CAWTHRON

Report No. 1979
July 2011

# Broad-scale Trout Habitat Mapping for Streams (Using Aerial Photography and GIS)


RESEARCH BASED SOLUTIONS

# Broad-scale Trout Habitat Mapping for Streams (Using Aerial Photography and GIS)

Robin Holmes

John Hayes

Cawthron Institute
98 Halifax Street East, Private Bag 2
Nelson, New Zealand
Ph. +64 3 548 2319
Fax. + 64 3 546 9464
www.cawthron.org.nz

Reviewed by: Iain Maxwell

Approved for release by: Rowan Strickland

Issue date: 4 August 2011
Recommended citation:
Holmes R, Hayes JW 2011. Broad-scale Trout Habitat Mapping for Streams (Using Aerial Photography and GIS). Cawthron Report. No. 1979. 40 p.

# EXECUTIVE SUMMARY

This report reviews information on trout habitat and describes an assessment protocol to create broad-scale trout habitat maps using aerial photography and GIS software. The protocol was designed to support stream habitat rehabilitation. A habitat inventory is the first step in understanding the need and scope for rehabilitation to benefit fish populations. In addition to rehabilitation, broad-scale stream habitat mapping can inform several facets of a fishery investigation. These include:

a. Locating and/or validating representative stream reaches for assessment or monitoring;
b. Locating sources and sinks of pollution;
c. Informing a limiting factor analysis;
d. Identifying areas suitable for protection or restoration to address limiting factors;
e. Monitoring habitat change at the stream-segment/catchment scale;
f. Cataloguing fish habitat quality and predicting fish distributions and relative abundances.

Many land management actions have far reaching consequences at the catchment level on water quantity, quality and stream habitat. Small-scale stream habitat assessments may overlook these catchment-scale influences with consequent risk that causes of habitat condition may go undetected or misdiagnosed. This survey protocol is configured to fill a perceived lack of broad-scale habitat assessment methods for New Zealand streams. A balance is sought in the survey design to acquire sufficient habitat detail whilst rapidly (and economically) surveying large tracts of stream to include broad-scale features influencing habitat condition.

The survey involves a desktop analysis of existing catchment knowledge followed by ground-truthing habitat features on aerial photographs. Stream-segments (5-10 km approximately) are stratified by the locations of catchment-scale geomorphological, hydrological, and land-use features that are considered to have an overriding influence on habitat condition. Survey areas are then randomly assigned within the stratified segments. The field protocol is split into two stages: a reach-scale in-stream assessment of trout habitat nested within a broader stream-segment scale assessment of riparian features and contaminant sources. An optional, subjective qualitative assessment of trout habitat, angling access and aesthetics is also included in the protocol.

Experience with a pilot trial on the Wakapuaka Stream (Nelson) suggests that a single field worker can complete a 1 km section of the riparian survey component in 2 hours and a 100 m section of the in-stream component in 1.5 hours. Once the habitat map information is digitised, the data can be analysed using ArcView software. Possible analysis outputs are discussed including the prospect of using the survey results to develop an index of trout habitat quality.

# TABLE OF CONTENTS



# LIST OF FIGURES

# LIST OF TABLES

# 1. INTRODUCTION

With the intensification of agriculture in New Zealand over the last 20 years in particular, there has been a growing concern, matched by comprehensive scientific evidence, that the water quality of rivers draining agricultural land has become degraded (Smith *et al.* 1993; Parkyn *et al.* 2004; Ballantine & Davies-Colley 2009). Associated with this widespread environmental impact, New Zealand's once extensive, world-renowned lowland trout fisheries have suffered widespread decline, substantiated largely by anecdotal accounts and by a lesser body of scientific evidence (Jellyman *et al.* 2003). New Zealand, a nation once blessed with a wealth of clean freshwaters and attendant quality trout fisheries has now entered a phase in its history where it must seriously entertain stream (and lake) rehabilitation – following the same path taken by much more populous, developed nations.

Widespread loss of trout fishing opportunities has been a significant driver in the nation's interest in reducing the environmental footprint of agricultural intensification and dairy farming in particular (*e.g.*, Fish and Game's dirty dairy publicity campaign). Moreover, the Dairying and Clean Streams Accord of 2003, aimed at mitigating effects of dairy farming on freshwaters, specifically mentions maintaining waters suitable for fish. Despite its clear relevance, trout fisheries research has not yet been integrated in stream habitat rehabilitation and restoration research efforts in New Zealand. Awareness of this oversight underpinned the inclusion of research targeted at restoration of trout fisheries in diary monitored catchments in the Ministry of Science and Innovation-funded Aquatic Rehabilitation Programme, which began in 2010. As a first step in that research effort, this report documents a broad-scale trout habitat mapping protocol that we designed for underpinning trout stream rehabilitation.

Our protocol differs from the habitat assessment protocols for wadeable New Zealand rivers and streams recently developed by Harding (et al. 2009). Its focus is on key trout habitat features rather than general stream habitat condition. Furthermore, this survey is designed to gather a more extensive dataset than the Harding et al. protocols. By considering stream-bed and mesohabitat features within a wider landscape context our protocol attempts to build a representative picture of trout habitat within an entire stream. It is intended to be trialled on one of the five streams across New Zealand that have been intensively monitored to assess the effects of implementing best dairy farming management practises (Toenepi in Waikato, Waiokura in Taranaki, Waikakahi in Canterbury, Bog Burn in Southland and Inchbonnie in the West Coast). The information gathered will be used to assess and assist the on-going restoration efforts in these streams.

# 2. BROAD-SCALE HABITAT MAPPING OVERVIEW

Riverine fish populations are strongly influenced by physical habitat parameters which can be used to predict their distribution and abundance (Maddock 1999; Roper *et al.* 2002; Whitacre *et al.* 2007; Harding *et al.* 2009). Broad-scale habitat inventories and assessments are a standard procedure for New Zealand estuary monitoring and freshwater fisheries management overseas (Fausch *et al.* 1988; Maddock 1999; Robertson *et al.* 2002; Creque *et al.* 2005; Dolinsek *et al.* 2007). However, most habitat investigations in New Zealand streams are limited to reach-scale assessments either of a data intensive, quantitative nature that model proposed flow alterations (Jowett 1997), or largely subjective habitat quality surveys conducted by regional councils (*e.g.* Quinn 2009). Reach-scale assessments are cost effective, however, they may not be representative of the entire waterway (O'Connor & Kennedy 2002) and may overlook influences of land management actions operating at the catchment level on stream habitat. There is a consequent risk that causes of habitat condition may go undetected or misdiagnosed. This myopic weakness of reach-scale assessments was demonstrated in a water quality report on the Waikakahi Stream (a dairy monitored stream) where the concern was raised that “the lower monitoring sites provide no certainty that sedimentation problems are not redeveloping in the upper catchment” (Meredith *et al.* 2003). By increasing the scale of habitat assessment to stream-segments (approximately 5-10 kilometres) the chances of detecting potential sources of pollutants and habitat degradation are increased. Once problems areas are identified, they can be targeted with restoration initiatives (such as stock fencing or riparian planting).

The Land and Water forum report of September 2010 signalled that water management should be conducted at the catchment scale (Bisley 2010). Assessment methods are needed which can monitor the effects of (and generate predictions about) management decisions which effect catchment scale features and processes. Broad-scale habitat mapping should serve as a useful tool to investigative the following common stream management objectives:

a. Locating and/or validating representative stream reaches for assessment or monitoring;
b. Locating sources and sinks of pollution;
c. Informing a limiting factor analysis;
d. Identifying areas suitable for protection or restoration to address limiting factors;
e. Monitoring habitat change at the stream-segment/catchment scale;
f. Cataloguing fish habitat quality and predicting fish distributions and relative abundances.

In most instances there will be insufficient resources to assess entire streams (except for very small streams *e.g.* <10 km long) and a stratified random survey design will be needed to map representative segments of a catchment. Stream-segments (5-10 km approximately.) can be stratified within a catchment by undertaking a desktop analysis that considers the locations of catchment-scale geomorphological, hydrological, and land-use features which can have an overriding influence on habitat condition (Collier *et al.* 2007; Harding *et al.* 2009). Survey areas can then be then randomly assigned within the stratified segments. For finer-scale habitat features that cannot be rapidly summarised on aerial photographs, a more intensive reach-scale survey is necessary. Reaches should be randomly chosen from the strata of stream-segments. If a stream survey is conducted in this manner, with assessments pitched at multiple scales, the condition of smaller-scale habitat features can be considered in the context of larger-scale influences (Parsons & Thoms 2007).

Habitat features can be ground-truthed by walking up each segment or reach and noting or tracing around relevant features (such as areas of riparian vegetation likely to provide cover or shade) on aerial photographs. Habitat features that are too small to be identified on aerial photographs can be measured indirectly by creating points and recording associated size estimates or measurements. Alternatively, data (such as % macrophyte cover within a reach) can be attached to a delineated reach on an aerial photograph. The benefit of this approach is that the two-dimensional area of some habitat features can be quantitatively measured, and semi-quantitative and qualitative data can be recorded rapidly in the field using the photograph as a template.

Maps can be drawn on hardcopy photographs in the field and subsequently digitised by scanning and then using ArcVeiw software to draw shapefiles over the recorded information. Alternatively, the maps can be created in a digital format that is ready for analysis using tablet style field computers capable of running ArcPad software. Once the habitat maps are digitised, the data set can be interrogated for groups of variables that may indicate areas of interest to specific management objectives (using ArcView software) and results can be effectively visually communicated on catchment maps.

Recording all the variables that contribute to good trout habitat on a stream segment-scale is an unrealistic goal. In practice, a significant amount of detail must be sacrificed for the increased spatial scale of investigation. However, variables such as microhabitat structure are correlated with fluvial geomorphic features and processes at the mesohabitat scale. Therefore, inference can be made about features and processes operating at smaller scales (*e.g.* microhabitat) from information gathered at large spatial scales (David *et al.* 2002; Creque *et al.* 2005). The primary focus of this broad-scale habitat mapping exercise is the rapid categorisation and measurement of "gross" trout habitat variables that can be distinguished on aerial photographs. Key features and processes that should be considered when undertaking a trout habitat mapping exercise are listed below.

# 3. TROUT HABITAT VARIABLES

## 3.1. Catchment scale variables

Catchment scale variables such as geology, valley form, rainfall, segment sinuosity, land-use type and flow history have significant influences on water quality and physical habitat variables down to the microhabitat scale (Brosse *et al.* 2003; Townsend *et al.* 2003; Creque *et al.* 2005). Catchment scale variables are an essential component of any stream habitat assessment. Information on the catchment scale variables listed (Table 1) can be obtained through regional councils, local and landowner knowledge, aerial photos and a desktop analysis of existing data sets such as REC and FENZ (see desktop protocol in Harding *et al.* (2009).

