environment Waikato and the Auckland Regional Council.

The team identified the main ecological functions of a series of streams in Albany, and through a series of workshops, developed a system for assessing the extent to which these functions are changed in modified streams compared to unmodified reference streams. To implement the system, field assessments were carried out on a group of relatively unmodified reference streams, as well as in some modified streams, to identify practical issues with variable measurement and to establish the reference stream baseline.

The first edition of the SEV Guideline was released in June 2006 (Rowe *et al*. 2006). The guideline was based on field data that were limited in quantity, geographical coverage and stream type. The second edition, released in January 2008 (Rowe *et al*. 2008), followed additional field experience using SEV, and several Environment Court cases that provided guidance on legal principles and terminology regarding environmental compensation. Based on this additional experience, the second edition expanded and modified some of the concepts in SEV, and provided updated formulae for calculating environmental compensation ratios for streams.

Since its first release in 2006, the SEV has been used extensively for a wide variety of purposes. It is commonly used in resource consent applications as part of an assessment of ecological effects and for calculating environmental compensation requirements. However, it has also been used for identifying streams of high natural value, for determining the effects of land use change (e.g. Macdonald 2006, Storey *et al*. 2009) for prioritising streams for restoration works and for identifying the most effective options for restoration to improve ecological function. Because SEV combines a broad range of physical, chemical and biological functions in a single assessment framework, it is also being used increasingly for monitoring of stream health, complementing more specific measures such as water quality and benthic invertebrates. The Auckland Council, for example, now conducts SEV assessments at each of its river ecology State of Environment monitoring sites.

As a result, since the publication of the SEV in 2006 a wide range of people have gained experience in using SEV and a large amount of SEV data has been collected from across Auckland. Over 50 resource consent applications using SEV received by the Auckland Council to date, and numerous scientific reports for councils have used SEV (e.g. Phillips *et al*. 2006, Storey 2008, 2009, 2010a; Storey *et al.,* 2009; Chapman *et al*., 2010). Over 100 people, including environmental consultants, engineers, and city, district and regional council staff, have attended Auckland Council SEV training courses. The SEV method has also reached an international audience, having been published in the international peer-reviewed scientific journal Environmental Management (Rowe *et al*., 2009).

# 3 SEV review

In the first edition of the SEV (Rowe *et al*. 2006), it was anticipated that improvements to the method would become apparent as user experience and field data accumulated, and as the science underlying the method developed. Since then, feedback on all aspects of the method has been gathered from SEV users, trainers and council staff. In addition, the method was independently reviewed in 2008 by Richard Rheinhardt (Department of Biology, East Carolina University, USA), an international expert in the field of environmental compensation, and again in 2009 for the journal Environmental Management by two anonymous reviewers (Rowe *et al*. 2009). Furthermore, a workshop was held with SEV practitioners in 2010 to gain further end-user feedback. The issues raised by the various reviewers and users ranged from the practicality of the method to its scientific robustness, level of subjectivity, degree of complexity, applicability in different situations, interpretation, and the consistency between the SEV manual, field sheets and spreadsheet calculator.

In late 2010, two workshops were held to address the issues raised, and review the performance of SEV in light of accumulated field data. The workshops involved an expert panel consisting of most members of the original SEV team, plus additional freshwater ecologists from NIWA and Auckland Council. Some general outcomes of those workshops were that:

- Some variables and functions were redundant and could be removed or combined with others
- The equations for some functions and their underlying variables could be simplified
- Some variables, while in theory being important drivers of ecological function, were not in practice distinguishing natural from modified conditions, and could be removed.
- The category descriptions for some variables should be made clearer and should cover a wider range of conditions.

In addition, the panel emphasised two fundamental points:

- For all functions, a stream in natural (unmodified) condition will always score close to 1. While the first edition of SEV also regarded naturalness as the ecological standard underpinning the assessment, it was possible for some function scores to be lowered by natural features (for example, a natural waterfall reduced the score for Connectivity for Species Migrations). To improve consistency, the definitions of some functions have been altered so that the natural condition is always given a score of close to 1, and a lower score indicates a departure from the natural condition.
- The focus of SEV is on the ecological functioning of individual stream reaches. This means that factors outside the reach are not considered, even if they affect the state of the reach, except where they affect its ability to perform the relevant ecological function.

The review has resulted in a series of changes to the SEV method; the number of functions has been reduced from 16 to 14 and the number of variables from 31 to 28. One function was removed completely, two functions merged into one and the calculations for several functions were simplified (see section 6.2 for more detail).

# 4 Guidelines for conducting SEV assessments

## 4.1 Timing

SEV is based on summer conditions, but it should be possible to conduct SEV assessments accurately in any season. Most variables will change little with season, but a few will be affected (e.g. $V_{shade}$ by changes in leaf cover on deciduous trees, $V_{dod}$ by changes in instream macrophyte growth). The general principle in these situations is to score variables according to what mid-summer conditions are likely to be.

SEV assessments should not be conducted within about three weeks of a major flood (typically defined as a stream flow greater than three times the median flow), as some characteristics of the stream, such as the invertebrate community, take time to recover from high flow events.

## 4.2 Length of stream reach

In some cases, the length of reach to assess is determined by the purpose of the assessment. For example, if resource consent is required to pipe 70 m of stream, the SEV assessment should be conducted over the entire 70 m. In other cases the reach length may not be pre-determined, e.g. if a reach is selected to represent streams of a certain size and type in a geographic area. In this case, the minimum reach length should be 20x the average stream width, and not less than 50 m long. We do not specify a maximum reach length, as the SEV score should not be affected by lengthening the reach beyond this minimum length. However, the reach should not extend across a major change in land use or stream physical characteristic.

## 4.3 Applicability of SEV in different stream types and geographic regions

SEV was developed specifically for wadeable, low-gradient streams in the Auckland region. Even within this description there exists a variety of stream types (e.g., soft-bottomed vs. hard-bottomed). Therefore, in order to correctly calculate certain variables (e.g., invertebrate variables) and interpret the final SEV scores, reference sites selected must be of the same stream type as the test sites. The River Environment Classification (REC; http://www.niwa.co.nz/our-science/freshwater/tools/rec) and Freshwater Environments of New Zealand (FENZ) can be used to identify stream types and locate suitable reference sites.

The like-with-like principle should be followed also when comparing SEV scores among test sites. Although SEV scores should be broadly comparable across the different stream types for which it has been tested, great care must be exercised when comparing individual functions among very different stream types.

Since it was developed, SEV has been used successfully in stream types and regions beyond for which it was developed. It has become apparent that SEV may be used in a wide range of stream types and regions, however we advise caution when applying SEV in some stream types and regions (Table 1). SEV should not be used in streams with salt-water influence, or those that drain wetlands where the channel is not clearly defined. SEV is expected to perform well in lake-fed and spring-fed streams, but has not been evaluated for situations where springs arise within the study reach (Storey, 2011). SEV may be used with caution in intermittent streams, but see Storey (2010b) for a review of potential issues. We have not tested the performance of SEV in streams and rivers of fourth order or larger. Streams and rivers with highly mobile gravel or cobble beds and extensive gravel/cobble banks have important ecological functions relating to the export of that material and the interactions of the wetted channel with the gravel banks (Storey, 2011). SEV does not include these functions, therefore is incomplete for assessing rivers of this type.

In all cases where SEV is used for different stream types or regions, reference data must be collected for the same stream type as the test sites in order to correctly calculate certain variables (e.g., invertebrate variables) and interpret the final SEV scores.

SEV has been reviewed by NIWA for use in Wellington, Hawke's Bay and Southland, and is considered applicable without modification to most stream and river types in those regions. However, reference sites must be located in the same geographic area as the test sites. It is likely, but not guaranteed, that SEV can be used in any region of New Zealand without modifying the method. If a user believes that a modification is required, the modification must be considered by at least three members of the expert panel (the authors of this report) and approved by the Manager (Research, Investigations and Monitoring) of the Auckland Council.

**Table 1**

Applicability of SEV in different stream types

| Stream type | Applicability of SEV |
|---|---|
| Saltwater influenced | Do not use |
| Tidally influenced | Can be used where stream water is backed-up by high tides but above saltwater influence. Data should be collected around low tide. |
| Wetlands (stream channel not well-defined) | Do not use |
| High gradient streams | OK to use |
| Lake-fed streams | OK to use |
| Spring-fed streams | OK to use |
| Intermittent streams | Use with caution (see Storey (2010b) for potential issues |
| Fourth-order and larger rivers | SEV performance not tested, but could be used if suitable reference data is collected |
| Rivers with mobile gravel beds and extensive gravel banks | Functions concerning gravel export and interaction of rivers with gravel banks are not captured by SEV (Storey, 2011). SEV can be used provided the absence of these functions is acknowledged. |

## 4.4 Dealing with lack of reference sites

The original version of the SEV required the user to collect reference site data to generate SEV scores, however in this revised version, reference site data for Auckland has been incorporated into the scoring algorithms. The reference data for the current version of SEV has been derived from the Auckland Council's State of Environment monitoring network, which means collecting reference data is no longer required in Auckland. For the purposes of the Auckland Council monitoring network, a reference site has a catchment with greater than 95% native forest cover and no urban development. When using the SEV outside of the coverage of this monitoring network, appropriate reference data should be collected.

Despite our strong recommendation to use reference data from sites equivalent to the test sites, it may be possible to conduct SEV in stream types or geographic areas where no equivalent reference sites are available. This will rely on best professional judgment by the user, and we recommend consulting with the authors of this report for the best option. One option may be to develop a hypothetical reference site that combines reference conditions from a variety of streams that are each unmodified in terms of particular functions. For example, one stream may be unmodified in terms of some natural flow regime, another in terms of organic matter input. Historical records (e.g., of vegetation cover) may also be used to describe the hypothetical reference stream. For some functions it may be valid to assume the natural condition, e.g., shading of 90% over small streams where forest once existed, or no artificial barriers to species migrations.

Reference assemblages of invertebrates and fish may be the most difficult to determine. Wherever possible, taxa lists should be based on real data, which are most likely to be held by the relevant regional council. Other resources such as FENZ (Freshwater Environments of New Zealand), a GIS geo-database that includes predictive models for freshwater fish and invertebrate distributions across New Zealand may be particularly helpful (Leathwick *et al*. 2008. NIWA's Freshwater Fish Database (http://www.niwa.co.nz/our-services/databases/freshwater-fish-database), and NIWA's Freshwater Biodata Information System (FBIS; https://secure.niwa.co.nz/fbis/index.do) also may help to predict reference fish and invertebrate assemblages.

## 4.5 Use of SEV by non-ecologists

SEV has been designed to be used by those with formal training in ecological field methods, and who have attended a SEV training course. We recommend that people without such training use less technical methods of stream assessment such as the Stream Health Monitoring and Assessment Kit (NIWA 2002), the WaiCare Invertebrate Monitoring Protocol (Jones *et al*. 2007) or elements of the Restoration Indicator Toolkit (Parkyn *et al*. 2010).

# 5 The variables, scoring methods and algorithms for each function

SEV consists of the 14 most important ecological functions identified by the expert panel (Table 2). In order to assess the performance of these functions, variables contributing to the functions, and how well they are being performed within a stream reach, need to be measured. The multi-variable approach to the assessment of an ecosystem function requires a way of combining variable measurements into a single comparable measure. This is achieved by scaling the values for each variable between 0 and 1, and by then weighting each variable's contribution to the ecological function to reflect its relative importance. This is accomplished by an algorithm, or formula, that combines each variable score into an overall score for the ecological function.

All potential variables considered useful for assessing each ecological function were identified and discussed during the SEV development workshops. Some variables could not be readily or practically assessed, whereas others were considered to be relevant but of minor value in assessing a particular ecological function in Auckland streams. These variables are omitted and only those considered the best indicators of a function are included in the algorithms. Furthermore, to keep SEV practical, measurements need to be made with a minimum of costly equipment and within a reasonable time period. In some cases, therefore surrogate variables are used in place of the variables directly determining the performance of a function.

Some variable scores of a test site are related to those from unmodified reference streams. This has been achieved by determining the variable values for 16 reference streams relative to 50 modified streams across the Auckland region in 2009 and 2010, then calculating the mean of these reference sites to act as the reference value. The particular variable value from a test site is expressed as a proportion of this reference value. Where this is greater than 1, indicating a higher level of performance than the reference stream, the value is set to 1 (i.e., the maximum score possible). This approach may result in an under-estimate of some functions for some modified streams. For example, biofilms important for decontaminating pollutants may be more extensive in a modified stream with a concrete channel than in a soft-bottomed reference stream.

Whilst some ecological functions could be performed to a greater extent in modified streams than in reference streams, the ecological standard underpinning our assessment of ecological functioning is 'naturalness'. Hence the method seeks to assess the degree to which the ecological performance of a modified stream now differs from its unmodified or 'natural' status. Any over-performance of an ecological function would bias the overall score upward and away from that of the stream in its natural state, just as under-performance reduces its score. Limiting either the variable or function scores to the maximum value for the reference sites is therefore considered valid for the purposes of this assessment.

In the following pages (Section 4), the ecological functions are listed, with the variables used to assess them. A brief commentary is provided on their measurement and the way in which each variable is scored, and then the algorithm for combining the variable scores into an ecosystem function score is presented. Section 5 describes how SEV variable scores are combined to determine an overall index of ecological value or SEV score for example stream reaches, how scores using the revised version compare to those using the previous version, and some examples of how SEV may be used.

**Table 2**
The ecological functions used in the SEV

| **Ecological Function** |
|---|
| Hydraulic Functions |
| • Natural flow regime |
| • Floodplain effectiveness |
| • Connectivity for natural species migrations |
| • Natural connectivity to groundwater |
| Biogeochemical Functions |
| • Water temperature control |
| • Dissolved oxygen levels |
| • Organic matter input |
| • Instream particle retention |
| • Decontamination of pollutants |
| Habitat Provision Functions |
| • Fish spawning habitat |
| • Habitat for aquatic fauna |
| Biodiversity Provision Functions |
| • Fish fauna intact |
| • Invertebrate fauna intact |
| • Riparian vegetation intact |

A companion field manual (Neale *et al.*, 2011) gives practical guidance for conducting SEV assessments in the field. The latest version of the SEV calculator, IBI software and field sheets can be downloaded from the Auckland Council website or the Knowledge Auckland website (http://www.knowledgeauckland.org.nz).

## 5.1 Natural flow regime (NFR)

Changes to the natural flow regime within a stream reach can change its ecological character in several ways. First, it can change the stream's morphological structure such as channel width and depth, the number of meanders, its pool, riffle, run structure, and its substrate characteristics. For example, an increase in current velocity, caused by a reduction in the water retention properties of the reach, may result in greater erosion of the stream channel as well as faster, delivery of water downstream, leading to more downstream flooding and channel erosion. In contrast, retention of water within the reach may affect stream morphology through changes in sediment deposition. A changed flow regime may also alter the biological community directly. Floods scour invertebrates and macrophytes, so increased frequency and severity of flooding may lead to permanent shifts in the composition and abundance of invertebrates, macrophytes and fish. Overall, a natural flow regime will contribute to maintaining the ecological status of streams whereas a departure from this can be expected to change it. The main variables causing change in the flow regime are used to assess this function. While we acknowledge that catchment scale changes in land use and flow management affect the flow regime, we confine the SEV to considering only influences within the study reach.