## 3.2. Land-use

In New Zealand, the catchments of lowland streams are dominated by agriculture (Quinn 2000). Agriculture and intensive dairy farming in particular, can cause considerable degradation to stream ecosystems primarily through diffuse inputs of fine-sediment and nutrients (nitrogen and phosphorus) (Quinn & Stroud 2002; Scrimgeour & Kendall 2003; Niyogi *et al.* 2004). Land clearance for agriculture (and forestry) can also profoundly alter flow patterns and sediment supply which affects geomorphology of streams (Bjornn & Reiser 1991). This can have lagged and long lasting effects on channel structure, the habitat template for fishes and other aquatic life. In this respect, a diagnosis of stream habitat condition must take into account the fact that current stream condition integrates past activities at the reach and catchment scale, current actions, and natural disturbance (Bauer & Ralph 1999).

Fine-sediment is considered the most harmful stressor in rural stream ecosystems (Quinn *et al.* 1997; Harding *et al.* 1999; Quinn 2000; Riley *et al.* 2003; Davies-Colley *et al.* 2004). Fine-sediment has a homogenising effect on the stream bed, infilling substratum interstices and smothering the stream bed in extreme cases, which can reduce available salmonid spawning habitat, juvenile trout cover and the productivity and diversity of the benthic invertebrate community (trout food) (Duncan & Ward 1985; Wood & Armitage 1997; Allouche 2002; Sutherland *et al.* 2002). Infilling of pools by fine sediment reduces the carrying capacity for juvenile and adult fish during the summer growth periods (Waters 1995). When Bjornn *et al.* (1977) added sand to a natural pool, reducing the pool volume by half and the area of water deeper than 0.5 m by two thirds, trout numbers were reduced by two thirds (Bjornn *et al.* 1977).

Furthermore, fine-sediment can decrease water clarity which can reduce primary productivity (benthic invertebrate food), the ability for salmonids to drift-feed, and the angling experience (Davies-Colley & Smith 2001; Yamada & Nakamura 2002; Eisworth *et al.* 2008; Harvey & White 2008). Activities such as catchment deforestation, riparian grazing, stock-induced bank erosion and ploughing increase sediment inputs to a stream.

Increased concentrations of nutrients can have positive effects in aquatic systems by increasing primary productivity. Moderately elevated nitrogen and phosphorus levels, as a result of dry-stock farming, can increase benthic invertebrate biomass, diversity and food chain length (Townsend *et al.* 1997; Quinn 2000; Dodds *et al.* 2002; Riley *et al.* 2003). However, highly elevated nutrient levels (commonly found in stream catchments dominated by dairy farming) can encourage the dominance of pollution tolerant invertebrate species and cause undesirable algal growths (Quinn & Stroud 2002; Slavik *et al.* 2004; Cross *et al.* 2006).
Potential sources (and sinks) of fine-sediment and nutrients should be considered during any stream protection or rehabilitation initiative. Little will be gained from a rehabilitation effort (such as riparian re-planting) if significant contamination is occurring upstream. Creating sediment and contaminant sinks in areas that were previously sources may provide the best results when faced with limited resources for a restoration initiative. The primary sources of agricultural contaminants are listed in (Table 1). These can be identified with local knowledge and during a ground-truthing exercise. Some, such as stock crossings, may be identified solely by aerial photography. Historic information on catchment land-use will be useful for considering possible hysteresis effects of land-use. This may be especially important in spring fed streams that may not have the hydrological power to substantially remobilise fine sediment during "high" flows.

## 3.3. Water quality

To assess trout habitat quality, water quality data must be obtained to confirm that standard water quality parameters (temperature, pH, dissolved oxygen, ammonia, nitrate, conductivity and turbidity) are within acceptable ranges for trout. The tolerance ranges of trout to standard water quality variables are well documented in the literature (Jonsson & Jonsson 2009). In many instances spot water quality data is routinely collected by regional councils and can be easily acquired. Ideally, continuous logged records of temperature, pH and dissolved oxygen should be obtained. However, in the absence of a substantial water quality data set, spot water quality measurements should be obtained during late summer low-flows. This will indicate the stream water suitability at a time when local trout populations are most likely to be under stress from various water quality parameters. Dissolved oxygen is best measured early in the morning when it is lowest (before photosynthesis by algae begins), and pH is best measured mid-afternoon when photosynthesis peaks.

## 3.4. Mesohabitat scale variables

Many features and processes that are fundamental to trout growth and survival are nested within mesohabitat structures. Mesohabitat structures are often the primary focus of rapid habitat inventories and assessments. Mesohabitats are commonly categorised into runs, riffles and pools (Bisson *et al.* 1981). In general, riffles are important areas for juvenile habitat and invertebrate production (Brown & Brussock 1991) and pools offer deep-water cover for adult trout and velocity refuges for trout fry (Baran *et al.* 1997; Heggenes *et al.* 1999; Armstrong *et al.* 2003). Runs are intermediate in hydraulic character. Riffles and runs are where the benthic invertebrate food is produced and transported by moderate – high water velocities to pools and deep runs where adult trout live.

Mesohabitat types can be recorded during a ground-truthing exercise. They can be divided into a several habitat sub-units or typologies that increase the resolution and complexity of a habitat assessment. This is a common practice in North America but is not in New Zealand where the following broad categories are usually used: riffle, run (sometimes split into fast-shallow and slow-deep) and pool (Jowett *et al.* 2008). One of the attractions of fine-splitting of mesohabitats is to increase survey and statistical power for predicting the distribution of diverse fish assemblages (Bisson *et al.* 1981). This is hardly justified in New Zealand streams where fish species richness is low and many species, including introduced trout, are generalists. The practice of coarse-splitting of mesohabitats in New Zealand has been done for pragmatic reasons in the belief that the potentially higher resolution in correlating fish communities or species abundance to habitat characteristics that is offered by fine-splitting does not warrant the extra survey and analysis costs.

Residual pool depth (pool depth at zero flow) has been correlated with salmonid abundance and provides a way to assess pool depth in a river independent of discharge (Lisle 1987). Residual pool depth can be measured by subtracting the depth at the downstream riffle crest from the maximum depth of the upstream pool (Harding *et al.* 2009). Residual pool depth measurements could be taken during a ground-truthing exercise.

## 3.5. Food (invertebrate productivity)

### *3.5.1. Drift feeding*

Trout in New Zealand rivers feed primarily on drifting macroinvertebrates (Hayes & Jowett 1994). They also preferentially select large invertebrates which are energetically most profitable (Hayes *et al.* 2000). However, river trout are also opportunistic predators and may supplement their diet (or feed exclusively) by browsing on sessile benthic invertebrates, feeding on floating terrestrial insect windfall or hunting for forage fish (Elliott 1994). Habitat features contributing to all of these feeding opportunities should be included in a trout habitat assessment.

Invertebrate data are very useful for assessing the food value of benthos in streams for trout. For instance, Ephemeroptera, Trichoptera and Plecoptera (EPT) taxa tend to be larger and have a higher propensity to drift than other invertebrates making them preferred trout food items (Shearer *et al.* 2003). Comparative density and biomass estimates have proved useful for predicting the abundance of trout (Jowett 1992). Thus, density/biomass, and/or percentage of EPT taxa can be used to indicate the suitability of a stream invertebrate community as a food resource for trout. When adult trout are the focus then % EPT minus hydroptilid caddis is more relevant because this modification helps to remove the influence of small taxa from the index (Collier 2009). However, small taxa (chironomids and hydroptilid caddis) are eaten by juvenile trout so the modified and standard EPT indices are less relevant to them.

A much overlooked potential of invertebrate data is that it can provide useful information on prey size composition (by density and biomass) (Shearer et al. 2003). This is most efficiently done by size-classing (*e.g.* 3 mm size classes) invertebrates when they are being processed for taxonomic composition and density. Excel macros are available from the Cawthron Institute that can estimate dry weight (for biomass) and energy value (from literature estimates) of taxa for summarising and adding value to invertebrate size class data. This information can then be interpreted with respect to food value for trout by comparison with minimum prey size predictions (Wankowski 1979; Hayes *et al.* 2000) and invertebrate size structure data available from other rivers (Shearer *et al.* 2003; Shearer & Hayes 2011).

However, quantitatively, and even qualitatively, assessing benthic and drifting invertebrate communities is data and labour intensive. Invertebrate samples are costly in terms of time and dollars to collect and process, and are usually taken from a limited range of locations that may not represent the invertebrate community throughout the entire stream. Nevertheless, benthic invertebrate density and biomass is clearly relevant to assessment of trout stream condition; having been shown to be strongly correlated with trout abundance in New Zealand rivers (Jowett 1992). If benthic invertebrate data are not available, substrate composition can be used as a proxy for the health of the invertebrate community, in particular of the abundance of EPT taxa (preferred trout food). The density and diversity of EPT taxa are positively associated with increasing substrate size, particle diversity and amount of interstitial spaces (Wood & Armitage 1997; Kaller & Hartman 2004). Furthermore they are sensitive to deposition of fine-sediment – being adversely affected by it (Wood & Armitage 1999; Rabeni *et al.* 2005; Matthaei *et al.* 2006).

The algal community also influences the invertebrate community. Thick algal growths tend to support invertebrate communities dominated by chironomids and other taxa which tend to be small and have a low propensity to drift (Shearer *et al.* 2003). In contrast, clean (diatom dominated) gravel/cobble/boulder substrates usually support an EPT dominated invertebrate community and thus a high quality trout food production base, especially for adult trout.

Substrate and algal characteristics can be visually estimated and mapped out on aerial photographs during a ground-truthing field exercise.

### *3.5.2. Browsing habitat*

Trout can browse or actively forage for benthic invertebrates in areas of slow/moderately flowing pool and run habitat (i.e. lake littoral zone like habitat within rivers). Occasionally they also exhibit this behaviour in faster runs, picking caddis larvae off bedrock shelves and boulders. Sediment characteristics are poor indicators of invertebrate food production in slow-water mesohabitats with low disturbance frequencies (*e.g.* stable pools or off-channel backwater habitats). In these habitats, which may be heavily silted, snails and chironomids can thrive and provide feeding opportunities for trout. The occurrence of large areas (*e.g.* >15m$^2$) of slow flowing, moderately deep water (*e.g.* 0.5-1m) may provide a coarse predictor of this form of feeding habitat. The presence of macrophytes is another indicator of low disturbance frequency, and these can also increase invertebrate production (Shupryt & Stelzer 2009). These habitat features can be mapped directly onto aerial photographs during a ground-truthing exercise.

### 3.5.3. *Other feeding opportunities*

Terrestrial insects supply a variable fraction of a trout's diet in rivers, depending on the abundance of aquatic invertebrates and extent and nature of riparian vegetation. Usually though terrestrial invertebrates form a lesser fraction of the diet than aquatic invertebrates (Hayes & Jowett 1994; Edwards & Huryn 1995). However, trout surface feeding on terrestrial insects offer a significant opportunity for anglers to easily locate and catch fish. Therefore, the quantity and type of terrestrial invertebrate input to a stream can affect the amenity value of the fishery (if not the total population of trout). A large riparian zone of native tussock or mature trees and overhanging vegetation is more likely to supply terrestrial prey than improved pasture (Edwards & Huryn 1996; Kawaguchi & Nakano 2001). Ground-truthing riparian vegetation on aerial photography will allow the area of stream where there is likely to be an abundance of terrestrial insects to be quantified.

Forage fish can be an important source of food to moderate-large river- and lake-trout. In small wadeable streams they are often assumed to be of less importance and so will not be considered in depth in this habitat assessment protocol (Hayes & Jowett 1994). However, in small streams that are close to the coast, lakes or large wetlands inanga, smelt and koaro (potential forage fish) can be abundant (McDowall 1990). In some instances, forage fish may be sufficient to maintain a trout fishery in the absence of adequate macroinvertebrate production. Therefore, the proximity of a stream to the coast or significant wetlands should be noted in any assessment of trout habitat.

## 3.6. Water velocity

Velocity differentials (or shear zones) are important features of adult trout habitat as they provide an opportunity for efficient drift feeding. Trout can conserve energy in "slow" water whilst actively feeding in adjacent fast water that has higher rates of drifting invertebrates (Fausch 1984). Any obstruction to water flow such as coarse substrate, a sudden change in depth, or a bed rock or bank protrusion can create a velocity refuge from which trout can feed most efficiently (Hayes & Jowett 1994). If moderate to fast-flowing water is present in combination with flow obstructions then this indicates good potential feeding habitat.

Fry require relatively slow water usually along the edge of the bank in runs and pools. The presence of stream edge-emergent or over-hanging vegetation creates pockets of slow velocity (and cover) and can produce good fry rearing habitat (Heggenes *et al.* 1999; Armstrong *et al.* 2003). Juvenile (fingerling) trout tend to occupy cobble-boulder riffles and runs with a diverse range of velocity microhabitats (Armstrong *et al.* 2003). Flow-gauging stream cross-sections to accurately assess stream velocities is not practical in a rapid habitat assessment. Coarse velocity estimates are implicit in mesohabitat types (riffle, run pools) and sub-types (fast run, slow run). In addition, noting features that may indicate potential locations of favourable velocities for the different trout life history stages can be recorded during a ground-truthing exercise.

## 3.7. In-stream cover

Cover is an essential component of trout habitat; it provides refuge from predators and high flows (Allouche 2002). Deep water obscures the stream bed and is possibly the most common form of trout cover in New Zealand low-land streams. Water >1 m deep (depending on water clarity) can be considered deep enough to provide good feeding habitat for adult trout (and in some conditions 0.5 m will suffice). However, such spots need to have a rippled surface preferably with surface turbulence to provide security cover. Otherwise depths need to be closer to 2 m to provide security cover (Hayes & Jowett 1994). Shallower water >0.3 m can provide cover if the water clarity or overhanging vegetation obscure the stream bed from view. This minimum depth (0.3 m) roughly corresponds to the lower limit for the adult trout depth-suitability curve based on Hayes and Jowett (1994) used in RHYHABSIM (Jowett 1998). In addition, any structure that provides a shadow or crevice such as large boulders, overhanging vegetation, undercut banks or woody debris can be considered cover (Raleigh *et al.* 1986; Allouche 2002).

Juvenile trout commonly use the interstitial spaces in coarse gravel/cobble/boulder substrate fractions as cover (Armstrong *et al.* 2003). Fry tend to occupy shallow water and areas next to overhanging vegetation associated with the stream bank (Bardonnet *et al.* 2006). The different types of cover are listed in (Table 6). The presence and extent of in-stream cover for different trout life history stages can be recorded during a ground-truthing exercise.

## 3.8. Riparian vegetation

Riparian vegetation can influence many in-stream habitat parameters including temperature (through shading), organic matter supply (leaf litter) and stream structure (large woody debris) (Broadmeadow & Nisbet 2004). It can have a directly positive influence on trout habitat by supplying cover and terrestrial insect windfall. Furthermore, riparian vegetation can prevent contaminants and fine-sediment entering a waterway from surface runoff (Yuan *et al.* 2009; Hubble *et al.* 2010; Zhang *et al.* 2010). Consequently, excluding stock from the riparian zone and riparian planting are common management initiatives when attempting to mitigate the effects of land-use on streams (Roni *et al.* 2002; Roni *et al.* 2008). The extent, type, size/width and maturity of riparian vegetation are important features in any assessment of trout habitat. Key riparian features are listed in (Table 1). These can be recorded and measured during a ground-truthing exercise. Some features may be determined from a desktop analysis of aerial photographs.

## 3.9. Spawning

Trout move to various extents to find spawning habitat. In some streams they may find spawning habitat close to their home range. In other rivers, typically large, flood prone ones, trout undertake substantial migrations to find suitable spawning habitat which is commonly located in the headwater reaches (Northcote 1992; Näslund 1993; Jonsson & Jonsson 2009). Trout require un-embedded coarse gravels and small cobbles to construct redds in which to incubate their eggs. These are commonly located in the tails of pools and runs, forward of the crest of a riffle, where down-welling percolates oxygen rich water through the gravels (Louhi *et al.* 2008). Usually in these locations the bed slopes upward in the direction of the current. As indicated above, suitable spawning areas may be remote from areas that support notable fisheries. Consequently, restoration efforts centred in a fishery area may not adequately address factors affecting recruitment such as sufficient spawning area. Broad-scale habitat mapping is potentially a good tool to identify spawning areas which may be critical locations for targeted protection or rehabilitation effort. Potential spawning areas can be identified from analysis of mesohabitat structure, sediment characteristics and depth estimates collected during a ground-truthing exercise. In addition, a subjective qualitative assessment of spawning areas can also be undertaken during a ground-truthing exercise to provide additional information (see section 6.6).

# 4. PROTOCOL PROCEDURE

Where possible we have chosen assessment procedures that are compatible with protocols developed in (Harding *et al.* 2009). However, the larger spatial scale of broad-scale habitat mapping means that some of their procedures are simplified or omitted.

A desktop collation of local and institutional knowledge and information from existing databases (section 4.1) and a ground-truthing field exercise (section 4.2) can be used to collect (or approximate) information on the following list of key trout habitat variables (Table 1). Once collected, the information can be recorded into ArcView to form information layers over a catchment map.

**Table 1.** Summary list of key trout habitat variables, suggested information to be gathered for each variable and suggested methods to acquire it to create a habitat map.

| Habitat Variable | Information to gather | Suggested Information gathering method |
|---|---|---|
| **Catchment scale variables** | | |
| Catchment landscape features | Location, length and size of catchment.<br>Stream order.<br>Valley form.<br>Flow source.<br>Geology.<br>Sinuosity.<br>Slope. | Desktop analysis, REC and FENZ data bases, Regional councils |
| Discharge | Mean annual low flow (MALF), Median, Mean flow, Specific discharge (flow per unit catchment area).<br>Frequency of floods as defined in the FRE3 index (Clausen & Biggs 1997). | Desktop analysis, REC and FENZ data bases, Regional councils |
| Rainfall (in the absence of river flow data) | Annual and seasonal averages. | Desktop analysis, REC and FENZ data bases, Regional councils |
| Erosion potential | Valley slope, Soil type. | Desktop analysis, REC and FENZ data bases, |
| Soil type | Soil type. | Desktop analysis, REC and FENZ data bases, Regional councils |
| Land-use type | Predominant land-use type(s). | Desktop analysis, REC and FENZ data bases, Aerial photographs, Regional councils |
| Channel alterations | Channel widening, shallowing, straightening, migration barriers. | Regional councils, ground-truthing aerial photographs |

| | | |
|---|---|---|
| **Riparian Vegetation** | | |
| Riparian vegetation structure | Riparian vegetation area, width of riparian zone, riparian vegetation type, riparian vegetation height/ maturity. Shading. Riparian vegetation boundary. | Ground-truthing aerial photographs |
| **Sediment/contaminant input sources** | | |
| Natural sediment sources | Substantial land-slips or locations of sediment laden tributaries. | Desktop analysis, REC and FENZ data bases, Regional councils, Ground-truthing aerial photographs |
| Stock access | Locations of fencing and/or natural stock barriers. | Desktop analysis, REC and FENZ data bases, Regional councils, Ground-truthing aerial photographs |
| Stock crossings | Type, number, locations. | Desktop analysis, REC and FENZ data bases, Regional councils, Ground-truthing aerial photographs |
| Standoff pads | Locations and times of year that they are in use. | Desktop analysis, Aerial photographs, Regional councils, Farmers, Local knowledge, Ground-truthing aerial photographs |
| Laneways | Locations. | Desktop analysis, Aerial photographs, Regional councils, Farmers, Local knowledge, Ground-truthing aerial photographs |
| Irrigation | Type/amount resource consent conditions as they relate to irrigation. | Desktop analysis, Aerial photographs, Regional councils, Farmers, Local knowledge |
| Fertiliser application | Type and amount applied annually. | Regional councils, Farmers |
| **In-stream cover features** | | |
| Depth | Presence, locations with depth <0.3m, 0.3-1m and >1m. Maximum pool depth. Residual pool depth. | Ground-truthing aerial photographs |
| Turbulence/broken water | Mesohabitat types (and subtypes: rapids and fast runs). | Ground-truthing aerial photographs |
| Bedrock/large boulders/Interstitial spaces (juveniles) | Presence, locations, % area of streambed. | Ground-truthing aerial photographs |
| Large woody debris | Presence, locations, % area of streambed. | Ground-truthing aerial photographs |
| Man-made structures (*e.g.* bridges, channel protection groins) | Presence, locations, % area of streambed. | Regional councils, Ground-truthing aerial photographs |
| Undercut banks | Presence, locations, % area of streambed. | Ground-truthing aerial photographs |
| Overhanging Vegetation | Presence, locations, % area of streambed. | Ground-truthing aerial photographs |
| Shading | Presence, locations, % area of streambed. | Ground-truthing aerial photographs |
| Turbidity | Logged continuous records: daily averages, maximums and | Ground-truthing aerial photographs |