The first variable ($V_{pipe}$) provides a measure of the main culprit for increased flows in Auckland urban streams: the amount of impermeable land within the catchment that is directly connected to the stream via stormwater pipes. Impermeable area includes areas of asphalt, concrete and roofs. As the area of impervious catchment directly connected to the stream increases, the flow regime will become more characterised by higher flood flows and lower base flows. The amount of impervious area that is directly connected to the stream reach is estimated by the number and size of stormwater discharges to the reach, relative to the size of the stream.

The second variable ($V_{chann}$) estimates the extent of modification to the stream channel that could contribute to a changed flow regime within the reach. Water transit times are decreased by removal of stream meanders (i.e., channel straightening) and removal of "roughness elements" (natural features such as logs and boulders) that cause water to take a more convoluted path between the start and end of the reach. Conversely, artificial features in the channel, such as rubbish, culverts, weirs or excess macrophyte growth, may slow the water and increase transit times. Water transit times during floods are decreased by deepening of the channel and widening of the upper banks. These modifications cause more of the flood waters to be retained within the channel rather than spilling onto flood plains.

Lining of the stream bank or bed (described by the third variable, $V_{lining}$) with smooth surfaces, such as concrete, increases water velocities by reducing the roughness of the stream bank or bed. However, permeable lining materials such as gabion baskets are likely to have less effect on velocities than concrete.

The method of scoring each of the three variables and the algorithm for combining them into the NFR function score is described below.

### 5.1.1 Measurement method

#### 5.1.1.1 $V_{pipe}$

Count the number and size of stormwater pipes and mole or tile drains entering the stream within the study reach. The size of the pipes should be estimated relative to the size of the stream. Here we assume a second-order stream of about 2 m wide, therefore, a small stormwater pipe would be less than 20 cm in diameter (i.e. less than 10% channel width). If you are assessing a larger or smaller stream, scale the influence of the pipe accordingly. Stormwater pipes are considered to have a major influence if they contribute more than 50% of stream flow during a rainfall event.

| Size and number of stormwater pipes and/or tile drains | Score |
|---|---|
| No stormwater pipes or tile drains enter stream reach | 1 |
| One small stormwater pipe or tile drain (<20 cm diam) enters the stream reach. | 0.7 |
| Stormwater pipes or tile drains entering the stream are many (>1) or >20 cm diam. | 0.3 |

#### 5.1.1.2 $V_{chann}$

Visual inspection is carried out to determine the extent of channel modification related to changes in the flow regime. The extent of modification is assessed according to the categories in the table below. If more than one type of modification occurs at a particular place, score the most severe of the modifications. Estimate the proportion of channel that matches each of the categories in the scoring table and sum the values of W x P for each row to obtain $V_{chann}$.

| Channel type | Weighting (W) | Proportion of channel (P) | Score (W x P) |
|---|---|---|---|
| Natural channel with no modification | 1 | | |
| Natural channel, but flow patterns affected by a reduction in roughness elements (e.g. woody debris, or boulders) | 0.8 | | |
| Channel not straightened or deepened, but upper banks widened to increase flood flow capacity | 0.5 | | |
| Natural channel, but evidence of channel incision from flood flows | 0.5 | | |
| Natural channel, but flow patterns affected by increase in roughness elements (e.g. excessive macrophyte growth) | 0.4 | | |
| Flow patterns affected by artificial in-stream structure (e.g. ponding due to culvert, weir or unnatural debris) | 0.1 | | |
| Channel straightened and/or deepened | 0.1 | | |
| | Sum W x P | | |

#### 5.1.1.3 $V_{lining}$

Visual inspection is carried out to determine the extent of channel lining, according to the categories in the table below. Estimate the proportion of channel that matches each of the categories in the scoring table and sum the values of W x P for each row.

| Type of channel lining | Weighting (W) | Proportion of channel (P) | Score (W x P) |
|---|---|---|---|
| Natural channel with no modification | 1 | | |
| Bed with unnatural loading of fine sediment | 0.8 | | |
| Bank OR bed lined with permeable artificial lining (e.g. gabion baskets) | 0.6 | | |
| Bank OR bed lined with impermeable artificial lining (e.g. concrete) | 0.4 | | |
| Bank AND bed lined with permeable artificial lining | 0.2 | | |
| Bank AND bed lined with impermeable artificial lining | 0 | | |
| | Sum W x P | | |

#### 5.1.1.4 Algorithm for scoring this function

$NFR = ((2V_{chann} + V_{lining})/3) \times Vpipe$

## 5.2 Floodplain effectiveness (FLE)

Floodplains, where they occur, play an important hydrological role in diffusing and delaying flood waters and so buffering the downstream effects of flood flows on stream ecosystems. Floodplain inundation reduces flooding downstream and it increases retention of particles and dissolved nutrients by increasing ponding and contact time with riparian vegetation and soil. This reduces contaminant loadings downstream. In addition, some fish species such as eels utilise flood events as an opportunity to access the floodplain and to feed on terrestrial prey. Other fish species utilise floodplains for spawning and require a flood to provide access to spawning sites.

The value of a floodplain to a stream reach is related mainly to its area, which is defined as the area of bank that would normally be inundated following a heavy or prolonged rainfall event. Floodplains are generally larger in the lower than in the upper regions of catchments, but all floodplains play an important ecological role relative to their position in the catchment. The area of a floodplain may be reduced by stopbanks built on the floodplain.

The function of floodplains can be expected to decline when hydrological connectivity to them (e.g. the frequency of flooding) is reduced. This occurs when stream works channelise or straighten streams, or change bank slope, height and vegetation, thereby containing more of the high flow events within the stream channel. The first variable ($V_{bank}$) estimates this connectivity based on modification to stream banks and floodplains.

Floodplains retain flood debris in topographic features and vegetation (including broken vegetation). They also retain fine silt particles, which settle in low velocity areas, thus reducing silt loads further downstream. Such deposited material gradually becomes processed and incorporated into the riparian terrestrial ecosystem, which then plays an important role in sustaining the ecological values of the adjacent stream reach. Out-of-channel particle retention on floodplains therefore plays an important role in stream ecosystem functioning as well as in the protection of ecosystems further downstream. The type and complexity of vegetation on the floodplain will influence the amount of material retained, and this is measured using the second variable ($V_{rough}$) in this function.

The method of scoring the two variables and the algorithm for combining the into the FLE function score is described below.

### 5.2.1 Measurement method

#### 5.2.1.1 $V_{bank}$

Visual inspection is carried out to determine the whether there is a floodplain present and what artificial barriers might prevent floodwaters from entering the floodplain. Estimate the proportion of channel that matches each of the categories in the scoring table and sum the values of W x P for each row to obtain the $V_{bank}$ variable score.

| Floodplain description | Weighting (W) | Proportion of channel (P) | Score (W x P) |
|---|---|---|---|
| Movement of flood flows onto and across the floodplain is not restricted by any artificial structures or modifications | 1 | | |
| Floodplain present, connectivity to floodplain is restricted by artificial modification (for example stop banks or urban development) | 0.4 | | |
| Floodplain present, but connectivity to floodplain reduced by channel incision or bank widening so that most flood flows are unlikely to reach the floodplain | 0.2 | | |
| No hydrological connectivity with floodplain as all flows are likely to be artificially contained within the channel | 0 | | |
| | Sum W x P | | |

5.2.1.2 $V_{rough}$

Visual inspection is carried out to determine the proportion of the floodplain covered by the vegetation types in the scoring table. Estimate the proportion of channel that matches each of the categories in the scoring table and sum the values of W x P for each row to obtain the $V_{rough}$ variable score. This variable uses the same information that is collected for $V_{ripcond}$, but the weightings are altered to reflect that we are measuring the “roughness” of the riparian zone in this variable.

| Vegetation type | Weighting (W) | Proportion of channel (P) | Score (W x P) |
|---|---|---|---|
| Mature indigenous vegetation with diverse canopy and understory | 1 | | |
| Regenerating indigenous vegetation in late stage of succession | 1 | | |
| Natural, diverse wetland vegetation on banks | 0.8 | | |
| Mature native trees, but damaged understory | 0.6 | | |
| Mature exotic trees (e.g. willows and plantation forest) | 0.7 | | |
| Low diversity regenerating bush (e.g. manuka scrub) with stock excluded, or<br>tall (> 2m) exotic shrubs | 0.8 | | |
| Mature flax, long grasses and sedges | 1 | | |
| Low diversity regenerating bush with stock access, or<br>early stage restoration planting, or<br>short (< 2m) exotic shrubs, or<br>immature plantation forest | 0.6 | | |
| Mainly long grasses (not grazed or mown) | 0.5 | | |
| Grazed wetlands | 0.2 | | |
| Mainly short grasses (grazed or mown) | 0.2 | | |
| Disturbed bare soil or artificial surfaces | 0 | | |
| | Sum W x P | | |

#### 5.2.1.3 Algorithm for scoring this function

$FLE = V_{bank} \times V_{rough}$

## 5.3 Connectivity for natural species migrations (CSM)

An important function of any stream reach is the connectivity it allows for species dispersal and in particular, fish and shrimp migrations between the estuary or sea and freshwater habitats to complete their life cycles. Connectivity may be naturally low due to a natural barrier such as a waterfall, resulting in a distinctive species assemblage above the barrier. Here we measure only artificially reduced connectivity caused by human structures or alterations to stream channels. If connectivity is reduced then top predators (eels) and keystone species may decline, biodiversity may fall and foodwebs become simpler and less stable.

Eels and banded kokopu are found in the upper reaches of many Auckland streams and are adept at climbing even high falls. They are only affected by steep, overhanging falls, perched culverts and high-velocity (>0.5 m $s^{-1}$) chutes. Redfin bullies occur in the middle reaches of streams and also climb wetted rock faces but they are less adept climbers than eels and banded kokopu so are affected by moderate falls and strong rapids. Freshwater shrimp and crayfish may also be capable of climbing small obstacles within the stream. Fish species such as inanga and smelt occur in the lower reaches of streams and are not climbers, nor strong swimmers, so are affected by even small barriers such as a >10 cm drop below a weir, or water velocities >0.2 $ms^{-1}$ in a culvert.

The variety of fish and crustacean species affected by a reduction in connectivity therefore depends on the type of barrier and its position in the stream network. A partial barrier is defined as one that, due to its physical type or position in the catchment, excludes or reduces the abundance of some fish and/or crustacean species. A total barrier is impassable to all species. Barriers may also be intermittent and only act at times of high or low flow. High turbidity and some chemicals can also act as a deterrent to upstream movement when concentrations are high and so are also intermittent barriers.

Therefore connectivity in Auckland streams depends on the type of barrier, its duration and the number of species potentially excluded or reduced in abundance. Because it is difficult to fully assess the exact nature of a barrier to migratory fish and crustaceans, scoring a reach using the variable $V_{barr}$ is simplified to three options; (a) a permanent, total barrier to all species is present, (b) a partial or intermittent barrier is present, (c) no barrier is present at any time.

The method of scoring $V_{barr}$ is described below. It is the only variable in this function (CSM), so the function score is the same as the variable score.

### 5.3.1 Measurement method

#### 5.3.1.1 $V_{barr}$

Inspect the reach to locate artificial barriers within the reach that could affect natural upstream passage by fish or shrimps and therefore reduce natural species diversity and/or abundance. Note that natural barriers are not considered here and if one exists, an artificial barrier is considered only if its effect is greater than or different to that of the natural barrier. If more than one artificial barrier is present, scoring is based on the one presenting the greatest barrier.

| Barrier type | $V_{barr}$ |
| --- | --- |
| No barriers to migration | 1 |
| Partial or intermittent barrier to migration | 0.3 |
| Total barrier to migration | 0 |

5.3.1.2 Algorithm for scoring this function

$CSM = V_{barr}$

## 5.4 Natural connectivity to groundwater (CGW)

Streams and ground waters interact in several ways. The dominant process in most stream reaches is the discharge of groundwater to the stream channel, which maintains stream flow during periods between rainfalls. In some stream reaches, the main flow direction is from the channel to the groundwater, which can be important for recharging the aquifer. As well as the net loss or gain of water, there is also exchange of groundwater and surface water through the hyporheic zone, the zone beneath and to the sides of the stream channel. The hyporheic zone is a place of active biogeochemical processing of nutrients and contaminants, and a habitat for small invertebrates. Water exchange with this zone increases the biogeochemical processing capacity of the stream and improves habitat quality for the invertebrate community. Wherever connectivity between the stream channel and the groundwater is reduced, these processes and the benefits they confer to the stream and aquifer are affected.

In many Auckland streams, where the stream bed and sides are generally composed of compacted clays, groundwater connectivity is already limited compared to gravel bottomed streams. However, even this will be reduced if the stream bed channel is altered in such a way that its porosity declines further (e.g., through culverting, concrete lining etc.). In cobble- or gravel-bottomed streams, fine silt that clogs the interstices between the rocks can reduce the porosity of the bed. The first variable ($V_{lining}$) assesses the primary factor influencing ground water connectivity, which is the streambed and its relative porosity. A secondary factor is the complexity of the stream channel, and this is measured using the second variable ($V_{chanshape}$). Features such as meanders, pool-riffle sequences and instream features such as logs and boulders promote exchange of surface water with the hyporheic zone. When these are removed, groundwater-surface water exchange declines.

The method of scoring the two variables and the algorithm for combining them into the CGW function score is described below. It should be noted that the data is the same as that collected for the NFR function, but it is used in a different manner to calculate CGW.

### 5.4.1 Measurement method

#### 5.4.1.1 $V_{lining}$

Visual inspection is carried out to determine the extent of channel lining, according to the categories in the table below. Estimate the length of channel affected as a proportion of the length of stream reach and sum the values of W x P for each row.

| Type of channel lining | Weighting (W) | Proportion of channel (P) | Score (W x P) |
|---|---|---|---|
| Natural channel with no modification | 1 | | |
| Bed with unnatural loading of fine sediment | 0.8 | | |
| Bank OR bed lined with permeable artificial lining (e.g. gabion baskets) | 0.6 | | |
| Bank OR bed lined with impermeable artificial lining (e.g. concrete) | 0.4 | | |
| Bank AND bed lined with permeable artificial lining | 0.2 | | |
| Bank AND bed lined with impermeable artificial lining | 0 | | |
| | Sum W x P | | |

5.4.1.2 $V_{chanshape}$

Visual inspection is carried out to determine the extent of channel modification related to changes in the flow regime. The extent of modification is assessed according to the categories in the table below. If more than one type of modification occurs at a particular place, score the most severe of the modifications. Estimate the proportion of channel that matches each of the categories in the scoring table and sum the values of W x P for each row to obtain $V_{chanshape}$.

| Channel type | Weighting (W) | Proportion of channel (P) | Score (W x P) |
|---|---|---|---|
| Natural channel with no modification | 1 | | |
| Natural channel, but flow patterns affected by increase in roughness elements (e.g. excessive macrophyte growth) | 0.9 | | |
| Flow patterns affected by artificial in-stream structure (e.g. ponding due to culvert, weir or unnatural debris) | 0.9 | | |
| Channel not straightened or deepened, but upper banks widened to increase flood flow capacity | 0.6 | | |
| Natural channel, but evidence of channel incision from flood flows | 0.6 | | |
| Natural channel, but flow patterns affected by a reduction in roughness elements (e.g. woody debris, or boulders) | 0.4 | | |
| Channel straightened and/or deepened | 0.2 | | |
| | Sum W x P | | |

#### 5.4.1.3 Algorithm for scoring this function

$$CGW = (2V_{lining} + V_{chanshape})/3$$

## 5.5 Water temperature control (WTC)

Water temperature affects water chemistry and quality, and has a pervasive, over-riding influence on the biota though its control of enzyme systems and the physiology of poikilotherms (cold blooded animals). Water temperature is therefore a key factor influencing the ecological performance of streams. Changes in the natural temperature regime of a stream reach can be expected to have major implications for its ecological value.