| | | |
|---|---|---|
| | minimums. Or at least, spot measurements. Visual estimates during ground-truthing. | |
| Macrophytes | Presence, locations, % area of streambed. | Ground-truthing aerial photographs |
| **Fish foraging variables** | | |
| Invertebrate productivity | Surber samples for densities, biomass, or use substrate quality as proxy*. | Regional Councils, Surber samples, Ground-truthing aerial photographs for substrate characteristics |
| Invertebrate community | Surber and/or kick net samples %EPT (with or without hydroptillid caddis), or use substrate quality and proxy*. | Regional Councils, Surber and/or kick net samples, Ground-truthing aerial photographs for substrate characteristics |
| Invertebrate size structure | % invertebrates per 3 mm size class by density and biomass, percent > 6 mm (for adult trout) or use proxys* (*e.g.*, substrate quality or EPT taxa minus hydroptilid caddis). | Regional Councils, Surber and/or kick net samples, Ground-truthing aerial photographs for substrate characteristics |
| Water velocity | Mesohabitats and mesohabitat sub-types. | Ground-truthing aerial photographs |
| Stream bed characteristics | Visual % estimates of dominant sediment types. | Ground-truthing aerial photographs |
| Mesohabitat | Run/riffle/pool types, presence, locations, % area of stream. Residual pool depth. Pool frequency and pool to riffle ratio. Wetted width. | Ground-truthing aerial photographs |
| Velocity boundaries | Locations of features that obstruct flow and create velocity refuges. | Ground-truthing aerial photographs |
| Browsing habitat | Presence, location of pools and slow run habitat, presence of aquatic macrophytes. | Ground-truthing aerial photographs |
| Aquatic macrophytes (submerged & emergent) | Presence, locations, area. | Ground-truthing aerial photographs |
| Forage fish | Fish community, proximity to coast, wetlands or lake. | Desktop analysis, REC, NZFF and FENZ data bases |
| Terrestrial inputs | Presence of significant areas of riparian vegetation, riparian land-use type. | Ground-truthing aerial photographs |
| Algal community | Dominant algal community. Specifically, % cover of thick algal mats (>3mm) and filamentous algae (>2mm). | Ground-truthing aerial photographs |
| **Water quality variables** | | |
| Water temperature | Continuous logged records: daily averages, maxima and minima. | Regional councils, Water testing during ground-truthing field work |
| Dissolved oxygen | Continuous logged records: daily averages, maxima and minima, or spot readings early morning. | Regional councils, Water testing during ground-truthing field work |
| pH | Ideally continuous logged | Regional councils, Water testing |

| | | |
|---|---|---|
| | records: Or seasonal spot measurements, or at least, spot measurements during summer low flows, made mid-afternoon. | during ground-truthing field work |
| Nutrient profile (nitrogen and phosphorus) | Summer and winter averages, maximums and minimums. | Regional councils, Water testing during ground-truthing field work |
| Turbidity. Suspended solids | Ideally continuously logged NTU (to enable duration analysis). Or Black disk and/or NTU seasonal averages, maximums and minimums, base- and low-flow records. | Regional councils, Water testing during ground-truthing field work |
| Faecal contaminant load | E. coli counts, summer and winter averages, maximums and minimums. | Regional councils, Water testing during ground-truthing field work |
| Algal production | Visual estimates of % cover and dominant algal community, seasonal averages for biomass (if available). | Regional councils, Ground-truthing aerial photographs |
| **Spawning variables** | | |
| Substrate | Substrate quality and locations of clean un-embedded gravels and small cobbles. | Ground-truthing aerial photographs |
| Temperature | Logged continuous records, daily averages, maximums and minimums. | Regional councils, Water testing during ground-truthing field work |
| Dissolved Oxygen | Logged continuous records: daily averages, maximums and minimums. Or at least, monthly spot measurements taken early morning. | Regional councils, Water testing during ground-truthing field work |
| Contaminant load | Faecal coliform counts: summer and winter averages, maximums and minimums. | Regional councils, Water testing during ground-truthing field work |
| Depth | Presence, locations with depth <0.3m, 0.3-1m and >1m. | Ground-truthing aerial photographs |
| Water velocity | Location of moderate velocities. | Ground-truthing aerial photographs |

*Coarse, un-embedded substrate tends to support large, drift prone invertebrates that are preferred trout food

## 4.1. Desktop protocol

Conduct a desktop analysis to obtain (where possible) the following information from regional council, local and landowner knowledge, and River Environment Classification (REC) and Fresh Water Ecosystems of New Zealand (FENZ) data bases (protocol is adapted from Harding *et al.* 2009).

Rainfall (hydrograph stats: Mean Annual Low Flow (MALF), specific discharge (flow per unit catchment area), FRE3, flow history for last 10 years)

Erosion potential (valley slope)

Soil type(s)

NZ Reach Number

Catchment Area

Catchment Proportion Exotic Forest

Catchment Proportion Indigenous Forest

Catchment Proportion Pastoral Farming

Catchment Proportion Urban

Distance to Coast/lakes/significant wetlands

Stream Order

REC Climate

REC Geology

REC Source of Flow

REC Valley Landform

Segment Sinuosity

Segment Slope

Stock access (fencing, natural barriers)

Sediment/contaminant input sources

Stock crossings

Riparian buffer presence/size/type

Standoff pads

Laneways

Irrigation type

Fertiliser application

Any macroinvertebrate information available (diversity, total densities, MCI, %EPT taxa, EPT densities, size composition)

Water quality data

Freshwater fishery data base information

## 4.2. Ground-truthing field protocol

GIS habitat maps are created in two steps:

1. Obtain recent colour orthorectified aerial photography to a resolution of 1:10,000 to generate base maps of the stream and its catchment. Google earth images may be sufficient if aerial photographs are unavailable.
2. Conduct field ground-truthing surveys to verify habitat features on the aerial photography and identify and map the locations of features not visible through aerial photography alone.

Aerial photographs of the stream should be taken during base flow conditions. These should be obtained from Regional councils or Land Information New Zealand (LINZ). Ground-truthing should be conducted during summer low flows, at least two weeks after a significant fresh. Ideally, images should be loaded into notebook or tablet style field computers, capable of running ArcPad (or equivalent) software so the habitat maps can be created in a digitised format ready for analysis. However, field computers are expensive and ArcPad software requires additional training. Consequently, the present description of the protocol assumes only hard-copy photographs are available. The habitat maps will be subsequently scanned and digitised for analysis with ArcView software.

Print and laminate the stream aerial photographs. On each photograph a northing arrow and two GPS location points should be present at the corners of the photograph to allow field workers to verify their position and to help with the digitisation process.

The assessment procedure is split into two stages. Stage one (Section 4.2.1) catalogues the riparian features, surrounding land-use and potential contaminant sources. Stage two (Section 4.2.2) is an in-stream assessment of the depth, sediment condition and in-stream cover.

In most instances (except in very short spring creeks or small feeder streams) it will be impractical to cover the entire stream with this type of assessment. The alternative to surveying the entire stream is a stratified random design where fine-scale assessments are nested within broader scale assessments (Bauer & Ralph 2001; Collier *et al.* 2007).

Taking into account catchment scale variables (including valley form, dominant land-use and possible significant contaminant sources), stratify the stream into approximately 5-10 km segments. A process for using GIS to stratify streams according to landscape variables is detailed in (Harding *et al.* 2009). The number of stratified segments and segment length will depend on the above variables and the size of the stream. Within these stratified stream segments randomly select 1-2 km reaches and conduct the Stage 1 survey of riparian features, land-use and potential contaminant sources (Section 4.2.1). Within the areas where the riparian survey has been conducted, randomly select two or three 100 m (or more) reaches and conduct the in-stream component of the survey (Section 4.2.2). Ensure that the reaches include at least one riffle-pool, riffle-run, or riffle-run-pool sequence. A pilot trial on the Wakapuaka Stream (Nelson) suggests that for the riparian component (Stage 1), a 1 km reach can be mapped by a single field worker in 2 h. For the in-stream habitat component (stage 2) a 100 m reach can be mapped in 1.5hrs. It is anticipated that with training and practice the maps could be created considerably faster.

The option exists for a subjective assessment of habitat quality (for the different trout life history stages), angling opportunity and aesthetics to be conducted during the field mapping process (Section 6.6). This optional assessment is meant as supplementary information to be recorded by qualified expert personnel. Before making a subjective assessment, record why you feel you are qualified to do so and list your qualifications (*e.g.* expert angler, fish ecologist, fisheries manager).

### 4.2.1. Stage One (riparian and land-use features) field guide

Consider stream gradient, stream order, valley slope and shape, land-use, sinuosity, major tributaries and significant (possible) sources of pollutants as part of the criteria to stratify the stream into (approximately) 5-10 kilometre segments. The number of stratified segments and segment length will depend on the above variables and the size of the stream.

Once the stream is divided into segments, randomly allocate one or two kilometre long reaches to each stream segment and record the listed riparian features, land-use features and potential sources of contaminants (see steps 1-3 below).

Record assessor name, date and GPS location of start point and end point of a habitat map (and differential GPS positions at two land marks if possible). Measure, temperature, dissolved oxygen, conductivity, pH, NTU) and black disk at the start and end of the assessed stream segments (optional).

**Where possible, trace around the habitat feature if it can be seen on the photograph** and attach the relevant code (see sections 6.1 and 6.2). If the feature is too small to be seen on the photographs then place a point at its location and estimate its size and/or length. For habitat features that are too small to be seen on the aerial photo and too numerous or continuous in nature to be recorded as single points mark with a line and estimate the percentage occurrence of the feature within that line. Figure 1 shows an example of a competed section of the riparian survey.

1. Note the land-use type: crop, sheep/beef cattle, dairy or other (specify) - record land-use type only at the start of the assessment or when it changes. Note, trace around or annotate a length of stream bank where significant potential sediment or contaminant sources are occurring (Section 6.1, Table 2).
2. Trace around the riparian buffer zone, or if it is too small to be seen on the aerial photograph estimate its size. Note, trace around or estimate the presence/size/type and occurrence, of any overhanging vegetation (Section 6.2 Table 3).

3. (Optional) If you are qualified and can state your qualifications (*e.g.* expert angler, professional fish ecologist or fisheries manager) you may wish to score (1=poor – 4 = excellent) the capability of **the area of the entire photo** to support the various life history stages of trout, the accessibility for angling and fishing aesthetics (Section 6.6, Tables 7-12).

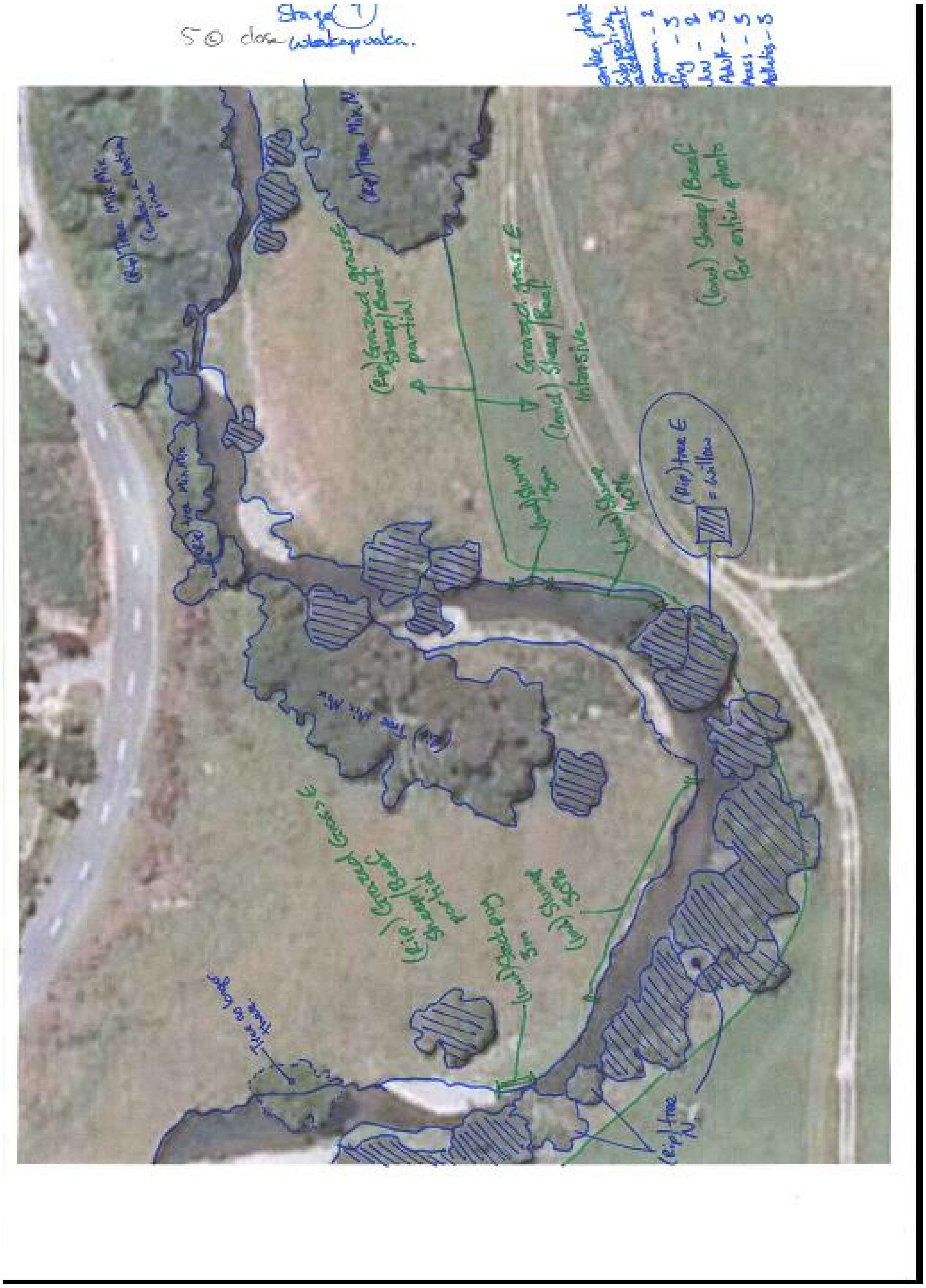

**Figure 1.** An example of a completed riparian component of the field survey (Stage 1) for a section of the Wakapuaka River (Nelson) showing the dominant riparian vegetation types and land use features. Note that willows dominate the riparian vegetation of this stream, stock access is possible to the stream for the entire area in the photo and significant areas of bank slumping are occurring.

### 4.2.2. Stage Two (in-stream habitat features) field guide

Randomly allocate two or three 100 m reaches within an area where the Stage 1 assessment has been conducted. Include at least one riffle-pool, riffle-run, or riffle-run-pool sequence. Follow steps 1-3 below.

**When possible, trace around the habitat feature if it can be seen on the photographs** and attach the relevant code (see sections 6.3 to 6.5). If the feature is too small to be traced on the photo, then place a point at its location and estimate its size and/or length. Alternatively , if small features are too numerous or continuous in nature to be recorded as single points (*e.g.* sediment characteristics), estimate the percentage within the mesohabitat or delineated stream reach; an example of a completed section of the in-stream survey for a 20 m reach is shown in (Figure 2). During the assessment select three pools and determine the residual pool depth. Measure the maximum depth of the pool and the maximum depth on the downstream riffle crest. Record this for three pools within the 100m reach.

Follow steps 1-4, recording information on acetate sheets overlaid on the aerial photographs:

1. Select a starting point by placing a line across the wetted channel on the aerial photograph and trace around the wetted edge of the stream for the mesohabitat or 20 m (approximate) reach that is being assessed and record the mesohabitat type(s) (Section 6.3, Table 4). On the first acetate sheet trace around or estimate the area of the stream that is <0.3m, 0.3-1m and >1m deep. Record the location of the deepest point of the mesohabitat and estimate or measure its depth.
2. After walking the mesohabitat section (or 20 m stream reach), on the second acetate sheet estimate the percentage of the bed dominated by the main substrate sizes, see (Table 5) for sediment type codes. Where possible, draw around patches of substrate that are dominated by a single substrate type or substrate composition (>50% cover). Note, trace around or estimate the percentage of coverage of any macrophyte beds. Do the same percentage cover of any thick (>3mm) algal mats, or filamentous periphyton mats greater than 2 mm long (section 6.4).
3. On the third acetate sheet trace around, note (and estimate size), or estimate the percentage of any in-stream cover and estimate its size and/or extent (section 6.5, Table 6).
4. (Optional) If you are qualified and can state your qualifications (*e.g.* expert angler, professional fish ecologist or fisheries manager) on a fourth acetate sheet you may wish to score (likert scale 1=poor – 4 = excellent) of the capability of the mesohabitat (or 20m reach) to support the various life history stages of trout, the accessibility for angling and fishing aesthetics (Section 6.6, Tables 7-12).

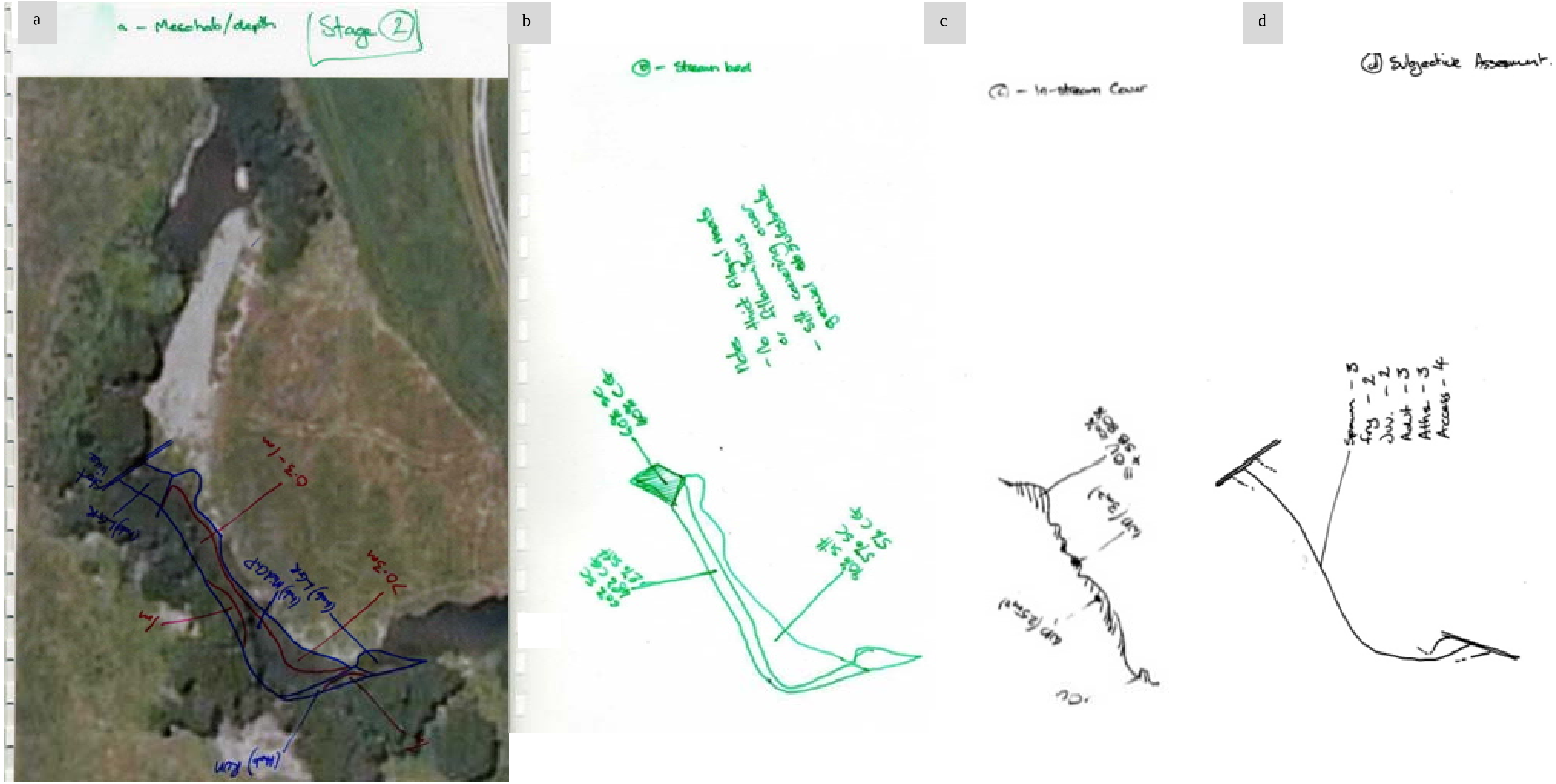


**Figure 2.** An example of a completed in-stream component of the field survey (Stage 2) for a section of the Wakapuaka River (Nelson). (a) Shows the wetted edge, mesohabitats and depth contours, b – d have been drawn on acetate overlays and show: (b) substrate characteristics (c) cover features and (d) subjective assessment scores. Note that a small area of the assessed reach is 1 m deep or more (a), a large area dominated by silt exists in the assessed reach (b), most of one bank has overhanging cover and two pieces of woody debris are present (c) and this areas scores excellent for access, good for adult habitat and OK for fry and juvenile trout habitat (d).

### 4.2.3. *Tips for in the field*

Use different coloured fine-point permanent marker pens to annotate the different layers.

Use a double sided "book" style clip-board so it is easy to refer to the field codes and guidelines whilst marking habitat features on a printed photograph.