Although some seasonal variation in water temperature regime may be optimal for Auckland streams, high temperatures in summer months can have a negative impact on in-stream biological communities. As temperature control is not so important during winter months, the processes that maintain cool water temperatures in summer are the key factors to measure. The main variable keeping Auckland streams cool in summer will be the extent of shade provided by the canopy of trees over the stream. However, shading of the stream surface is also provided by stream banks that protrude over the water surface, by overhanging bank vegetation, emergent vegetation within the channel and by high banks and/or hills along the northern sides of stream channels. Hence the variable used to measure shade ($v_{shade}$) includes shading from all features.

The method of scoring $V_{shade}$ is described below; this is the only variable in this function (WTC), so the function score is the same as the variable score.

### 5.5.1 Measurement method

#### 5.5.1.1 $V_{shade}$

Assess the proportion of the stream channel that is shaded by overhead vegetation (i.e., the tree canopy, overhanging bank vegetation and emergent vegetation within the channel) or by topographic factors (i.e., high, narrow stream banks on northern side of stream, and any artificial structures, such as fences on these). 0% shading would be scored only for a flat plain with no stream banks, riparian vegetation or other structures. Assign each of the 10 cross-sections to the category in the scoring table below that most closely matches the conditions at that cross-section. This assessment attempts to recreate what a photo taken from the stream surface with a fish-eye lens would record. The assessment assumes mid-summer conditions, so regardless of when the assessment is carried out, assume the sun is following its summertime arc and annual plant species are in full summer leaf cover.

| Shading description | Weighting (W) | Frequency (F) | Score (W x F) |
|---|---|---|---|
| Very high shading; shading from vegetation and topographical features > 90% | 1 | | |
| High shading; shading from vegetation and topographical features 71 – 90% | 0.8 | | |
| Moderate shading; shading from vegetation and topographical features 51 – 70% | 0.6 | | |
| Low shading; shading from vegetation and topographical features 31 – 50% | 0.4 | | |
| Very low shading; shading from vegetation and topographical features 11 – 30% | 0.2 | | |
| No effective shading; shading from vegetation and topographical features < 10% | 0 | | |
| | Sum W x F | | |

$V_{shade} = (\Sigma(WxF))/10$

5.5.1.2 Algorithm for scoring this function

$WTC = V_{shade}$

## 5.6 Dissolved oxygen levels maintained (DOM)

The amount of dissolved oxygen (DO) present in the water of streams is, like water temperature, a pervasive factor influencing many of the chemical and biotic processes that contribute to a stream's ecological functioning. Most stream biota, and especially the rarer species that are often less tolerant of environmental degradation, are usually found in pristine or near natural ecosystems because these organisms require an adequate level of DO to survive. Where DO levels are low, the biota can be reduced and restricted to species tolerant of low DO.

Maintenance of DO in a stream reach will be primarily a function of the oxygen reserves already present in the water column (influenced mainly by water depth), the processes that increase oxygen content (e.g., photosynthesis and diffusion) and the processes that reduce oxygen levels in streams (e.g., plant and microbial respiration). Oxygenation processes include both diffusion of oxygen gas across the air-water interface and oxygen production in the water by plants. Re-aeration of stream water via rapids, falls and increased turbulence increases the surface area of water exposed to oxygen diffusion. Diffusion is increased by a large stream surface area:volume ratio and/or water turbulence. Aquatic plants supply DO as a product of photosynthesis during the day but consume it at night such that DO levels can fall well below the 100% saturation level by dawn. Since minimum DO levels are of greatest concern, abundant plant growth is seen as a threat to DO maintenance.

Here, DO maintenance is evaluated through an assessment of the reducing factors as these can be expected to indicate the potential for DO reduction in the stream reach and this is the main factor affecting the maintenance of dissolved oxygen levels. Oxygen reducing processes include decomposition of organic matter and nitrification of ammonia by microbes, plus nocturnal respiration by plants. These processes are best assessed by measuring the symptoms of dissolved oxygen depletion in a stream reach as per the table below.

If there are no oxygen reducing processes present, then re-aeration is not an issue. However, if oxygen reducing processes are present, then their impact on oxygen maintenance needs to be corrected for the degree of re-aeration that can be expected from the velocity and depth characteristics of the stream reach. The correction factor applied to Vdod (the dissolved oxygen demand) is based on mean velocity ($V_{veloc}$ - an estimate of water turbulence) and mean depth ($V_{depth}$ - an estimate of surface area: volume ratio) (Wilcock 1999).

The method of scoring the three variables and the algorithm for combining them into the DOM function score is described below.

### 5.6.1 Measurement method

#### 5.6.1.1 $V_{dod}$

Assess the dissolved oxygen demand (D) as per the descriptors of oxygen reducing processes in the scoring table below for the entire stream reach.

| Status | Indicators of oxygen reducing processes | D |
|---|---|---|
| Optimal | • No anaerobic sediment<br>• No odours or bubbling when sediments are disturbed<br>• Little or no macrophyte (in summer) or areas of slow flow, low shade and soft substrate (in winter) | 1 |
| Sub-optimal | • No anaerobic sediment<br>• Some bubbling when sediments are disturbed, but no sulphide odour<br>• Moderate macrophyte biomass (in summer), or areas of slow flow, low shade and soft substrate (in winter) | 0.75 |
| Marginal | • Small patches of anaerobic sediment present<br>• Some bubbling with sulphide odour when sediments are disturbed<br>• Some sewage fungus may be present<br>• Dense macrophyte biomass (in summer) or large areas of slow flow, low shade and soft substrate | 0.5 |
| Poor | • Much black anaerobic sediment<br>• Extensive bubbling with sulphide odour when sediments are disturbed<br>• Surface scums may be present<br>• Abundant sewage fungus | 0.25 |

If D is 1 (i.e., no oxygen reducing process are present) then $V_{dod}$ = D and no correction factor is required. However, if D is less than 1, then $V_{dod}$ = D x ($V_{veloc}/V_{depth}$). If this value is greater than 1 (i.e., re-aeration is high), then Vdod is set at 1. However, if the value is less than 1, it becomes $V_{dod}$.

##### 5.6.1.2 $V_{veloc}$

Use the 'ruler method' for measuring water velocity (see page 114 in Harding *et al.*, 2009) as it provides a suitable level of information for the purposes of an SEV assessment. The water depth is measured twice at the fastest point on each cross section using a flat bladed metal ruler. For the first measurement, position the ruler parallel to the current and record the depth (d1). For the second measurement, turn the blade so that it is perpendicular to the current and a "bow wave" forms on the upstream face of the ruler. Record the depth at the top of this bow wave (d2). The difference in these two depth measurements (d2-d1) can be used to calculate the water velocity within 10% of flow meter readings (Harding *et al.*, 2009).

If the difference (d2-d1) is less than 2mm, then the usefulness of the method is compromised. In such cases, measure the distance a floating particle travels in a fixed time period (commonly 10 seconds). Therefore, for each of cross sections, there should be a measurement based on either the ruler method or the floating particle method. These measurements are used in the SEV calculator to estimate the maximum flow velocity (m/s) at each cross section;

The velocity estimate (v) based on the ruler method is calculated as, $v = \sqrt{(196 \times (d2-d1))}$.

The velocity estimate (v) based on the floating particle method is calculated as, v = distance travelled (m)/time taken (s).

The mean of the ten velocity estimates is $V_{veloc}$

#### 5.6.1.3 $V_{depth}$

Measure the water depth at five points across the width of the stream channel (10, 30, 50, 70 and 90% of the distance across the channel) at each of the 10 cross sections. The mean of the 50 depth measurements is $V_{depth}$.

#### 5.6.1.4 Algorithm for scoring this function

$DOM = V_{dod}$

## 5.7 Organic matter input (OMI)

Biological production in streams depends on a number of factors including the contributions of organic matter from outside the stream (i.e., allochthonous inputs) as well as the in-stream production by plants and algae via photosynthesis. Organic matter availability does not necessarily limit biological productivity but is often a major driver of it. The amount of organic matter input that occurs to streams is therefore the most important indicator of production potential and the bulk of this is provided by leaf fall.

Organic matter input from leaf fall is best measured by assessing the total amount of overhead cover provided by the canopy of vegetation within the riparian zone, up to 20 metres either side of the stream channel (Vripar). As leaf fall from deciduous trees and shrubs only occurs during autumn and winter months, the total amount of overhead summer vegetation needs to be reduced by the proportion of this that is deciduous and that contributes to leaf fall for at most only half the year (Vdecid). This assessment does not account for the thickness of the tree canopy, but for Auckland streams this is unlikely to be as important as the overall extent of riparian canopy cover.

The method of scoring the two variables and the algorithm for combining them into the OMI function score is described below.

### 5.7.1 Measurement method

#### 5.7.1.1 $V_{ripar}$

Assess the proportion of the riparian zone, defined as 20 metres either side of the stream channel that is covered by woody vegetation (trees or shrubs). The variable $V_{ripar}$ is the proportional value produced from this assessment.

#### 5.7.1.2 $V_{decid}$

Assess the proportion of the riparian cover identified in $V_{ripar}$ that is not deciduous (i.e. none of the riparian cover is deciduous = 1, all of the riparian cover is deciduous = 0). The variable Vdecid is the proportional value produced from this assessment.

#### 5.7.1.3 Algorithm for scoring this function

$OMI = V_{ripar} \times ((1+V_{decid})/2)$

## 5.8 Instream particle retention (IPR)

Leaf fall provides a major source of external carbon and nutrients to streams (see function 5.7 OMI). However, leaf fall is only useful for stream productivity if the leaves are retained in the reach long enough for biological processing (e.g., by shredders, grazers and microbes such as fungi and bacteria) to occur. Streams naturally retain some of the organic matter that enters, and deliver the rest downstream to enhance the productivity of downstream reaches. Both retention and downstream delivery are important, so over- and under-retentiveness are both regarded as a degradation of stream function.

Instream particle retention depends on the length of the reach and its flow characteristics. However, the extent of leaf and debris retaining structures within the reach will also influence its 'processing' ability and overall contribution to productivity. Streams may become "over-retentive" if they are clogged with macrophytes (aquatic plants) or human rubbish, or if water depth is reduced. The most common factor increasing retentiveness in Auckland streams is excessive growth of macrophytes (assessed using $V_{macro}$). On the other hand, they may become under-retentive if natural features of the stream, such as logs, boulders or stream meanders, are removed, or if water depth is increased (assessed using $V_{retain}$).

This function is assessed by estimating the extent to which human activities have increased or decreased retentive structures in the stream. Because many urban modifications decrease stream retentiveness while macrophyte growth always increases retentiveness (i.e. they have opposite effects), these two variables are not combined, but instead the more dominant of the two is used to score IPR.

The method of scoring the two variables and the algorithm for combining them into the IPR function score is described below.

### 5.8.1 Measurement method

#### 5.8.1.1 $V_{macro}$

This macrophytes measure is based on the Macrophyte Channel Clogginess Index developed for Waikato Regional Council (Collier *et al.*, 2007).

For each of the 10 cross-sections, estimate the proportional cover of macrophytes within a 1 m wide band upstream of the cross-section. Score cover of "surface-reaching or emergent" (reaching to, or above, the water surface) and bankside vegetation separately from "below surface" macrophytes. The combined proportional cover for each cross-section should not exceed 1.

| Cross section | Surface reaching macrophytes (SRM) | Below surface macrophytes (BSM) |
|---|---|---|
| 1 | | |
| 2 | | |
| 3 | | |
| 4 | | |
| 5 | | |
| 6 | | |
| 7 | | |
| 8 | | |
| 9 | | |
| 10 | | |
| Mean cover | | |

Calculate the average proportional cover (P) of each macrophyte type for the 10 cross-sections, and use these values to calculate $V_{macro}$ as follows; $V_{macro}$ = 1 - (mean SRM + (mean BSM x 0.5))

#### 5.8.1.2 $V_{retain}$

Visual inspection is carried out to determine the extent of channel modification according to the categories in the scoring table below. If more than one type of modification occurs at a particular place, score the most severe of the modifications. It should be noted that the data is the same as that collected for the $V_{chann}$ and $V_{chanshape}$ variables, but it is used in a different manner to calculate $V_{retain}$.

Estimate the proportion of channel that matches each of the categories in the scoring table and sum the values of W x P for each row to obtain $V_{retain}$.

| Channel modification | Weighting (W) | Proportion of channel (P) | Score (W x P) |
|---|---|---|---|
| Natural channel with no modification | 1 | | |
| Natural channel, but evidence of channel incision from flood flows | 0.8 | | |
| Natural channel, but flow patterns affected by a reduction in roughness elements (e.g. woody debris, or boulders) | 0.6 | | |
| Channel not straightened or deepened, but upper banks widened to increase flood flow capacity | 0.6 | | |
| Natural channel, but flow patterns affected by increase in roughness elements (e.g. excessive macrophyte growth) | 0.2 | | |
| Flow patterns affected by artificial in-stream structure (e.g. ponding due to culvert, weir or unnatural debris) | 0.2 | | |
| Channel straightened and/or deepened | 0.2 | | |
| | Sum W x P | | |

5.8.1.3 Algorithm for scoring this function

IPR = the lesser of $V_{macro}$ or $V_{retain}$

## 5.9 Decontamination of pollutants (DOP)

One of the major ecological functions of streams is their ability to dilute and absorb chemicals and contaminants that reduce biological production, and to transform some of these into chemical complexes that are ecologically benign. Many physical and chemical processes are involved in this, both within the stream and in the riparian zone. The main driver of in-stream decontamination in small streams is the type and extent of micro-organisms growing on suitable substrates under water. Therefore this function is related primarily to the area of substrate for bio-films to develop on. The most important substrates are listed in the scoring table below and their extent is used to calculate the first variable ($V_{surf}$).

The riparian zone plays an important role in reducing particulate contaminants in overland run-off before it enters the stream. The riparian zone filters out contaminants by slowing the run-off and making its flow path more tortuous so that particles settle out. Therefore the filtering capacity of the riparian zone is increased by greater width, denser vegetation or leaf litter layer and a more open soil matrix. It is decreased by soil compaction and the formation of run-off channels or "rills" in the soil. These characteristics are assessed in the second variable ($V_{ripfilt}$).

The method of scoring the two variables and the algorithm for combining them into the DOP function score is described below.

### 5.9.1 Measurement method

#### 5.9.1.1 $V_{surf}$

Assess the type and proportional cover of surfaces suitable for biofilms as per the scoring table below, recording the cover of different surface types at ten places across each of the ten cross-sections. Sum the W x P values and express as a proportion of the mean for the Auckland Council's State of Environment reference sites (which is 0.76), so that $V_{surf} = \Sigma(W \times P)/0.76$.

| Surface type | Weighting (W) | Proportion cover (P) | W x P |
|---|---|---|---|
| Leaf litter | 1 | | |
| Periphyton and submerged macrophytes | 1 | | |
| Wood, roots and emergent or floating macrophytes | 0.5 | | |
| Boulders | 0.4 | | |
| Gravel and cobble | 0.3 | | |
| Silt and bedrock | 0.1 | | |
| | Sum W x P | | |

#### 5.9.1.2 $V_{ripfilt}$

This filtering capacity measure is based on that developed for Environment Canterbury to inform riparian management (Quinn, 2009). Assess the capacity of the riparian zone to filter overland run-off by estimating the proportion of the riparian zone in your test reach that matches the categories in the scoring table.

When referring to drainage channels, it specifically means where surface run off is confined to small channels, or “rills”, so that run off rapidly passes through the riparian zone, with little time for filtering or infiltration. Exclude any large tributaries in this assessment.

Estimate the proportion of channel that matches each of the categories in the scoring table and sum the values of W x P for each row to obtain $V_{ripfilt}$.

| Riparian zone description | Proportion of channel (P) | Weighting (W) | W x P |
|---|---|---|---|
| Very high filtering activity<br>Dense ground cover vegetation OR thick organic litter layer under a tree canopy, AND<br>Run off into stream diffuse, with only minor defined drainage channels, AND<br>Width of buffer greater than 5x channel width | | 1 | |
| High filtering activity<br>Dense ground cover vegetation OR thick organic litter layer under a tree canopy, AND<br>Run off into stream diffuse, with only minor defined drainage channels, AND<br>Width of buffer less than 5x channel width | | 0.8 | |
| Moderate filtering activity<br>Uniform ground cover vegetation OR abundant organic litter layer under a tree canopy, AND<br>Run off into stream mostly diffuse, with few defined drainage channels | | 0.6 | |
| Low filtering activity<br>Patchy ground cover vegetation OR little organic litter layer under a tree canopy, AND/OR<br>Some run off into stream in small defined drainage channels | | 0.4 | |
| Very low filtering activity<br>Short (mown or grazed) vegetation with high soil compaction, AND/OR<br>Run off into stream mostly contained in small defined drainage channels | | 0.2 | |
| No filtering activity<br>Banks bare or impermeable | | 0 | |
| | Sum W x P | | |

5.9.1.3 Algorithm for scoring this function

$DOP = (V_{surf} + V_{ripfilt})/2$

## 5.10 Fish spawning habitat (FSH)

A key habitat function of certain reaches of Auckland streams will be the provision of spawning habitat for fish (i.e., places where they can lay their eggs). For the species of the Galaxiidae family (inanga, banded kokopu, koaro, giant kokopu and shortjaw kokopu), eggs are deposited at high water level, mainly on stream banks among the roots of both grasses and shrubs (in the case of inanga and banded kokopu) or among stones and woody debris (in the case of koaro and shortjaw kokopu). They are laid when water levels are temporarily raised either following rainfall or by spring tides in lower reaches (note that SEV can be used in reaches where stream flow is backed up by high tides but not where salt water intrudes).

Spawning habitats for galaxiids therefore occur on the landward margins of shallow, shelving banks and/or the edges of floodplains that are periodically inundated by a rise in water level caused by heavy rain or high tides. However, not all such areas are used for spawning. The type and quality of vegetation and stream bank materials play a major role in determining the location of galaxiid spawning habitat within such areas. Therefore, the first variable ($V_{galspwn}$) assesses the extent of suitable habitat for spawning and the second variable ($V_{galqual}$) assesses the quality of the suitable habitat.

For species of the Gobiidae family (e.g., common, redfin and Cran's bullies), eggs are deposited primarily on hard surfaces, such as rocks and wood, in the stream channel. The undersides of large (minimum diameter > 15 cm) rocks are preferred (and perhaps required) by redfin bullies, but common bullies will readily deposit eggs on both the top and bottom surfaces of hard objects including rocks, shells, wood and even some woody plant stems. The third variable ($V_{gobspwn}$) assesses the extent of such hard, stable substrates that are suitable for bully spawning.

The method of scoring the three variables and the algorithm for combining them into the FSH function is described below.

### 5.10.1 Measurement method

#### 5.10.1.1 $V_{galspwn}$

Measure the total lengths of stream bank on both banks (Lb) where floods or spring tides would create a shallow (<5 cm) layer of water over relatively flat (<10º) land. Express this length as a proportion of the total bank length (i.e. length of suitable flat surface/2 x reach length) and call this value R.

If R is greater than 0.25 then $V_{galspwn}$ = 1, and if R is less than 0.01 then $V_{galspwn}$ = 0. For other values of R, $V_{galspwn}$ = 0.25 + (3 x R).

#### 5.10.1.2 $V_{galqual}$

If in a tidally-influenced reach, assess the quality of spawning habitat for inanga. If above tidally-influenced reaches, assess the quality of spawning habitat for kokopu (i.e., banded kokopu, koaro, giant kokopu, shortjaw kokopu).

For inanga, rushes, tall (but not rank) grass or dense low-growing vegetation (e.g., *Tradescantia sp.*) is required in the flattish areas inundated by spring flood tides. The vegetation should be thick enough to trap moisture near the ground and so prevent egg desiccation but not so thick as to prevent inanga accessing the upper margin of the inundated area. For kokopu species the overhead tree canopy should provide more than 80% cover to ensure that eggs are not exposed to direct sunlight and that conditions along the stream bank are moist enough to prevent egg desiccation. Low-growing vegetation, leaf litter, stones or even stable soil provides suitable substrate.

The $V_{galqual}$ score corresponds with the category in the scoring table that best describes the Galaxiidae spawning habitat in your test reach.

| Quality | Tidally influenced reaches | Above tidal influence | $V_{galqual}$ |
|---|---|---|---|
| High | • Nearly flat (<1°) stream bank, with near total (>60%) cover by dense stemmed, low growing vegetation<br>• Inundated by spring tides and/or floods | • Under a dense tree canopy (>80% shade).<br>• Nearly flat (<1°) stream bank with heavy cover of (>50%) of dense stemmed, low growing vegetation, twigs or gravels.<br>• Inundated by high rainfall events | 1 |
| Medium | • Gently sloping (1-5°) bank, with moderate (20 to 60%) cover of low growing vegetation<br>• Inundated by spring tides and/or floods | • Under a moderate tree canopy (50 to 80% shade).<br>• Gently sloping (1-5°) bank, with moderate (20 to 50%) cover of low growing vegetation, twigs or gravels.<br>• Inundated by high rainfall events | 0.75 |
| Low | • Sloping bank (5-10°) with sparse (10 to 20%) cover of low growing vegetation<br>• Inundated by spring tides and/or floods | • Under a partial tree canopy (10 to 50% shade). Sloping bank (5-10°) with sparse (1 to 20%) cover of low growing vegetation, twigs or gravels.<br>• Inundated by high rainfall events | 0.25 |
| Unsuitable | • Bank slope >10°, or less than 10% cover of low growing vegetation | • Less than 10% shade from tree canopy, or bank slope > 10°, or < 1% cover of low growing vegetation, twigs or gravels | 0 |

#### 5.10.1.3 $V_{gobspwn}$

The extent of habitat for spawning by Gobiidae fish species is determined by the proportion of suitable hard substrate present on the stream bed. Combine the proportions of stream bed areas occupied by large cobbles (128-256 mm diameter), by boulders (>256 mm diameter) or overlain by medium or large wood debris (diameter > 50 mm) (this variable uses the same data as $V_{surf}$) to determine the total proportion occupied by potential spawning habitat (P). Exclude areas occupied by bedrock, concrete, sand and silt, small rocks and stones (<128 mm diameter), and small wood < 50 mm diameter. (N.B. the base of a concrete culvert does not provide good spawning habitat and occasional rocks or wood jams within culverts are generally not used because the surrounding water velocities are too high).

Vgobspwn is determined as follows;

- ☐ If $P > 10\%$ then $V_{gobspwn} = 1$
- ☐ If P is between 5 and 10% then $V_{gobspwn} = 0.8$
- ☐ If P is between 2 and 4% then $V_{gobspwn} = 0.2$
- ☐ If $P < 2\%$ then $V_{gobspwn} = 0.1$

5.10.1.4 Algorithm for scoring this function

$FSH = ((V_{galspwn} \times V_{galqual}) + V_{gobspwn})/2$

## 5.11 Habitat for aquatic fauna (HAF)

Physical habitat for fish and invertebrates is created by the interaction between the hydraulic and biogeochemical functions described so far. It is also related to a number of factors beyond these functions, including the run, riffle, pool and rapid configuration within the stream and the arrangement and density of instream cover. The quality of physical habitat can be assessed using a physical habitat assessment. The amount of habitat degradation is assessed relative to the habitat assessment score for Auckland reference sites in the first variable ($V_{physhab}$).

The potential effects of water quality degradation and the presence of contaminants in the stream reach also need to be assessed in relation to habitat for aquatic fauna. Water quality for the biota is related mainly to water temperature (a function of stream shading) and dissolved oxygen (see DOM in section 5.6) and is assessed in the second variable ($V_{watqual}$).The potential for contaminants to reduce habitat is related primarily to the amount of toxic metals, PAHs, chemicals and acid waters that could be present. The presence of these contaminants in Auckland streams is likely to be related mainly to the amount of urban development and light industry within the upstream catchment. This is assessed by the amount of impervious cover present upstream and is used to produce the third variable ($V_{imperv}$).

The method of scoring the three variables and the algorithm for combining them into the HAF function is described below.

### 5.11.1 Measurement method

#### 5.11.1.1 $V_{physhab}$

Assess the physical habitat of the stream reach using the scoring sheet below. For each of the five habitat parameters, select the quality class that best describes the condition, and within the quality class select the appropriate score. Note the riparian integrity is scored separately for each bank. Sum the six scores produced by the assessment and divide by 100 to produce H.

$V_{physhab}$ is calculated by standardising H using the mean score for Auckland reference sites (0.85), where $V_{physhab}$ = H/0.85.

| **Habitat Parameter** | **Optimal** | **Suboptimal** | **Marginal** | **Poor** |
|---|---|---|---|---|
| Aquatic Habitat Abundance - proportion of stream channel occupied by suitable habitat features for in-stream fauna | > 50% of channel favourable for macroinvertebrate colonisation and fish cover; includes woody debris, undercut banks, root mats, rooted aquatic vegetation, cobble or other stable habitat. | 30-50% of channel contains stable habitat. | 10-30% of channel contains stable habitat. | < 10% of channel contains stable habitat. Note: Algae does not constitute stable habitat. |
| | 20 19 18 17 16 | 15 14 13 12 11 | 10 9 8 7 6 | 5 4 3 2 1 0 |
| Aquatic Habitat Diversity | Wide variety of stable aquatic habitat types present including: woody debris, riffles, undercut banks, root mats, rooted aquatic vegetation, cobble or other stable habitat. | Moderate variety of habitat types; 3-4 habitats present including woody debris. | Habitat diversity limited to 1-2 types; woody debris rare or may be smothered by sediment. | Stable habitats lacking or limited to macrophytes (a few macrophyte species scores lower than several). |
| | 20 19 18 17 16 | 15 14 13 12 11 | 10 9 8 7 6 | 5 4 3 2 1 0 |
| Hydrologic Heterogeneity | Mixture of hydrologic conditions i.e. pool, riffle, run, chute, waterfalls; variety of pool sizes and depths. | Moderate variety of hydrologic conditions; deep and shallow pools present (pool size relative to size of stream). | Limited variety of hydrologic conditions; deep pools absent (pool size relative to size of stream) . | Uniform hydrologic conditions; uniform depth and velocity; pools absent (includes uniformly deep streams). |
| | 20 19 18 17 16 | 15 14 13 12 11 | 10 9 8 7 6 | 5 4 3 2 1 0 |
| Channel Shade | >80% of water surface shaded. Full canopy. | 60 - 80% of water surface shaded; mostly shaded with open patches. | 20 - 60% of water surface shaded; mostly open with shaded patches. | <20% of water surface shaded. Fully open; lack of canopy cover. |
| | 20 19 18 17 16 | 15 14 13 12 11 | 10 9 8 7 6 | 5 4 3 2 1 0 |
| Riparian Vegetation Integrity (within 20 metres) | No direct human activity in the last 30 years; mature native tree canopy and intact native understorey | Minimal human activity; mature native tree canopy or native scrub; understorey shows some impact (e.g. weeds, feral animal grazing). | Extensive human activity affecting canopy and understorey; trees exotic (pine, willow, poplar); understorey native or exotic. | Extensive human activity; little or no canopy; managed vegetation (e.g. livestock grazing, mowed); permanent structures may be present (e.g. building, roads, car parks). |
| Left bank | 10 9 | 8 7 6 | 5 4 3 | 2 1 0 |
| Right bank | 10 9 | 8 7 6 | 5 4 3 | 2 1 0 |

#### 5.11.1.2 $V_{watqual}$

Water quality is an important component of habitat and is a function mainly of oxygen maintenance (i.e., see DOM in Section 5.6) and especially temperature, with the latter influenced primarily by shading. Shading of the stream catchment upstream of the reach being assessed will have a much greater influence on water temperature in the stream reach than shading over the reach. Therefore shade needs to be assessed over the stream reach being assessed (see $V_{shade}$ in Section 5.5) as well as upstream of the site. The extent of shade upstream of the reach (S) is scored as per the table below.

| Extent of upstream shading | S |
|---|---|
| Well shaded (> 50% of catchment upstream is forested) | 1 |
| Partially shaded (< 50% of catchment upstream is forested) | 0.5 |
| Minimal shade (mainly pasture, but some riparian cover present) | 0.2 |
| No upstream shade | 0 |

Calculate the score for $V_{watqual}$ as follows, $V_{watqual} = DOM \times ((V_{shade} + S)/2)$

#### 5.11.1.3 $V_{imperv}$

Calculate the proportion of the catchment upstream that is impervious to surface water (e.g., from REC (Snelder & Biggs 2002) or aerial photos). As the impact of imperviousness on water quality will depend on the flow control measures present and mitigations to reduce the connectivity of first flush run off to streams, an adjustment is needed to estimate the ‘effective’ degree of imperviousness. In the table below, the cell best describing the conditions in the stream reach is selected and the cell value is used as the measure of $V_{imper}$. Where there are no impervious surfaces, $V_{imper} = 1$.

| Impervious surface | Flood flow and first flush run off controls | | |
|---|---|---|---|
| | Much control | Some control | No control |
| 0% | 1 | 1 | 1 |
| < 10% | 0.9 | 0.8 | 0.7 |
| 10 – 25% | 0.5 | 0.4 | 0.3 |
| > 25% | 0.3 | 0.2 | 0.1 |

#### 5.11.1.4 Algorithm for scoring this function

$HAF = (V_{physhab} + ((V_{watqual} + V_{imper})/2))/2$

## 5.12 Fish fauna intact (FFI)

Habitats for fish may well be present and of high quality in a stream reach, but they may not be inhabited because of factors limiting colonisation and survival of the fauna. If the stream fauna is deficient or reduced in a stream reach, then its food web will be altered and the sustainability of biotic processes weakened. Biological production may be skewed towards certain species and the natural balance between predator and prey populations will be less stable. The degree of ‘intactness’ of the fish fauna therefore needs to be assessed because it is an important correlate of ecological stability and this underpins a stream’s ecological value. The ‘intactness’ of the fish fauna is also a measure of the stream’s ability to convert primary production into tertiary production.