Carry a small cloth soaked in alcohol sealed in a zip-lock bag to erase mistakes.

When creating the in-stream (Stage 2) maps record only the wetted area directly onto the photograph sheet, use a different acetate sheet for each layer to avid confusing lines when mapping out the different layers on different acetate sheets (that are each placed over top of the aerial photograph).

# 5. SCOPE FOR ANALYSIS AND LIMITATIONS

## 5.1. Some possible analysis outputs

Once the data are digitised and entered into ArcView, the data set can be interrogated for information about habitat features of interest. This could include the area of stream bank that is lined with willow trees or the percentage of the stream bed covered by fine sediment. In addition, indexes of habitat characteristics such as the stream width to depth ratio, pool frequency and the riffle to pool ratio could be calculated.

Information displayed on catchment maps could highlight potential pollution hot-spots, such as areas of significant bank slumping or other sources of fine sediment. In addition, the habitat characteristics of rehabilitated reaches could be compared with 'control' reaches.

The habitat maps could be used to model trout habitat quality in assessed reaches. Key habitat variables for life-history stages could be assigned scores derived from the literature and expert opinion. These could be weighted and summed to generate an index of trout habitat quality for mapped stream reaches (Milner *et al.* 1985; Raleigh *et al.* 1986; Modde *et al.* 1991; Wang *et al.* 1998; Creque *et al.* 2005; Mouton *et al.* 2009; Mouton *et al.* 2011). The distributions of key habitat variables or an index of trout habitat quality could be displayed on a catchment map using a simple traffic light system to highlight problem areas or assess how various management initiatives (such as stock fencing) have affected overall trout habitat. Furthermore, this type of index could be used as a tool for choosing appropriate rehabilitation options. By assessing the sensitivity of the habitat index score to variation in key habitat features rehabilitation options could be tailored to specific stream reaches or segments. A trout habitat quality index based on this mapping methodology would need calibrating against density and biomass data collected simultaneously in the assessed catchments. We intend to do this under the Ministry of Science and Innovation-funded Cumulative Effects Programme, led by NIWA (National Institute of Water and Atmosphere).

Some fine scale in-stream variables measured during ground-truthing may correlate with broad-scale variables which can be analysed from the desktop (*e.g.* residual pool depth or pool frequency and channel sinuosity). The occurrence of such fine-scale variables could then be predicted from broad-scale variables for stream segments that have not been ground-truthed.

## 5.2. Limitations

Some limitations apply to this habitat mapping methodology. Firstly, some of the listed features are flow dependent (Mossop & Bradford 2006). For instance, the water depth variables, wetted width, percentage of pools (since mesohabitat boundaries change with flow) and bank cover (which can vary when the water edge retreats from the bank). This will contribute to measurement error between times and recorders and therefore reduce the precision of such variables. Nevertheless, we consider the maps will be useful as a diagnostic tool and will improve to the current approach to assessing trout habitat condition in New Zealand streams (which is largely based on anecdotal reports or fishery manager opinion).

Creating a habitat map is essentially taking a snapshot of habitat conditions at a single point in time. The accuracy of the ground-truthing field data will depend on how recently the aerial photographs were taken. If images are several years old then major changes to channel shape or riparian vegetation could have occurred. These changes can be corrected during the ground-truthing process. However, discrepancies between features in the photographs and observations in the field will slow the ground-truthing process and increase observer estimation error in the data set. To minimize this source of error, ground-truthing needs to be undertaken shortly after the photos are taken and before significant flood events (eg: 10 times base flow). The necessity of using recent aerial images during field work will depend on how stable the stream is and the magnitude of floods since the photos were taken. For this reason, our broad-scale habitat assessment method is best suited to small “stable” streams, especially spring-fed streams. Adapting this protocol to larger or “unstable” rivers that are subject to a higher level of natural disturbance would require considerably greater survey effort (in both spatial extent and the number of repeated mapping events). In these systems high levels of natural change may mask changes induced by anthropogenic factors.

Overseas studies suggest that habitat based fish distribution models can be successful but are not broadly applicable across different states or regions (Fausch *et al.* 1988; O'Connor & Kennedy 2002; Roper *et al.* 2002; Creque *et al.* 2005; McCleary & Hassan 2008). Jowett’s “100 rivers” study suggests that this limitation may not apply here since it has demonstrated strong associations between physical habitat and trout abundance throughout New Zealand (Jowett 1992).

Another potential caveat of this assessment method is that some of the information gathered on habitat attributes will be percentage and area estimates. These estimates can vary between observers which is a problem for most rapid habitat assessments (Bauer & Ralph 2001). However, the broad scale of our method requires a lower degree of estimation precision. Larger estimation category blocks (*e.g.*, only three depth categories) or percentage estimates reduce inter-observer variation, although this results in a coarser data resolution (Bauer & Ralph 2001; Whitacre *et al.* 2007). Nevertheless, the focus of this survey is assessing effects at large spatial scales. Therefore, coarser data resolution is warranted in this context; precision must be relaxed for the sake of increasing the spatial scale of assessment. Our intention is that this survey design will allow gross landscape scale effects on trout habitat (and potentially trout populations) to be diagnosed.

We anticipate that there could be considerable variability between observer scores for the subjective assessment component of the survey (Section 6.6). By allowing only professional fish ecologists, fishery managers or expert anglers (*e.g.* 10years experience) to contribute to the subjective assessment database we hope to increase the validity of this aspect of the survey. In addition, expert assessment has been shown to be comparable with objective measurement when assessing the suitability of trout spawning areas (Platts *et al.* 1979; Shirazi & Seim 1979; 1981). The subjective assessment scores will be useful for assessing the accuracy of predictions generated from the more objectively mapped area measurements and percentage estimates collected during the ground-truthing exercise. For example, if a stream data set is interrogated for groups of variables that indicate areas of good adult trout habitat (by combining depth data, invertebrate habitat, cover etc.) and the results are consistent with those of the adult habitat scores collected by experts then this will boost confidence in the assessment (and the experts).

# 6. HABITAT FEATURE DECRIPTIONS AND CODES

## 6.1. Land-use features

Note the presence of any potential sediment/contaminant input sources: trace around the feature if possible otherwise annotate its location, estimate its size and attach the appropriate code from Table 2.

**Table 2.** Descriptions and codes for various potential sediment and contaminant sources.

| Land-use feature | Description | Code |
|---|---|---|
| **Bank slumping** | Note areas where bank slumping occurs along the stream cannel edge Record % damage within the affected area. | **(land) Slump** |
| **Stock access** | Record presence/absence of fencing (yes/no?), (annotate any fence gaps or natural stock barriers). | **(land) Fence (y or n)** |
| **Stock barriers (where fencing does not exist)** | Record presence of cliffs or significant stands of dense vegetation. | **(land) Stock B (y or n)** |
| **Stock crossings** | Note areas where stock have been driven through the stream. | **(land) Stockcross** |
| **Stock pugging** | Note areas where stock have accessed the stream edge and caused damage the bank. Record % damage within the affected area. | **(land) Stockpug** |
| **Laneways** | Note any cattle tracks adjacent to stream. | **(land) Laneway** |
| **Tributaries/drainage ditches** | Record where any tributary or ditches that drain paddocks enter the stream. Record if stock have access to the tributary or ditch and if it has obvious pugging or turbidity and is likely to contribute sediment to the stream. | **(land) Trib** |
| **Winter sacrifice paddock** | Note presence of any sacrificial paddocks where stock are kept for extended periods of time and supplied food. | **(land) sac. pad.** |

## 6.2. Riparian features

Draw around any riparian vegetation that is visible in the photo (do not include grazed improved pasture). If the riparian zone is too narrow to be traced on the aerial photograph, draw a line to represent its presence and estimate its width. Record the riparian feature and the dominant vegetation type code(s) from Table 3.

**Table 3.** Descriptions and codes for the various riparian features that should be recorded.

| Riparian feature | Riparian sub-feature | Description | Code |
|---|---|---|---|
| **Grazed or un-grazed** | **n/a** | Note if riparian zone (within the first 10 m) is actively grazed by stock and trace around/estimate the width of the un-grazed zone. Record if the pasture is un-grazed, partially or occasionally grazed or intensively grazed | **(rip) Graze (un-grazed), (partial), (intensive)** |
| **Riparian vegetation height** | **n/a** | Estimate average vegetation height (knee, waist, head or overhead high) within the first 5 m of the riparian zone. | **(rip)<0.5m, (rip) <1m, (rip) 1-2m or (rip) >2** |
| **Are large trees present** | **n/a** | Note or trace around any solitary large trees (*e.g.* willows) or prominent vegetation features like large flax stands that are present along the stream bank note the tree type if known. | **(rip) Tree (*e.g.* willow)** |
| **Swamp/marsh grasses/herbs** | **Exotic** | Trace around or estimate % exotic swamp/wetland herbs/grasses and /or large areas of emergent vegetation, note any riparian seepage areas (where soils are waterlogged and have some wetland plants present). | **(rip) Sw E** |
| | **Mixed Native and Exotic** | Trace around or estimate % mixed exotic and native swamp/wetland herbs/grasses and/or large areas of emergent vegetation. | **(rip) Sw Mix** |
| | **Native** | Trace around or estimate % native swamp/wetland herbs/grasses and/or large areas of emergent vegetation. | **(rip) Sw N** |
| **Grasses/herbs** | **Exotic** | Trace around or estimate presence of exotic grasses. | **(rip) Grass E** |
| | **Mixed Native and Exotic** | Trace around or estimate presence of exotic un-grazed grasses and native tussocks and/or sedge grasses. | **(rip) Grass Mix** |
| | **Native** | Trace around or estimate presence of native tussocks, flax and/or sedge grasses. | **(rip) Grass N** |

| | | | |
|---|---|---|---|
| **Shrub** | **Exotic** | Trace around or estimate presence of exotic shrubs *e.g.* gorse and broom. | **(rip) Shrub E** |
| | **Mixed Native and Exotic** | Trace around or estimate presence of mixed Exotic shrubs, *e.g.* gorse, broom, blackberry occurring with native shrubs such as matagouri or manuka. | **(rip) Shub Mix** |
| | **Native** | Trace around or estimate presence of native shrubs such as matagouri or manuka. | **(rip) Shrub N** |
| **Tree** | **Exotic** | Trace around or estimate presence of exotic tree stands *e.g.* pine, gum, or willows (record type if known). | **(rip) Tree E** |
| | **Mixed Native and Exotic** | Trace around or estimate presence of mixed mature native and exotic trees *e.g.* willow and cabbage trees. | **(rip) Tree Mix** |
| | **Native** | Trace around or estimate presence of mature native bush. | **(rip) Tree N** |
| **Mixed mature canopies** | **Exotic** | Trace around or estimate presence of mature riparian zone with a mixed canopy of exotic grasses, shrubs and trees. | **(rip) Mix E** |
| | **Mixed Native and Exotic** | Trace around or estimate presence of mature riparian zone with a mixed canopy of exotic and native grasses and or grassed, shrubs and trees. | **(rip) Mix Mix** |
| | **Native** | Trace around or estimate presence of mature riparian zone with a mixed canopy of native grasses and or grassed, shrubs and trees. | **(rip) Mix N** |

## 6.3. Mesohabitat classifications

Trace around the boundaries of a mesohabitat feature on the aerial photograph and record the mesohabitat type code. If mesohabitat types occur at a scale too small to be traced on the aerial photo then delineate an approximate 20 m reach and record the percentages of the different types of mesohabitat within (preferably estimate this by pacing or alternatively by eye). Coded habitat types and descriptions are shown in (Table 2). Trace around or estimate the area of the stream that is <0.3m, 0.3-1m and >1m deep within the mesohabitat or delineated reach. Mark the location of the deepest point in the mesohabitat or 20m reach and measure or estimate its depth.