Fish populations are a major component of the fauna in streams and can be assessed using the index of biotic integrity developed for Auckland streams (Joy & Death 2005).

### 5.12.1 Measurement method

Sample the reach to identify all fish species present (e.g., electric fishing) and determine the IBI index for Auckland streams (see Appendix). Calculate $V_{fish}$ using the scoring algorithm below.

$V_{fish}$ = IBI/60

#### 5.12.1.1 Algorithm for scoring this function

FFI = $V_{fish}$

## 5.13 Invertebrate fauna intact (IFI)

The integrity of the invertebrate fauna is also a key biotic component of stream ecosystem stability. It is fundamental to the conversion of primary production into secondary production and hence for the productivity of higher trophic levels, particularly fish.

Invertebrate species have very different levels of tolerance to the typical effects of stream habitat degradation (such as raised water temperature, increased siltation, lowered dissolved oxygen). Therefore, the species assemblage is expected to change significantly when degradation of the stream habitat occurs. The Macroinvertebrate Community Index (MCI; Stark & Maxted 2007) gives a score to each invertebrate taxon that reflects its sensitivity to the suite of habitat changes occurring when catchments are converted from native forest to pasture. The more high-scoring invertebrate taxa that are present, the higher the MCI score. In this way, MCI score reflects the health of the stream invertebrate community. The first variable ($V_{mci}$) captures this measure of the invertebrate community and places it into context using Auckland reference site information.

Three of the most abundant orders of stream insect, the Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies) (collectively known as EPT taxa), are the most likely to disappear when stream habitats are degraded. Therefore, another index, the richness (or number) of EPT taxa, gives another measure of the health of the stream invertebrate community. The second variable ($V_{ept}$) captures this measure of the invertebrate community and places it into context using Auckland reference site information.

Although the presence of sensitive invertebrates can indicate that the ecosystem is intact and is supporting a healthy invertebrate community, these species are not the only ones that contribute to a stream's biodiversity. Biodiversity also depends on the presence of particular taxa that are expected to occur in that locality. Ideally a measure of the intactness of the invertebrate fauna should include all the rare taxa as well the common species. However, by definition the presence of particular rare taxa in particular locations (especially in particular samples) is highly variable. Thus it is not possible to predict all the rare taxa that should be found in a particular locality, nor to be confident of collecting them in samples. Instead, the invertebrate biodiversity of the stream reach is estimated by comparing the taxa present to a list of taxa that are more than 50% likely to occur in reference sites in that geographic area ($V_{invert}$). In this case the list of taxa is derived from 16 reference sites around the Auckland region, and separate lists have been produced for hard- and for soft-bottomed streams.

The method of scoring the three variables and the algorithm for combining them into the IFI function is described below.

### 5.13.1 Measurement method

Sample the invertebrate community in the stream reach using the national protocols for semi-quantitative sampling, i.e. C1 for hard-bottomed sites or C2 for soft-bottomed sites (Stark *et al.* 2001). Process the samples according to Protocol P1 or P2, but note that only presence-absence (not quantitative or semi-quantitative) data are required to calculate the variables for IFI. Use the data to calculate the variables described below.

#### 5.13.1.1 $V_{mci}$

Calculate the Macroinvertebrate Community Index (MCI) for the test site using the appropriate scoring system for soft- or hard-bottomed sites (Stark and Maxted, 2007). This value needs to be expressed relative to the range of MCI values recorded in Auckland streams (40-130) using the formula below. If MCI is < 40 then $V_{mci} = 0$. If MCI > 130, then $V_{mci} = 1$. For MCI scores between 40 and 130, $V_{mci} = (MCI - 40)/90$.

#### 5.13.1.2 $V_{ept}$

Calculate the $EPT_{test}$ index for the test site (number of EPT taxa present). This value also needs to be expressed in relation to the value for reference sites. Therefore, $V_{ept} = EPT_{test}/EPT_{ref}$, where $EPT_{ref}$ is 6 for soft-bottomed streams and 18 for hard-bottomed streams. If $V_{ept} > 1$ it defaults to 1.

#### 5.13.1.3 $V_{invert}$

All the invertebrate taxa that are present in the test site are compared to a list of taxa occurring at >50% of Auckland reference sites (Note that the table has separate lists for hard- and soft-bottomed sites). The number of taxa in common between the test site and the reference list is recorded ($Taxa_{test}$) and divided by the weighted sum (sum of the proportions of presences) of expected taxa in the reference list $Taxa_{ref}$). $Taxa_{ref}$ is 8.58 for soft-bottomed streams and 18.2 for hard-bottomed streams. Vinvert = $Taxa_{test/}$ $Taxa_{ref}$.

| Soft-bottom taxa | | Hard-bottom taxa | |
|---|---|---|---|
| *Arachnocolus* | | *Acanthophlebia* | *Ichthybotus* |
| *Paradixa* | | *Ameletopsis* | *Latia* |
| *Paraleptamphopus* | | *Aphrophilia* | *Megaleptoperla* |
| *Paratya* | | *Archichauliodes* | *Olinga* |
| *Polypedilum* | | *Austroclima* | Orthocladiinae |
| *Polyplectropus* | | *Austroperla* | *Orthopsyche* |
| *Potamopyrgus* | | *Austrosimulium* | *Polypedilum* |
| Talitridae | | *Coloburiscus* | *Potamopyrgus* |
| Tanypodinae | | *Costachorema* | *Psilochorema* |
| *Tepakia* | | Elmidae | Ptilodactylidae |
| *Triplectides* | | *Helicopsyche* | *Stenoperla* |
| *Zephlebia* | | Hydraenidae | *Tanytarsus* |
| | | *Hydrobiosella* | *Zelandoperla* |
| | | *Hydrobiosis* | *Zephlebia* |

#### 5.13.1.4 Algorithm for scoring this function

$IFI = (V_{mci} + V_{ept} + V_{invert})/3$

## 5.14 Riparian vegetation intact (RVI)

This function recognises the strong inter-dependence between streams and riparian vegetation. The role of riparian vegetation in maintaining stream ecosystem function has been incorporated partly in previous functions (e.g. keeping summer water temperatures low in WTC, filtering overland run-off in DOP, providing an input of organic matter in OMI). However, these functions do not capture the other aspects of the role of riparian vegetation, including;

- anchoring stream banks via roots
- acting as a filter for ground water entering the stream
- providing habitat for aquatic fauna through producing instream wood and tree roots
- providing suitable habitat for the terrestrial adult phases of aquatic insects

Conversely, stream water is needed to support and maintain a number of plant species that occur within the riparian zone, to rear the larval stages of many terrestrial and winged insects, and to support native birds (e.g., kingfishers) and amphibia (native frogs) that depend on stream ecosystems.

The integrity of the ecosystem that characterises the land-water interface is therefore a key component of stream ecosystem functioning and is assessed primarily through the condition of its riparian vegetation ($V_{ripcond}$). However, the degree of connection between the two zones is also important ($V_{ripconn}$). For example a stream may have a well-developed and mature riparian buffer strip, but there may be little or no connection between this and the stream because the latter is culverted or concrete-lined.

The method of scoring the two variables and the algorithm for combining them into the RVI function is described below.

### 5.14.1 Measurement method

#### 5.14.1.1 $V_{ripcond}$

Visual inspection is carried out to determine the proportion of the floodplain covered by the vegetation types in the scoring table. Estimate the proportion of channel that matches each of the categories in the scoring table and sum the values of W x P for each row to obtain the $V_{ripcond}$ variable score. This variable uses the same information that is collected for $V_{rough}$, but the weightings are altered to reflect that we are measuring the condition of the vegetation in the riparian zone for this variable.

| Vegetation type | Weighting (W) | Proportion of channel (P) | Score (W x P) |
|---|---|---|---|
| Mature indigenous vegetation with diverse canopy and understory | 1 | | |
| Regenerating indigenous vegetation in late stage of succession | 0.8 | | |
| Natural, diverse wetland vegetation on banks | 0.8 | | |
| Mature native trees, but damaged understory | 0.7 | | |
| Mature exotic trees (e.g. willows and plantation forest) | 0.7 | | |
| Low diversity regenerating bush (e.g. manuka scrub) with stock excluded, or<br>tall (> 2m) exotic shrubs | 0.6 | | |
| Mature flax, long grasses and sedges | 0.4 | | |
| Low diversity regenerating bush with stock access, or<br>early stage restoration planting, or<br>short (< 2m) exotic shrubs, or<br>immature plantation forest | 0.3 | | |
| Mainly long grasses (not grazed or mown) | 0.2 | | |
| Grazed wetlands | 0.2 | | |
| Mainly short grasses (grazed or mown) | 0.1 | | |
| Disturbed bare soil or artificial surfaces | 0 | | |
| | Sum W x P | | |

5.14.1.2 $V_{ripconn}$

Determine the proportion of the stream channel (C) where the connections between riparian vegetation and the stream channel (e.g., through root linkages) are not prevented by culverts, concrete lining, gabions, fencing or by deep channel incision that lowers the water table below the root zone of riparian vegetation. If there are no impediments to connection, then C = 1, if there is no connection then C = 0.

Stormwater pipes and tile drains, which cause groundwater to bypass the riparian zone, reduce the riparian connectivity and hence their presence should lower the $V_{ripconn}$ score. These have been assessed in $V_{pipe}$, and are used in the calculation of $V_{ripconn}$ as follows.

$V_{ripconn} = C \times ((1+V_{pipe})/2)$

5.14.1.3 Algorithm for scoring this function

$RVI = V_{ripcond} \times V_{ripconn}$

# 6 Applications of the SEV method

## 6.1 Derivation of SEV scores

The scoring formulae (algorithms) and variables outlined in the preceding section for assessing the ecological value of each function are summarised in Table 3. The mean of the 14 ecological functions provides the overall measure of stream ecological value (SEV) for the reach assessed. The scores calculated for each function are provided for 19 test sites from across Auckland Council's monitoring network in Table 4.

Among the reference streams most of the individual function scores were very high. This reflects the fact that the ecological standard underpinning SEV was defined as "naturalness". The hydraulic functions all scored perfectly, and the biogeochemical functions were almost all above 0.9 (the exception, Water Temperature Control, was due to some natural canopy gaps at some sites). The habitat provision functions were more variable, mainly due to the lack of bully spawning habitat and hard surfaces for invertebrate habitat in some of the soft-bottomed streams. Among the biodiversity functions, invertebrate and riparian scores were high, but the fish scores were more variable, indicating that a full complement of native fish cannot be guaranteed, even in apparently pristine catchments. In some cases, this may be due to a migration barrier downstream.

The overall SEV scores of the five reference sites were all greater than or equal to 0.90. This indicates that while sites in native bush catchments score very highly, they do not typically get perfect scores, due to the reasons given above.

The function scores for streams representing varying degrees of catchment land use modification (urban, open pasture and exotic forest) are also shown in Table 4. In general, the function scores for the modified streams are lower than for the reference streams and reflect the extent of catchment modification expected. The overall SEV score and the mean hydraulic, biogeochemical, habitat and biodiversity functions all show a gradient of increasing scores from urban to rural to exotic forest sites. Individual functions, however, did not necessarily follow this gradient, due to the particular characteristics of each site. For example, Aroaro had a relatively unmodified flow regime, giving a high score for Natural Flow Regime, but it was deeply incised, giving it a very low score for Floodplain Effectiveness and for Fish Spawning Habitat.

Mean scores for the function categories show which ecological functions in the modified streams are below par compared with the reference streams. For many of the modified streams, the lowest scores were shown by the biodiversity and habitat provision functions. This may indicate the fact that habitat and biota depend on a wide variety of physical and chemical characteristics of a stream being intact. For example, while connectivity for species migrations was intact in all but one stream (raising the hydraulic function mean score), the fish fauna was impoverished to varying degrees (decreasing the biodiversity mean score), probably because factors other than access through the reach were limiting native fish colonisation.