**Table 4.** Descriptions and codes for the various mesohabitat units and habitat sub-units.

| Mesohabitat | Habitat sub-unit | Description | Code |
|---|---|---|---|
| **Riffle** | **Low gradient riffle** | Shallow to moderate depth, moderate to fast water velocity with mixed currents, surface rippled but unbroken (Harding *et al.* 2009). | **(hab) LGR** |
| | **Rapids** | Shallow to moderate depth, swift flow and strong currents, surface broken with white-water (Harding *et al.* 2009). | **(hab) Rap** |
| | **Cascade** | A series of step pools, alternating small waterfalls and shallow pools, surface broken with white-water (Harding *et al.* 2009). | **(hab) Cas** |
| | **Pocket water** | Riffle or fast run habitat with swift to moderate water velocity and large boulders protruding above the surface creating a wide range of velocities | **(hab) Pocket** |
| **Run** | **Fast run** | Habitat in between that of riffle and pool, moderate to fast water velocity, slightly variable current surface smooth and/or rippled (Harding *et al.* 2009) | **(hab) FRun** |
| | **Slow run** | Habitat in between that of riffle and pool, moderate depth and moderate to slow water velocity, uniform and/or slightly variable current surface unbroken smooth and rippled sections (Harding *et al.* 2009). | **(hab) SRun** |
| **Pool** | **Mid channel pool** | Deep, slow-flowing with a smooth water surface, usually where the stream widens or deepens (Harding *et al.* 2009). | **(hab) MidChP** |
| | **Backeddy pool** | Deep or moderate depth, slow flowing with a current reversal or eddy, associated with a bank protrusion or any obstruction to flow (Harding *et al.* 2009). | **(hab) BwP** |
| | **Secondary channel pool (or backwater)** | A pool habitat that is not part of the main channel, usually formed by old river channels. | **(hab) SChP** |
| | **Plunge pool** | Deep slow flowing areas formed where the stream passes over a nearly complete channel obstruction and drops vertically into the streambed below scouring out a depression (Bisson *et al.* 1981). | **(hab) PP** |

## 6.4. Sediment classifications

After walking the mesohabitat section or stream reach, estimate the percentage of the bed dominated by the main substrate sizes: mud/silt/sand (<2 mm), gravel (2-63 mm), small cobble (64-159), large cobble (160-255mm), boulder (>256 mm) and bedrock (continuous) (see Table 3 for codes). Where possible, draw around patches of substrate that are dominated (>50% cover) by a single substrate type or substrate composition. Trace around or estimate the percentage coverage of any macrophyte beds. Trace around or estimate the percentage cover of any thick algal mats (>2 mm long for filamentous algae, > 3 mm for other algae).

**Table 5.** Descriptions and codes for the different stream-bed features that should be recorded.

| Stream bed characteristic | Description | Code |
|---|---|---|
| **Estimate % bed dominated by the main substrate sizes** | Record % coverage of: mud/silt/sand (<2mm), gravel (2-63mm), small cobble (64-159), large cobble (160-255mm), boulder (>256mm) and bedrock (continuous). | **(sed) %** |
| **Estimate % cover of macrophytes** | Record % coverage of conspicuous macrophytes (>1m$^2$ stream bed area within the reach), record type if known. | **(weed) %** |
| **Estimate % cover of algal mats** | Record % coverage of conspicuous algal mats (>2 mm long for filamentous algae, > 3mm for other algae). | **(algal) %** |

## 6.5. Trout cover

Trace around any cover objects that can be seen on the aerial photo. If the cover objects are too small to be traced on the photograph then record the types of cover as points where they occur and then estimate their size. Alternatively, if the cover objects are highly abundant then estimate the total areal percentage of cover within the mesohabitat (or 20 m reach) and attach the relevant code. Cover types and codes are shown in (Table 4).

**Table 6.** Descriptions and codes for the different cover features that should be recorded.

| Cover type | Description | Code |
|---|---|---|
| **Turbulence/broken water (obscured stream bed)** | Record presence of turbulent water cover if the stream bed is obscured and >0.3m deep. | **(cov) Turb** |
| **Bed Rock/large boulders** | Record presence, and estimate size, of any large boulders >0.5m or bed rock. | **(cov) Rock** |
| **Large woody debris** | Record presence, and estimate size, of woody debris (>1m x 0.3m). Include only woody debris (or the part) that is within the wetted channel. | **(cov) WD** |
| **Man-made cover** | Record presence, and estimate size, of any man-made structures. Include only the structure (or the part) that is within the wetted channel. Record any relevant notes on the type of man-made cover *e.g.*, bridge pylons, flood protection works. | **(cov) Man** |
| **Undercut banks** | Record presence, and annotate length, of any undercut banks >0.3 undercut. | **(cov) Undercut** |
| **Overhanging Vegetation** | Record presence, and annotate length, of any overhanging vegetation (>0.3m overhang that obscures the stream bed from an observer directly above the stream). Record only vegetation that is touching the water surface or obscuring the stream bed from view. Estimate % stream bed that is obscured from view. | **(cov) OV** |

## 6.6. (Optional) subjective habitat assessment

After assessing the reach for the various habitat features, if you are qualified and can state your qualifications (*e.g.*, expert angler, professional fish ecologist or fisheries manager) you may wish to score (on a 1-4 scale) the stream mesohabitat or reach's capacity to support some (or all) of the trout life history stages (Tables 7-10), angling accessibility (Table 11) and aesthetic values (Tables 12). The suggestions under the description columns are not meant as a definitive list, to some degree you are expected to exercise your personal judgment when assigning a score.

**Table 7.** Scores, descriptions and codes for the subjective assessment of spawning habitat quality.

| Spawning score | Description | Code |
|---|---|---|
| **1 (poor)** | Heavily embedded, and/or fine sediment (< 6 mm), or large cobble/boulder substrate (> 250mm), and/or excessive periphyton growths, and/or too shallow (<0.2 m). | **(spawn) 1** |
| **2 (adequate)** | Substrate has limited proportions (<10%) of gravel, and cobble fractions between 6 mm and 64 mm, which have less than 20% fines and are less than 50% embedded; run habitat with a depth range of 0.3-1m. | **(spawn) 2** |
| **3 (Good)** | Some areas of potential down-welling upstream of riffle-crests and pool tailouts are present where the bed slops upwards. Some areas where 20-50% of the substrate comprises gravel-small cobbles and has >10% of fine-sediment and less than 25% embedded; water with medium velocities and a depth range of 0.3-1m. | **(spawn) 3** |
| **4 (excellent)** | Extensive areas of potential down-welling upstream of riffle-crests and pool tailouts are present where the bed slops upwards. Extensive areas where 20-50% of the substrate comprises gravel-small cobbles and has >10% of fine-sediment and less than 25% embedded; water with medium velocities and a depth range of 0.3-1m. | **(spawn) 4** |

**Table 8.** Scores, descriptions and codes for the subjective assessment of fry-rearing habitat quality.

| Fry rearing score | Description | Code |
|---|---|---|
| **1 (poor)** | Excessive water velocities (turbulent rippled water surface conditions) with no flow refugia. | **(fry) 1** |
| **2 (adequate)** | Limited areas with slow margins and water velocity refuges and slow water back eddies (<5%), limited areas of emergent bank vegetation (<10%), some overhanging vegetation present (between 5 and 10% of bank area). | **(fry) 2** |
| **3 (Good)** | Variable water velocities within most (>50%) of the mesohabitat, some slow water along stream margins (>20% of bank length) and or some overhanging vegetation or root wads in contact with the water (>20% of bank length). | **(fry) 3** |
| **4 (excellent)** | Extensive slow water along stream margins (>50%), swampy margins with eddies and extensive overhanging and/or bank side emergent vegetation, and/or coble boulder pocket water (>50% of bank length). | **(fry) 4** |

**Table 9.** Scores, descriptions and codes for the subjective assessment of juvenile-rearing habitat.

| Juvenile rearing | Description | Code |
|---|---|---|
| **1 (poor)** | Excessive velocities (turbulent, broken surface conditions) with no flow refuge, or, very slow/still flowing water. Excessive periphyton growths (>30%) and/or heavily embedded and/or fine sediment/silt substrate (90% fine sediment cover). | **(juv) 1** |
| **2 (adequate)** | Limited areas of moderate depth (< 10% 0.1-1m deep). Some coarse gravel/cobble and/or boulder fraction in the substrate and/or bank side cover or woody debris (10-50%). Moderate water velocities with rippled surface conditions with some variation in water velocity. | **(juv) 2** |
| **3 (Good)** | Areas of riffle/run habitat with coarse gravel/cobble and/or boulder substrate (>50% of reach) pocket water and/or bank side cover or woody debris. A diverse range of water velocities in >50% of the reach. | **(juv) 3** |
| **4 (excellent)** | Heterogeneous un-embedded gravel/cobble and boulder substrate (>70% of stream bed) and/or overhanging vegetation and/or woody debris present in the majority of the reach, full range of velocities throughout the reach with shallow "pocket water" riffle and runs, pool habitat in close proximity. | **(juv) 4** |