**Table 3**

The variables and algorithms for calculating SEV function scores

| Function (section) | Variables required | Algorithm |
|---|---|---|
| Natural flow regime (section 5.1) | $V_{pipe}$<br>$V_{chann}$<br>$V_{lining}$ | $NFR = [(2V_{chann} + V_{lining})/3] \times V_{pipe}$ |
| Floodplain effectiveness (section 5.2) | $V_{bank}$<br>$V_{rough}$ | $FLE = V_{bank} \times V_{rough}$ |
| Connectivity for natural species migrations (section 5.3) | $V_{barr}$ | $CSM = V_{barr}$ |
| Natural connectivity to groundwater (section 5.4) | $V_{lining}$<br>$V_{chanshape}$ | $CGW = (2V_{lining} + V_{chanshape})/3$ |
| Water temperature control (section 5.5) | $V_{shade}$ | $WTC = V_{shade}$ |
| Dissolved oxygen levels maintained (section 5.6) | $V_{dod}$ | $DOM = V_{dod}$ |
| Organic matter input (section 5.7) | $V_{ripar}$<br>$V_{decid}$ | $OMI = V_{ripar} \times (1+V_{decid})/2$ |
| In-stream particle retention (section 5.8) | $V_{macro}$<br>$V_{retain}$ | IPR = lesser of $V_{macro}$ and $V_{retain}$ |
| Decontamination of pollutants (section 5.9) | $V_{surf}$<br>$V_{ripfilt}$ | $DOP = (V_{surf} + V_{ripfilt})/2$ |
| Fish spawning habitat (section 5.10) | $V_{galspwn}$<br>$V_{galqual}$<br>$V_{gobspwn}$ | $FSH = [(V_{galspwn} \times V_{galqual}) + V_{gobspwn}]/2$ |
| Habitat for aquatic fauna (section 5.11) | $V_{physhab}$<br>$V_{watqual}$<br>$V_{imper}$ | $HAF = [V_{physhab} + ((V_{watqual} + V_{imperv})/2)]/2$ |
| Fish fauna intact (section 5.12) | $V_{fish}$ | $FFI = V_{fish}$ |
| Invertebrate fauna intact (section 5.13) | $V_{mci}$<br>$V_{ept}$<br>$V_{invert}$ | $IFI = (V_{mci} + V_{ept} + V_{invert})/3$ |
| Riparian vegetation intact (section 5.14) | $V_{ripcond}$<br>$V_{ripconn}$ | $RVI = V_{ripcond} \times V_{ripconn}$ |

**Table 4**

SEV assessment results from 19 sites in Auckland

| Site | Marawhara Stream | Cascades Stream | Okura River | Nukumea Stream | West Hoe Stream | Mahurangi River | Orere Stream | Opanuku Stream | Vaughan Stream | Aroara Stream |
|---|---|---|---|---|---|---|---|---|---|---|
| Easting | 1730764 | 1735628 | 1753241 | 1749408 | 1748314 | 1747626 | 1796911 | 1742086 | 1755414 | 1789893 |
| Northing | 5910714 | 5916378 | 5940408 | 5951420 | 5950610 | 5964866 | 5903704 | 5915581 | 5938729 | 5903498 |
| Catchment land cover | Native forest | Native forest | Native forest | Native forest | Native forest | Exotic forest | Exotic forest | Rural | Rural | Rural |
| **Function** | | | | | | | | | | |
| Natural flow regime | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.59 | 0.97 | 0.99 | 0.53 | 0.72 |
| Floodplain effectiveness | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.48 | 0.92 | 0.76 | 0.14 | 0.12 |
| Connectivity for species migrations | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Natural connectivity to groundwater | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.81 | 0.99 | 0.99 | 0.83 | 0.86 |
| Hydraulic function mean | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.72 | 0.97 | 0.94 | 0.63 | 0.67 |
| Water temperature control | 0.76 | 0.80 | 0.94 | 0.94 | 0.80 | 0.76 | 0.90 | 0.56 | 0.20 | 0.48 |
| Dissolved oxygen levels maintained | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.68 | 1.00 | 1.00 | 0.34 | 0.68 |
| Organic matter input | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.70 | 1.00 | 0.70 | 0.00 | 0.20 |
| In-stream particle retention | 1.00 | 1.00 | 1.00 | 0.94 | 0.98 | 0.56 | 0.98 | 1.00 | 0.20 | 0.84 |
| Decontamination of pollutants | 1.00 | 1.00 | 1.00 | 0.96 | 1.00 | 0.86 | 0.88 | 0.80 | 0.74 | 0.80 |
| Biogeochemical function mean | 0.95 | 0.96 | 0.99 | 0.97 | 0.96 | 0.71 | 0.95 | 0.81 | 0.30 | 0.60 |
| Fish spawning habitat | 0.93 | 0.47 | 0.55 | 0.90 | 0.60 | 0.50 | 0.76 | 0.63 | 0.40 | 0.22 |
| Habitat for aquatic fauna | 0.97 | 0.98 | 0.82 | 0.98 | 0.94 | 0.77 | 0.99 | 0.81 | 0.36 | 0.54 |
| Habitat provision function mean | 0.95 | 0.72 | 0.68 | 0.94 | 0.77 | 0.64 | 0.88 | 0.72 | 0.38 | 0.38 |
| Fish fauna intact | 0.77 | 0.80 | 0.73 | 0.70 | 0.63 | 0.47 | 0.57 | 0.87 | 0.70 | 0.43 |
| Invertebrate fauna intact | 0.96 | 0.80 | 0.93 | 0.93 | 0.98 | 0.74 | 1.00 | 0.48 | 0.36 | 0.91 |
| Riparian vegetation intact | 1.00 | 0.80 | 1.00 | 0.80 | 1.00 | 0.64 | 0.80 | 0.59 | 0.30 | 0.28 |
| Biodiversity function mean | 0.91 | 0.80 | 0.89 | 0.81 | 0.87 | 0.62 | 0.79 | 0.65 | 0.45 | 0.54 |
| Overall SEV score | 0.96 | 0.90 | 0.89 | 0.94 | 0.92 | 0.68 | 0.91 | 0.80 | 0.44 | 0.58 |

| Site | Puhinui Stream | Papakura Stream | Waiwera River | Omaru Creek | Avondale Stream | Oakley Creek | Botany Creek | Paremuka Stream | Chatswood Stream |
|---|---|---|---|---|---|---|---|---|---|
| Easting | 1770072 | 1771240 | 1747612 | 1766268 | 1750685 | 1754917 | 1769788 | 1743365 | 1752861 |
| Northing | 5903308 | 5900290 | 5953946 | 5916749 | 5912301 | 5914269 | 5915080 | 5917644 | 5924029 |
| Catchment land cover | Rural | Rural | Rural | Urban | Urban | Urban | Urban | Urban | Urban |
| **Function** | | | | | | | | | |
| Natural flow regime | 0.99 | 0.37 | 0.63 | 0.20 | 0.67 | 0.04 | 0.06 | 0.77 | 0.94 |
| Floodplain effectiveness | 0.92 | 0.00 | 0.13 | 0.34 | 0.44 | 0.00 | 0.00 | 0.48 | 0.86 |
| Connectivity for species migrations | 0.30 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Natural connectivity to groundwater | 0.97 | 0.67 | 0.80 | 0.74 | 0.77 | 0.20 | 0.33 | 0.80 | 0.93 |
| Hydraulic function mean | 0.80 | 0.51 | 0.64 | 0.57 | 0.72 | 0.31 | 0.35 | 0.76 | 0.92 |
| Water temperature control | 1.00 | 0.08 | 0.70 | 0.40 | 0.64 | 0.60 | 0.22 | 0.78 | 0.84 |
| Dissolved oxygen levels maintained | 1.00 | 0.45 | 1.00 | 0.50 | 0.40 | 0.68 | 0.45 | 1.00 | 1.00 |
| Organic matter input | 1.00 | 0.00 | 0.57 | 0.03 | 0.80 | 0.00 | 0.00 | 1.00 | 0.80 |
| In-stream particle retention | 1.00 | 0.20 | 0.80 | 0.80 | 0.77 | 0.20 | 0.20 | 0.90 | 0.98 |
| Decontamination of pollutants | 0.75 | 0.60 | 0.76 | 0.81 | 1.00 | 0.50 | 0.60 | 0.80 | 0.98 |
| Biogeochemical function mean | 0.95 | 0.27 | 0.76 | 0.51 | 0.72 | 0.40 | 0.29 | 0.90 | 0.92 |
| Fish spawning habitat | 0.57 | 0.15 | 0.63 | 0.23 | 0.78 | 0.40 | 0.05 | 0.55 | 0.61 |
| Habitat for aquatic fauna | 0.85 | 0.30 | 0.77 | 0.25 | 0.50 | 0.22 | 0.20 | 0.59 | 0.74 |
| Habitat provision function mean | 0.71 | 0.23 | 0.70 | 0.24 | 0.64 | 0.31 | 0.13 | 0.57 | 0.67 |
| Fish fauna intact | 0.67 | 0.50 | 0.43 | 0.17 | 0.23 | 0.23 | 0.30 | 0.43 | 0.50 |
| Invertebrate fauna intact | 0.58 | 0.21 | 0.83 | 0.12 | 0.35 | 0.19 | 0.12 | 0.24 | 0.23 |
| Riparian vegetation intact | 1.00 | 0.00 | 0.60 | 0.18 | 0.41 | 0.00 | 0.00 | 0.60 | 0.90 |
| Biodiversity function mean | 0.75 | 0.24 | 0.62 | 0.16 | 0.33 | 0.14 | 0.14 | 0.42 | 0.54 |
| Overall SEV score | 0.83 | 0.32 | 0.69 | 0.41 | 0.63 | 0.30 | 0.25 | 0.71 | 0.81 |

## 6.2 Summary of changes to SEV

The SEV method outlined in this report includes a number of changes from the original SEV method (Rowe *et al.*, 2008). Most of the changes involved addressing functions or variables that were redundant or duplicated elsewhere in the method. In addition some changes were made to address those functions or variables that were not performing as expected, that were too subjective or that were difficult to assess in the field. As a result, most of the changes represented simplifications of the original method.

One function (Aquatic Biodiversity Intact) was removed as the function was already captured in the fish and invertebrate fauna intact functions. Two functions (Floodplain Particle Retention and Connectivity to Floodplain) were merged into one (Floodplain Effectiveness) as they were closely related. The calculations for several functions (Natural Flow Regime, Connectivity for Species Migrations, Water Temperature Control and Riparian Vegetation Intact) were simplified by removing variables. In a few cases, new variables were introduced. For example, In-stream Particle Retention is now measured by assessing the factors causing retention rather than measuring retention directly.

In summary, the result of the changes made to the SEV reduces the number of functions from 16 to 14 and the number of variables from 31 to 28. However, of the 28 variables in the revised SEV, seven variables are calculated from the same base data. This was a deliberate effort to reduce duplication in the collection of field data. We are confident there are valid theoretical or practical reasons for each of the changes made. However, in order to understand how scores in the original and revised systems relate to each other, a formal comparison of the two systems was needed.

## 6.3 Comparison of original and revised SEV systems

Scores produced by the revised and original SEV systems were compared by applying the revised SEV to 19 streams in Auckland Council's monitoring network that had previously been assessed with the original SEV method. The sites were in catchments chosen to represent the main land use types in the Auckland region, including native bush, exotic forest (pine plantation), rural (pasture), and urban. The sites thus spanned the range from minimal human impact to highly modified streams. As expected, among the 19 sites there was a very strong correlation between the original and revised SEV systems (Figure 1), with a Pearson Correlation Coefficient of 0.97 (Table 5). The average score changed very little from the original to revised systems, increasing by only 0.04 (Table 5). However, the range of scores increased, with the most severely modified sites decreasing from 0.39 to 0.25 and the most pristine sites increasing from 0.84 to 0.96. This increase in range was one of the desired outcomes of the SEV revision process, giving greater discriminatory power to the system. The increase in the reference site scores also results from clarifying the definition of some functions to ensure that "naturalness" was the ecological standard against which sites were assessed.

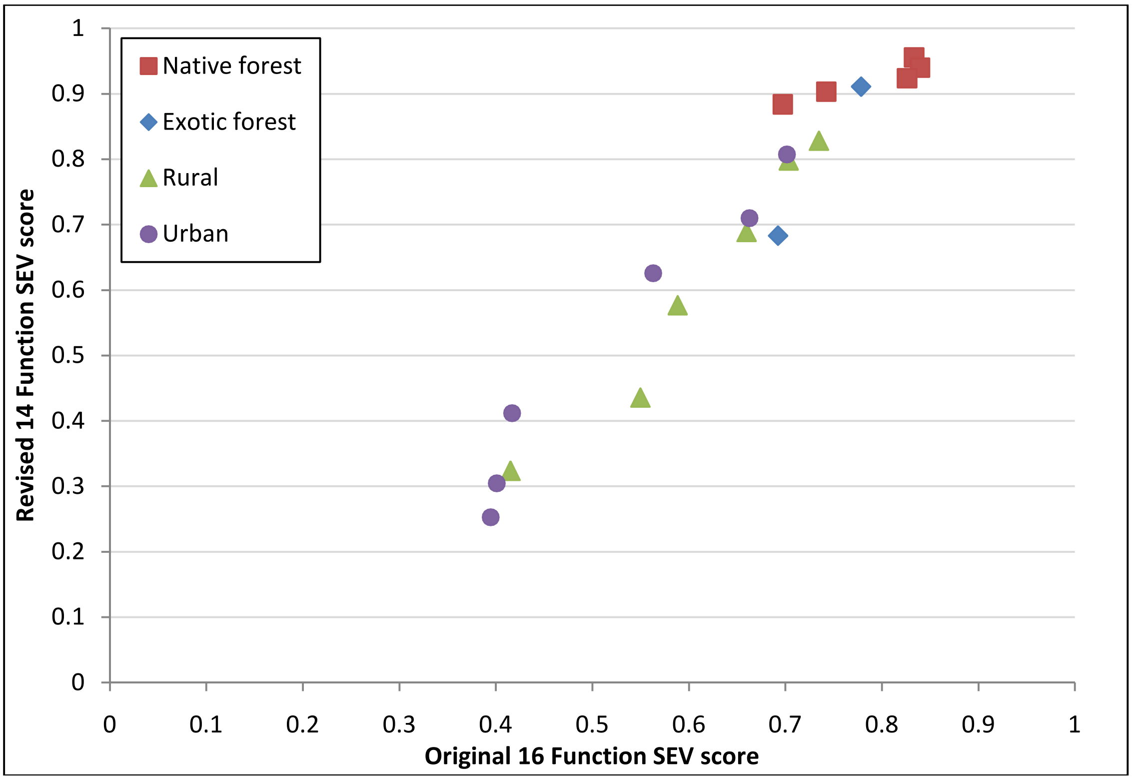



**Figure 1**

The relationship between original and revised SEV scores for 19 sites in Auckland Council's monitoring network.

Apart from the tendency to increase the scores of more pristine sites and lower the scores of more modified sites, the revised SEV did not seem to alter the scores in one land use type any differently from those in another. For example, the average score of the six urban sites was lower by 0.02 in the revised SEV than the original SEV, whereas the average score of the six rural sites was lower by 0.002. Among the 14 functions, the hydraulic functions changed most between original and revised SEV (Table 5). The mean hydraulic function score was 0.10 greater in the revised than in the original SEV system, whereas the mean biogeochemical score was 0.03 greater and the mean habitat provision score was 0.04 lower. The mean biodiversity score was almost unchanged.

From this analysis we conclude the revised SEV performs in a similar way to the previous version, but with greater discrimination amongst sites. In our opinion, this is a welcome result, which shows that the amendments made to simplify and streamline the SEV method have not resulted in the loss of any important information. The strong correlation between scores produced by the revised and original versions, which appears to be maintained in each of the four main land use types surveyed, also gives us confidence that overall mean SEV scores from the two methods can be related to each other. Relating individual function scores between original and revised versions is somewhat more risky, but it appears we can have reasonable confidence in relating biodiversity mean scores and habitat provision mean scores. Knowing the comparability between revised and original versions is important for interpreting a database of SEV assessments that will include both versions.

**Table 5**

Comparison of SEV function scores between the original (old) and revised (new) SEV for 19 sites in Auckland Council's monitoring network that cover a range of land use types. The Pearson Correlation coefficient ("R" in the final column), represents the strength of the correlation between the scores in the original and revised SEV, with an R of 1 indicating a perfect correlation. *Floodplain Effectiveness (FLE) in the revised SEV replaces Connectivity to Floodplain and Floodplain Particle Retention in the original SEV. For these functions, "change" is between FLE and the average of CFP and FPR.

| Function | Average score | | | Minimum score | | | Maximum score | | | R |
|---|---|---|---|---|---|---|---|---|---|---|
| | old | new | change | old | new | change | old | new | change | |
| Natural flow regime | 0.56 | 0.71 | 0.14 | 0.08 | 0.04 | -0.04 | 1.00 | 1.00 | 0.00 | |
| Floodplain effectiveness | | 0.56 | 0.02 | | 0.00 | -0.17 | | 1.00 | 0.03 | |
| Connectivity to floodplain* | 0.54 | | | 0.05 | | | 1.00 | | | |
| Floodplain particle retention | 0.54 | | | 0.30 | | | 0.94 | | | |
| Connectivity for species migrations | 0.83 | 0.96 | 0.13 | 0.06 | 0.30 | 0.24 | 1.00 | 1.00 | 0.00 | |
| Natural connectivity to groundwater | 0.74 | 0.83 | 0.08 | 0.10 | 0.20 | 0.10 | 1.00 | 1.00 | 0.00 | |
| Hydraulic mean score | 0.67 | 0.76 | 0.10 | 0.40 | 0.31 | -0.09 | 0.88 | 1.00 | 0.12 | 0.74 |
| Water temperature control | 0.70 | 0.60 | -0.10 | 0.49 | 0.00 | -0.49 | 0.85 | 1.00 | 0.15 | |
| Dissolved oxygen maintained | 0.69 | 0.77 | 0.08 | 0.10 | 0.34 | 0.24 | 1.00 | 1.00 | 0.00 | |
| Organic matter input | 0.44 | 0.62 | 0.18 | 0.00 | 0.00 | 0.00 | 0.82 | 1.00 | 0.18 | |
| In-stream particle retention | 0.73 | 0.76 | 0.02 | 0.32 | 0.20 | -0.12 | 1.00 | 1.00 | 0.00 | |
| Decontamination of pollutants | 1.00 | 0.83 | -0.17 | 1.00 | 0.50 | -0.50 | 1.00 | 1.00 | 0.00 | |
| Biogeochemical mean score | 0.68 | 0.71 | 0.03 | 0.48 | 0.26 | -0.22 | 0.88 | 0.97 | 0.09 | 0.82 |
| Fish spawning habitat | 0.61 | 0.52 | -0.09 | 0.05 | 0.05 | 0.00 | 1.00 | 0.93 | -0.08 | |
| Habitat for aquatic fauna | 0.65 | 0.66 | 0.01 | 0.19 | 0.20 | 0.02 | 0.96 | 0.99 | 0.03 | |
| Habitat prov. mean score | 0.63 | 0.59 | -0.04 | 0.12 | 0.13 | 0.01 | 0.92 | 0.95 | 0.03 | 0.90 |
| Fish fauna intact | 0.53 | 0.53 | 0.00 | 0.17 | 0.17 | 0.00 | 0.87 | 0.87 | 0.00 | |
| Invertebrate fauna intact | 0.53 | 0.58 | 0.05 | 0.00 | 0.12 | 0.12 | 1.00 | 1.00 | 0.00 | |
| Riparian vegetation intact | 0.68 | 0.57 | -0.11 | 0.02 | 0.00 | -0.02 | 1.00 | 1.00 | 0.00 | |
| Biodiversity mean score | 0.56 | 0.56 | 0.00 | 0.16 | 0.14 | -0.02 | 0.88 | 0.91 | 0.03 | 0.98 |
| SEV score | 0.64 | 0.68 | 0.04 | 0.39 | 0.25 | -0.14 | 0.84 | 0.96 | 0.12 | 0.97 |

## 6.4 Uses of the SEV method

Since the first description of this method was published (Rowe *et al*. 2006), SEV has been used for a much wider variety of purposes than originally envisioned. The most common use is still for resource consent applications for developments that involve impacts on streams. However, increasingly SEV is being integrated into stream ecological monitoring programmes, such as Auckland Council's State of Environment stream monitoring.

The SEV method has also been used in catchment planning and stream restoration planning. For example, in Papakura District (Phillips *et al*. 2006), Waitakere City (Storey, 2008) and Napier City (B. Stansfield, pers. comm.) SEV was used to identify the most effective restoration options and to rank streams in terms of their potential for ecological restoration.

The SEV has also been applied successfully in scientific research. Storey *et al*. (2009) used SEV to compare the ecological functioning of very small headwater streams to larger streams in Waikato pastoral catchments, comparing both low-gradient and steep hill country streams. Macdonald (2006) used SEV to see whether agricultural development results in a decline in the ecological function of streams within the Wairarapa district. The scores for each ecological function were used in a multivariate analysis to see whether they could be used to discriminate streams affected by different types of land use. The mean SEV for similar classes of streams was then used to determine the mean decline in ecological value caused by a change from forest to pasture. The method proved to be successful and provided a sensitive indicator of impairment in ecological function caused by changed land use.

## 6.5 Use of the SEV values to derive environmental compensation ratios

The Resource Management Act (1991)(RMA) provides resource managers with a number of options for dealing with environmental impacts caused by development projects. One option, that of Environmental Compensation (EC) (more commonly referred to as 'offset mitigation' in the international literature), has been accepted by the Environment Court in New Zealand in a number of cases, see for example J F Investments Ltd v's Queenstown District Council (C 48/2006). However in terms of the RMA there is a need to differentiate between 'EC' and 'mitigation'. Mitigation is something that is included to minimise the adverse effects as part of the proposal design process. Compensation is something that is done when all practical steps have been taken to minimise adverse effects and relates to the residual effects that cannot be mitigated. It is important to note that EC is not the default position when considering applications to modify streams. It is only invoked after all other options for avoiding damage have been fully considered as part of a 4th Schedule evaluation. The use of the SEV to determine EC in the manner is consistent with the direction of the National Policy Statement for Freshwater Management 2011.

Although the concept of EC is sound in principle, and is used almost globally now to help compensate for environmental damage, a number of technical difficulties have arisen with its application. Sites for EC usually differ in ecological character from the site to be impacted and this makes it difficult to determine a fair amount of environmental compensation to ensure that there is no net loss in ecological value. For example, the loss of a large, near-natural, second order stream within a predominantly native forest catchment would clearly not be adequately compensated for by the restoration of a similar length of smaller, first order stream in an urban catchment. Where the sites for restoration and development differ in ecological character or size, decisions on the appropriate amount of restoration involve a judgement about relative ecological values and the setting of an environmental compensation ratio (ECR).

The ECR determines the amount of stream restored relative to the amount of stream degraded or, when restoration is not feasible, the quantum of financial contribution taken in lieu of this. Where a stream reach set to be degraded is similar in most respects to a reach that will be restored then, assuming full restoration is possible over a short time frame, a theoretical ECR of close to 1:1 may be warranted. However, where the stream reach to be restored is lower in overall ecological value than the stream reach being degraded, then the ECR needs to be set at a higher level to compensate for this. For example, if the restored stream would result in a stream with only a third of the ecological value of the degraded stream, then a theoretical ECR of 3:1 (or 3 units of stream restoration for every unit of stream degraded) might be appropriate.

The ECR is also influenced by other factors. For example, restoration projects are not always as successful as anticipated and for every unit of restoration undertaken; only a proportion may result in close to full ecological value being achieved. Furthermore, there is inevitably a significant time delay before EC involving riparian planting achieves it maximum ecological benefit.

The setting of an actual ECR therefore requires a judgement about the relative ecological values of the site being impacted and that being restored. It also requires knowledge of the relative success rate of restoration projects and the time scale over which restoration achieves full ecological value. Because up until now the judgement of what constitutes ecological value has been subjective, decisions on appropriate ECRs are open to dispute. Environmental compensation is often required where on-site remediation is not possible, but at present there is little guidance for decision-makers or developers on the amount of EC required for a given development, or where EC could be usefully carried out and to what extent. Furthermore, there is no current basis for planning and coordinating to avoid a piecemeal approach to restoration.

One of the aims of developing the SEV method in Auckland streams was to determine whether it was possible to use the SEV values to develop a formula for calculating offset environmental compensation. Offset environmental compensation is being used increasingly in a number of countries around the world to balance the environmental damage at a development site with improvement of habitat at another site. In this context, 'offset' is defined as compensation for the negative impacts of an activity by undertaking a separate action with positive, and hence 'compensatory', impacts elsewhere. An environmental compensation ratio helps determine the amount of stream area that would need to be restored relative to the amount degraded in order to maintain 'no net loss' in overall ecological function. We consider that environmental compensation ratios greater than 1 (i.e., more compensation is required to match the amount of stream habitat lost/damaged) are valid because of:

- the ecological risk factors associated with the cumulative loss of streams to development and the steady change in areal distribution of high quality stream reaches;
- the long time-lag before full benefits of environmental compensation (e.g., from riparian planting) accrue to the mitigated site, this may exceed 10 years; and
- the overall difference between the expected and actual success of stream restoration methods.

In the calculations explained below, we use the SEV method to derive environmental compensation ratios based on the functions that will be lost at the impact site and the potential improvements to be gained at an environmental compensation site.

## 6.5.1 Justification for use of environmental compensation

Underlying the concept of environmental compensation is the principle of “no net loss”, and currently for Auckland streams 8.9 km of stream length on average is subjected to consented stream works each year (Auckland Regional Council, 2009). By using the function based valuation of streams, the aim is to achieve “no net loss of area-weighted stream function”. Stream area is important to conserve in order to keep habitat values, but this should not be at the expense of stream length. For example, if a 100 m stream reach, 1.6 m wide, is being lost and the calculated area to be replaced is 160 $m^2$, then if the proposed offset site for restoration is a wider stream, say 3.2 m, the replacement area would be gained in only 50 m of stream length. It is recognised that there are values associated with edge habitat and the proximity to banks so that a minimum replacement length equal to stream length lost needs to be part of the environmental compensation framework. In other words, replacement stream length would have to equal the stream length lost or be longer if the replacement stream was narrower than the one lost.

The SEV analysis should be carried out only after all alternatives to loss/damage of stream have been fully considered in terms of the 4th Schedule of the RMA. We are assuming that Council staff would have assessed sites of high value as part of the RMA process. The philosophy of the approach is to provide environmental compensation options as a final step after all other efforts to avoid or remedy impact have been investigated.

## 6.5.2 Definition of terms and concepts

A general agreement in the offset environmental compensation literature is that replacement should be “like-for-like” because the purpose should be to restore specific functions and values of the same kind that are going to be lost. We consider that in terms of stream ecological function in-kind includes streams of the same stream order and streams that are close to the development site. This requirement will help guard against the cumulative loss of certain stream types within catchments and will help maintain habitat connectivity (e.g., for fish migrations). Local communities will also retain the amenity value of the stream if restoration is nearby.

In certain cases, the potential for on-site stream environmental compensation (i.e., on an adjacent reach of the same stream) may be low or non-existent, therefore an environmental compensation stream ‘off-site’ may be needed. On-site environmental compensation is preferable but if environmental compensation is off-site, the principle of proximity should be used. Our recommendation is to choose a stream of similar size and/or stream order and within the same catchment as the impact site. If this is not possible, then environmental compensation in an adjacent catchment is preferable, but any such ‘outside-catchment’ environmental compensation should be negotiated on a case-by-case basis with the Council. The Council may decide that environmental compensation can be performed off-site if there is greater environmental benefit for the region to be gained by doing so. The SEV scores can be applied as described below to indicate when an on-site environmental compensation site may not be suitable for restoration and where off-site environmental compensation should be sought.

## 6.5.3 Where to undertake environmental compensation

Threshold SEV values are required to identify whether a site is suitable for on-site environmental compensation or not. This is because, the reach proposed for remediation may already have a very high ecological value such that no further improvement is required, even if a small amount is possible. Alternatively, the reach may have a very low SEV value indicating that it may not be feasible to create a significant improvement in ecological performance. For example, if the amount of impervious area caused by urban development above the site is >25% then it is likely that the potential for restoration of ecological functions will be very low.

We consider that threshold SEV values of 0.4 and 0.8 would provide the best indicators for whether environmental compensation is appropriate at a site. If the SEV value for a site being considered for environmental compensation is between 0.4 and 0.8, then on-site remediation is likely to be beneficial and it should be considered appropriate. However, if the SEV value is lower than 0.4 or greater than 0.8 then an alternative location is recommended.

## 6.5.4 Conditions for the calculation of environmental compensation ratios

In calculating the amount of restoration for environmental compensation, stream area should be conserved in order to maintain the ‘no net loss’ in terms of overall habitat, but this should not be at the expense of stream length because of the inherent values associated with the edges of streams. Therefore, in applying environmental compensation ratios the length of stream to be mitigated should never be less than the length of stream degraded.

Clearly, the acquisition of pristine forest streams (by preservation) should not be acceptable as environmental compensation for stream loss, as no new area of habitat has been improved or restored.

## 6.5.5 Calculation of environmental compensation ratios

The panel of experts explored a number of options for calculating an environmental compensation ratio. This proved to be a difficult task as such a ratio needs to take into account the ecological values of the site to be impacted as well as those of the site to be mitigated. In addition, such a ratio needs to account for the fact that best practice remediation often fails to achieve what is expected and that some environmental compensation measures (e.g., riparian planting) may take many years before their full effect accrues to the site.

The method described here is considered the best of the various options that were explored. We used the SEV method to derive environmental compensation ratios based on the functions that will be lost at the impact site and the potential improvements to be gained at an environmental compensation site. This provides a scientific basis for determining an environmental compensation ratio scaled to the streams where the development and environmental compensation is intended. The rationale for the formula selected is that it compares the loss of functions at the impact site relative to the functions gained at an environmental compensation site. However, the functions lost at the impact site include not only those that are actually degraded as a consequence of the development, but also the potential for improvement in these functions that is forgone by development of the site. Failure to take this component into account is likely to result in a steady decline of stream values on a regional scale.

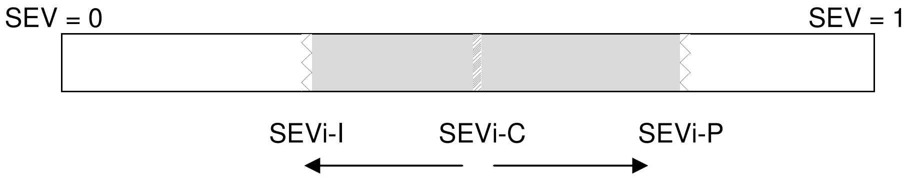
The formula gives the number needed to multiply the area of the impacted stream by, to determine what area needs to be restored in the environmental compensation stream, in order to replace the functions lost in the impacted stream.

The values used in this calculation are defined as follows and are shown graphically below:

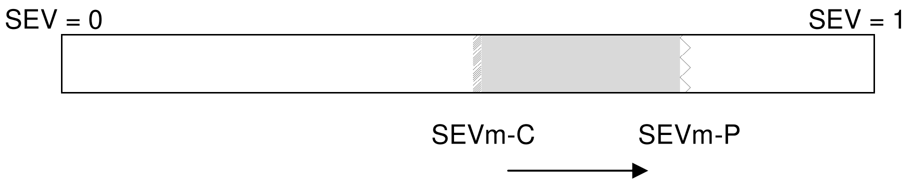
- SEVi-C & SEVi-P are the current and potential SEV values respectively for the site to be impacted.
- SEVm-C & SEVm-P are the current and potential SEV values respectively for the site where environmental compensation is to be applied.
- SEVi-I is the predicted SEV value of the stream to be impacted, after impact.

The values defined above are represented schematically in the diagram below. The arrows indicate the direction of change in ecological value from the marked points (i.e. vertical line above value name) on the SEV scale of 0 to 1.

**Impact site**




**Environmental compensation site**




The steps in the calculation of the variables above and in the environmental compensation ratio for a stream reach to be modified and a stream reach selected for environmental compensation are outlined in the box below.

If the calculation produces an ECR value of less than 1, then the ECR defaults to 1. The area of stream impacted should be multiplied by this value to establish the area required for remediation.

**Steps in the calculation of the environmental compensation ratio**

**Step 1:** Establish the 'current' SEV values for the site that will be impacted and for the proposed environmental compensation site. (Note; do not include biotic functions (IFI and FFI) in this calculation because of the difficulty of predicting these outcomes).

**Step 2:** Determine the 'potential' SEV values for both the impact and environmental compensation sites by recalculating the variables using 'predicted' function scores assuming 'best-practice' remediation works have been carried out at both sites. Predictions are the best scores possible if the sites were to be restored as far as practical from present with current best-practice. (Note; do not include potential scores for biotic functions (IFI and FFI) in these calculations because of the difficulty of predicting these outcomes

**Step 3:** Determine the SEV value at the impact site (SEVi-I) again using predicted function scores but now assuming that the proposed development works (e.g., piping, filling) have been carried out. (Note; do not include potential scores for biotic functions (IFI and FFI) because of the difficulty of predicting these outcomes.

**Step 4:** Follow the formula for calculating an environmental compensation ratio below. This value will be the amount you have to multiply the area of the stream you are impacting by to determine how much area of stream needs to be restored.

$$\text{ECR} = [(\text{SEVi-P} - \text{SEVi-I})/(\text{SEVm-P} - \text{SEVm-C})] \times 1.5$$

This formula was tested using real and predicted data for the four non-reference streams used in the development of the SEV method, together with an hypothetical degraded stream (Rowe *et al.*, 2006). The formula works in the sense that environmental compensation ratios were highest when a relatively unmodified stream is used for environmental compensation and lower for more degraded streams. The formula also works as would be expected in that if high quality sites are impacted they require a greater amount of environmental compensation to account for functions lost than a lower quality site.

It was recognised that this methodology, and in particular the functions, variables and algorithms used to assess ecological value will undoubtedly be improved and further developed as the understanding of ecological processes in streams increases. While the initial methodology was developed using data from soft-bottomed streams in the Albany area of Auckland a considerable amount of experience has now accumulated with its application to a wide range of streams where it has been found to be appropriate for use.

# 7 Acknowledgements

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# 9 Appendix

# A fish index of biotic integrity (IBI) for the Auckland Region

**Report and user guide for use with**

**the Auckland_Fish_IBI software**

**July 2004**

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## Introduction

The index of biotic integrity (IBI) was originally developed using fish in the USA by James Karr during the early 1980s. The original version had 12 metrics that reflected fish species richness and composition, number and abundance of indicator species, trophic organization and function, reproductive behavior, fish abundance, and condition of individual fish. This process has been repeated and IBIs developed on many continents. The fish fauna of New Zealand is radically different from the continental faunas the IBI was developed on so to apply here a number of changes have been made. The basic concept has been retained applying metrics to fish assemblages and the use of a large number of sites to give a background level of biological condition and then comparing a site of interest with that dataset to assess the status of the test site.

New Zealand's freshwater fish fauna has only a single trophic level and disease in wild fish populations is virtually absent thus, we did not include these metrics. We used a six metrics measuring taxonomic richness over a number of habitat types, indicator species by measuring the number of species showing intolerance to degraded conditions and the ratio of native to exotic species. Many studies have shown that New Zealand's fish fauna is largely structured by elevation and distance from the coast and this is obvious in the Auckland region (Fig. 1).

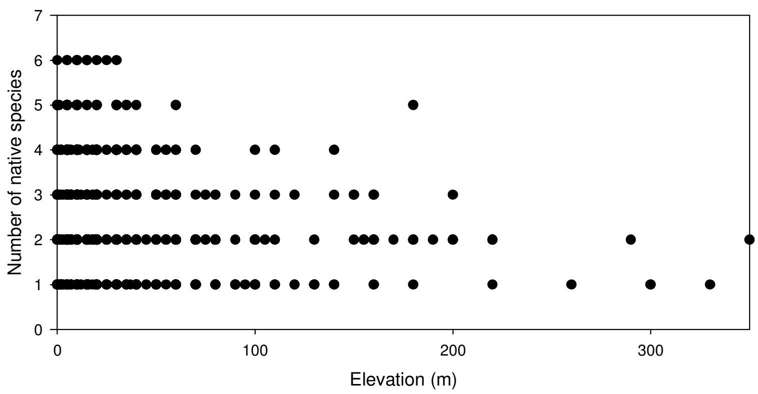


**Figure 1**. Number of native species from 1133 sites in the Auckland region plotted against elevation.

Because elevation and distance from the coast are the overriding controllers of species distribution they were used to structure expectations of fish assemblages. The six metrics were assessed for both elevation and distance from the coast to give 12 metrics overall and these were summed to give the final score.

The scoring process for each metric is summarized using the example of native species richness. The sites are plotted against elevation as in Fig. 1 and an upper line is drawn by eye from the highest elevation to include approximately 95% of the sites (Fig 2).

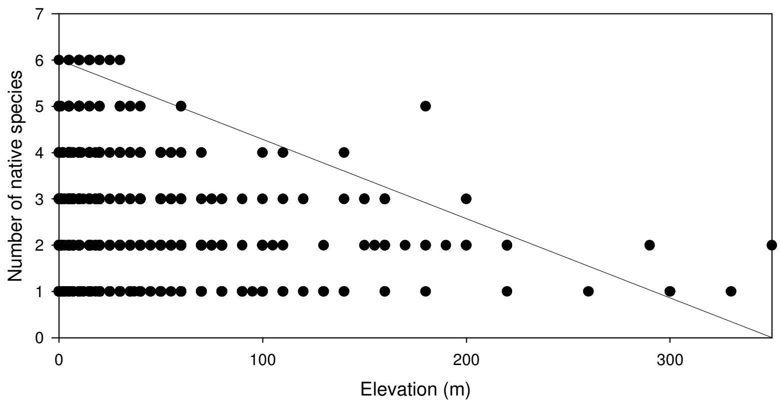


**Figure 2**. Fitting of line by eye line to include 95% of sites.

This line was named by James Karr as the maximum species richness line (MSRL) and shows the upper bound for species richness and is only used for the following step. The area under the line was then trisected to score sites (Fig. 3). The three lines then became the scoring lines; if a site is below the lower line it scores 1 (no score for 0 species), between the lower two lines scores 3 and above the second line it scores 5 (Figure 4).

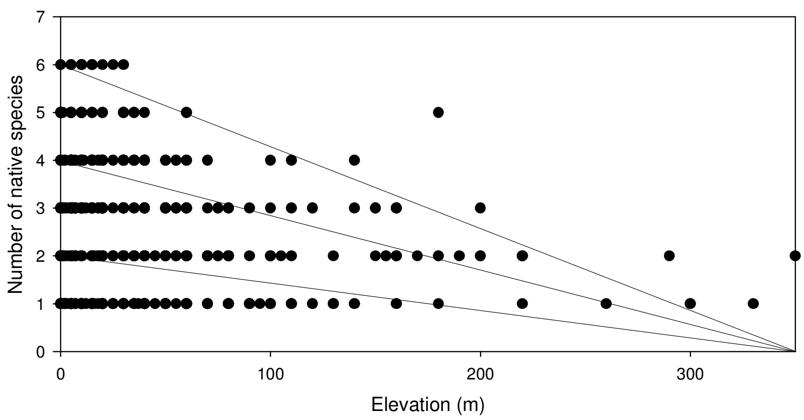


**Figure 3**. The area below the MSRL was trisected to give the scoring lines.

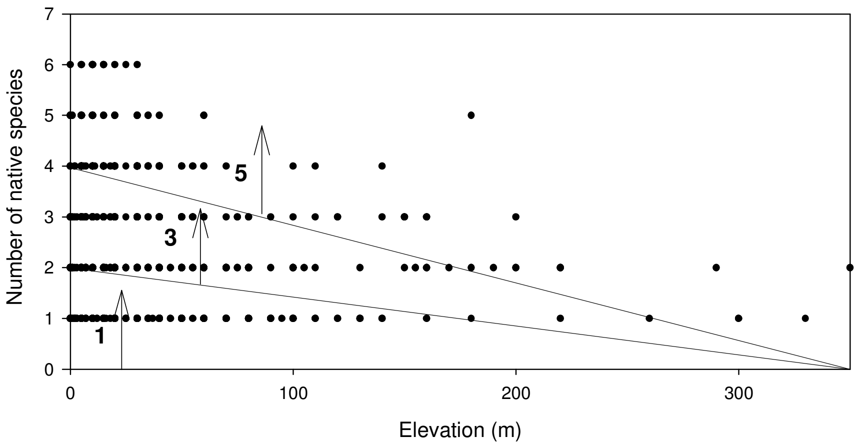


**Figure 4**. An example of site scoring from the lines below the MSRL.

The process outlined above is repeated for the 6 metrics (described below) and for distance from the sea for the same 6 metrics.

## Auckland Fish IBI metrics

### Taxonomic richness

**Metric 1** is the number of native species, an attribute of freshwater biotas commonly used in biological assessment. We used native species richness, as opposed to total species richness as non-native species may prefer degraded habitats and thus increase species richness. The assumption underpinning the use of the species richness metric is that environmental degradation will change diverse communities containing many species to simple assemblages dominated by a few species.

### Habitat Guilds

**Metric 2**, the number of native benthic riffle species is used as an indicator of degradation in riffle zones in rivers. **Metric 3** is the number of native benthic pool species and metric 4 is the number of native pelagic pool species. These metrics were used to make the index sensitive to changes in stream geomorphology resulting from the effects of channelisation and dams on habitats required by fish in these guilds. Only native pelagic pool species were included because many of the alien species indicative of degradation found in New Zealand are pelagic.

### Tolerant species

**Metric 5** is the number of intolerant species and makes use of limited information on the tolerance of New Zealand freshwater fish to different environmental variables. Species were selected based on their tolerance to impacts such as migration barriers and water quality variables such as temperature, sediment and ammonia.

### Invasive species

**Metric 6** is the proportion of native to alien species and measures the extent to which the fish assemblage has been invaded by introduced species. The presence of non-native species reflects biological pollution, and generally, these species in New Zealand are more tolerant of degradation of habitat and water quality than the native species and thus, they may indicate degraded conditions

**Calculation of total IBI score**

To calculate the total IBI, the scores for the six metrics are summed to give the IBI score for each sampling site. There are six metrics each for elevation and distance from the coast (maximum possible of 60 and minimum 0).

**Interpretation of results**

As a guide to interpreting the final scores (Karr et al. 1986) gave the following ranges of qualitative assessments given for the IBI scores: excellent (58 – 60), good (48 – 52), fair (40 – 44), poor (28 – 34), and very poor (0 – 22) (the IBI is 0 at sites where no native fish are caught). Table 1 gives the attributes and integrity classes adapted from the Karr groups to help with assessment of site scores. As a further guide the software produces a distribution histogram to give an indication for how the site you are interested in compares with the 1200 sites in the region used to build the model (fig 5). The graphs used to calculate the MSRLs can be seen in the Appendix.

**Table 1** Attributes and suggested integrity classes for the Auckland IBI

| Total IBI score | Integrity class | Attributes |
|---|---|---|
| 50 – 60 | Excellent | Comparable to the best situations without human disturbance; all regionally expected species for the stream position are present. Site is above the 97th percentile of Auckland sites |
| 42 - 49 | Very good | Site is above the 90th percentile of all Auckland sites species richness is slightly less then best for the region |
| 36 - 42 | Good | Site is above the 70th percentile of Auckland sites but species richness and habitat or migratory access reduced some signs of stress |
| 28 - 35 | Fair | Score is just above average but species richness is significantly reduced habitat and or access impaired |
| 18 - 27 | Poor | Site is less than average for Auckland region IBI scores, less than the 50th percentile, thus species richness and or habitat are severely impacted |
| 6 - 17 | Very poor | Site is impacted or migratory access almost non existent |
| 0 | No fish | Site is grossly impacted or access non existent |

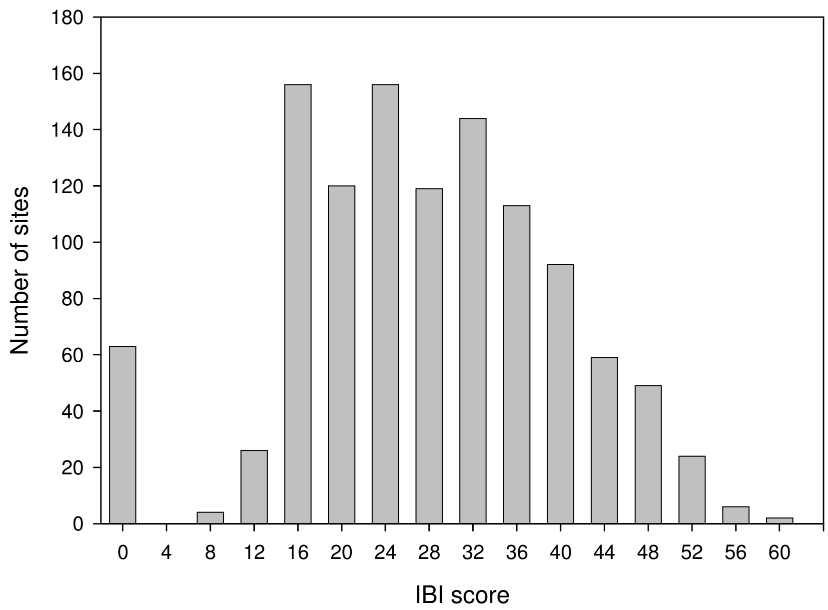


**Figure 5** The distribution of IBI scores across the 1133 sites used to calibrate the IBI

**Running a set of sites through the Auckland_Fish_IBI software to calculate scores an example:**

1. Open the excel file **Auckland_Fish_IBI**
2. Enter details in the Batch notes cell any information you want to appear on the output file
3. The fish presence data can be pasted in from another file or entered by hand, the first row is for the site name or number, the second row is for the height above sea level in meters of the site, the third is the distance (as the fish swims) of the site from the coast.
4. In the column below the site details the fish captured at the site are entered, you can enter the numbers caught but the model is based on presence/absence only so anything greater than zero will be counted as a presence and zero or no data will be counted as an absence.
5. To test a single site click on a cell in the column containing the site of interest then click on “test one site” button in IBI toolbar. The IBI score is calculated and the score is shown with its Integrity class are shown above the graph. The graph gives the position of site in relation to all the sites from the region as a red bar.
6. To remove the graph click on the remove graphs button on the IBI toolbar and start again for another site.
7. To run a group of sites through you can paste a set of sites in following the format of the example sites. To run them all click on the test all sites button, this will take you to the output sheet where the results are summarized. This page can then be printed.

**Find out more:** phone 09 301 0101
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