**Table 10.** Scores, descriptions and codes for the subjective assessment of adult trout habitat.

| Adult habitat score | Description | Code |
|---|---|---|
| **1 (poor)** | Heavily silted stream bed and/or excessive periphyton growths and/or shallow, uniform water velocities and channel form. Little or no in-stream or bank cover and/or very turbid water (<0.3 m visibility). | **(adult) 1** |
| **2 (adequate)** | Some cover available (one or two hiding areas) and/or some water greater than 1 m deep and/or moderately turbid water (0.3-0.5 m). Bank vegetation sparse but present, some opportunity for drift feeding (some moderate velocity areas and velocity variation) and/or active browsing areas (i.e. 5-10 $m^2$ of shallow pool habitat with macrophytes). | **(adult) 2** |
| **3 (Good)** | Variable depths and velocities, riparian cover and shading for >50% of the reach, undercut banks and/or other cover forms in much of the reach. Water clarity > 0.5m. Good opportunities for drift feeding (*e.g.* where a run or riffle meets a pool) and/or active browsing areas (i.e. $10\text{-}15^2$ shallow pool habitats with macrophytes). | **(adult) 3** |
| **4 (excellent)** | A diverse range of depths and water velocities within close proximity. A diverse range of mesohabitats. Course substrate. Good drift feeding opportunities in water > 0.5 m deep and ideally > 1 m deep, with abundant velocity boundaries, and/or stable shallow pool habitat with extensive macrophyte beds providing browsing feeding habitat (i.e., >15 $m^2$ shallow pool habitat with macrophytes). Plenty of stream cover, mature diverse riparian vegetation. Good water clarity for visual feeding (> 1 m). | **(adult) 4** |

**Table 11.** Scores, descriptions and codes for the subjective assessment of "fishing access."

| "Fishing access" (reach scale) water score | Description | Code |
|---|---|---|
| **1 (poor)** | Poor access, both banks thickly vegetated with prickly vegetation (*e.g.*, gorse or blackberry) and/or deeply incised banks and/or electric fences along bank margins and/or very murky/turbid water and/or excessive in-stream snags (*e.g.* woody debris) that would prohibit fishing. Mud, current and/or depth prohibit wading. | **(access) 1** |
| **2 (adequate)** | Access to the stream bank limited to one or two locations. River may be wadeable in places. | **(access) 2** |
| **3 (Good)** | Good access to at least one bank in several locations, a good range of depths and water velocities available to the angler. Some areas with clear "back casting" area for fly fishing. Potential to spot trout in areas of accessible stream. River may be wadeable | **(access) 3** |
| **4 (excellent)** | Excellent access to at least one bank in several locations, a good range of depths and water velocities available to the angler. Large areas with clear "back casting" area for fly fishing. Potential to spot trout in extensive areas of accessible stream. River may be wadeable | **(access) 4** |

**Table 12.** Scores, descriptions and codes for the subjective assessment of "fishing aesthetics."

| "Fishing aesthetics" (reach scale) water score | Description | Code |
|---|---|---|
| **1 (poor)** | Highly modified landscape* with poor aesthetic values, excessive in-stream thick-mat or filamentous algae cover (>30%) and/or very turbid murky water. prominent anthropogenic features nearby (*e.g.* excessive road noise) and/or unpleasant odours (*e.g.* effluent spreaders nearby). Little or no riparian vegetation. Surrounding landscape may include urban and/or pasture. | **(ath) 1** |
| **2 (adequate)** | A modified landscape with anthropogenic features such as roads and powerlines noticeable but not excessive. Algal mats or filamentous algae present but not excessive (10-30% bed cover). Some riparian trees present. Water clarity >1m. Surrounding landscape may include forested hills and pasture. | **(ath) 2** |
| **3 (Good)** | Some unmodified landscape present and mature riparian vegetation present. Water clarity 1-2 m. Sounding landscape may include forested hills and pasture. | **(ath) 3** |
| **4 (excellent)** | Very clear water (>2 m), clean (low algae biomass or cover) un-embedded stream bed, diverse range of depths and velocities, a large amount mature riparian vegetation (possibly native) is present. Sounding landscape may include native forested hills, mountains and pasture. | **(ath) 4** |

* Some personal discretion needs to be exercised when assessing aesthetics, as highly modified landscapes can be aesthetically pleasing (*e.g.* town gardens) and exotic riparian zones can provide idyllic fishing settings (*e.g.* wild lupin stands in the Central South Island). Additional notes should be supplied if scores recorded do not match the descriptions given.

# 7. ACKNOWLEDGEMENTS

Funding for this project was provided by Ministry of Science and Innovation (MSI) as part of the Maintenance and Rehabilitation of Aquatic Ecosystems program (C01X1002). Thanks to John Quinn, Iain Maxwell, Roger Young, Eric Goodwin and Phaedra Terezaki for their suggestions and input into this report.

# 8. REFERENCES

Allen, K.R. (1951). The Horokiwi Stream – a study of a trout population. New Zealand Marine Department. Fisheries Bulletin 10. 231 p.

Allouche S 2002. Nature and functions of cover for riverine fish. Bulletin Francais De La Peche Et De La Pisciculture (365-66): 297-324.

Armstrong JD, Kemp PS, Kennedy GJA, Ladle M, Milner NJ 2003. Habitat requirements of Atlantic salmon and brown trout in rivers and streams. Fisheries Research 62 (2): 143-170.

Ballantine DJ, Davies-Colley RJ 2009. Water quality trends at National River Water Quality Network sites for 1989-2007. NIWA Client Report HAM2009-026 for the Ministry for the Environment, March 2009. 43 p.

Baran P, Delacoste M, Lascaux JM 1997. Variability of mesohabitat used by brown trout populations in the French central Pyrenees. Transactions of the American Fisheries Society 126 (5): 747-757.

Bardonnet A, Poncin P, Roussel JM 2006. Brown trout fry move inshore at night: a choice of water depth or velocity? Ecology of Freshwater Fish 15 (3): 309-314.

Bauer SB, Ralph SC 2001. Strengthening the use of aquatic habitat indicators in Clean Water Act programs. Fisheries 26 (6): 14.

Bisley A 2010. Summary of the Report of the Land and Water Forum: A Fresh Start for Freshwaters. New Zealand Land and Water Forum Procedings: 19 p.

Bisson PA, Nielson JL, Palmason RA, Grove LE 1981. A system of naming habitat types in small streams, with examples of habitat utilization by salmonids during low stream flow. Symposium Proceedings, October 28- 30, 1981, Portland, OREGON.: 62-73

Bjornn TC, Brusven MA, Molnau MP, Milligan JH, Klamt RA, Chacho E, Schaye C 1977. Transport of granitic sediment in streams and its effects on insects and fish. Prepared for University of Idaho.

Broadmeadow S, Nisbet TR 2004. The effects of riparian forest management on the freshwater environment: a literature review of best management practice. Hydrology and Earth System Sciences 8 (3): 286-305.

Brosse S, Arbuckle CJ, Townsend CR 2003. Habitat scale and biodiversity: influence of catchment, stream reach and bedform scales on local invertebrate diversity. Biodiversity and Conservation 12 (10): 2057-2075.

Brown AV, Brussock PP 1991. Comparisons of benthic invertebrates between riffles and pools. Hydrobiologia 220 (2): 99-108.

Clausen B, Biggs B 1997. Relationships between benthic biota and hydrological indices in New Zealand streams. Freshwater Biology 38 (2): 327-342.

Collier KJ 2009. Linking multimetric and multivariate approaches to assess the ecological condition of streams. Environmental Monitoring and Assessment 157 (1-4): 113-124.

Collier KJ, Haigh A, Kelly J 2007. Coupling GIS and mulitvariate approaches to reference site selection for wadeable stream monitoring. Environmental Monitoring and Assessment 127 (1-3): 29-45.

Creque SM, Rutherford ES, Zorn TG 2005. Use of GIS-derived landscape-scale habitat features to explain spatial patterns of fish density in Michigan rivers. North American Journal of Fisheries Management 25 (4): 1411-1425.

Cross WF, Wallace JB, Rosemond AD, Eggert SL 2006. Whole-system nutrient enrichment increases secondary production in a detritus-based ecosystem. Ecology 87 (6): 1556-1565.

David G, Scott M, Guertin DP 2002. Deriving Stream Channel Morphology Using GIS-Based Watershed Analysis. In: ed. GIS for Water Resource and Watershed Management. CRC Press. Pp 53-60.

Davies-Colley RJ, Nagels JW, Smith RA, Young RG, Phillips CJ 2004. Water quality impact of a dairy cow herd crossing a stream. New Zealand Journal of Marine and Freshwater Research 38 (4): 569-576.

Davies-Colley RJ, Smith DG 2001. Turbidity, suspended sediment, and water clarity: A review. Journal of American Water Resources Association 37 (5): 1085-1101.

Dodds WK, Smith VH, Lohman K 2002. Nitrogen and phosphorus relationships to benthic algal biomass in temperate streams. Canadian Journal of Fisheries and Aquatic Sciences 59: 865-874.

Dolinsek IJ, Biron PM, Grant JWA 2007. Assessing the effect of visual isolation on the population density of Atlantic Salmon (Salmo salar) using GIS. River Research and Applications 23 (7): 763-774.

Duncan SH, Ward JW 1985. The influence of watershed geology and Forest roads on the composition of salmon spawning gravel. Northwest Science 59: 204-212.

Edwards ED, Huryn AD 1995. Annual contribution of terrestrial invertebrates to a New Zealand trout stream. New Zealand Journal of Marine and Freshwater Research 29 (4): 467-477.

Edwards ED, Huryn AD 1996. Effect of riparian land use on contributions of terrestrial invertebrates to streams. Hydrobiologia 337 (01/03/09): 151-159.

Eiswerth ME, Kashian RD, Skidmore M 2008. Examining angler behavior using contingent behavior modeling: A case study of water quality change at a Wisconsin lake. Water Resources Research 44 (11): 10.

Elliott JM 1994. Quantitative ecology and the brown trout. Oxford University Press, Oxford.

Fausch KD 1984. Profitable stream positions for salmonids: relating specific growth rate to net energy gain. Canadian Journal of Zoology 62: 441-451.

Fausch KD, Hawkes CL, Parsons MG 1988. Models that predict standing crop of stream fishes from habitat variables: 1950-85. Prepared for U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 1-52 p.

Harding JS, Clapcott JE, Quinn JM, Hayes JW, Joy MK, Greig HS, James T, Beech M, Ozane R, Hay J, Meredith A, Boothroyd IKG 2009. Stream habitat assessment protocols for wadeable rivers and streams of New Zealand. University of Canterbury Press., Christchurch. 133 p.

Harding JS, Young RG, Hayes JW, Shearer KA, Stark JD 1999. Changes in agricultural intensity and river health along a river continuum. Freshwater Biology 42: 345-357.

Harvey BC, White JL 2008. Use of Benthic Prey by Salmonids under Turbid Conditions in a Laboratory Stream. Transactions of the American Fisheries Society 137 (6): 1756-1763.

Hayes JW, Jowett IG 1994. Microhabitat models of large drift-feeding brown trout in three New Zealand rivers. North American Journal of Fisheries Management 14 (4): 710-725.

Hayes JW, Stark JD, Shearer KA 2000. Development and test of a whole-lifetime foraging and bioenergetics growth model for drift-feeding brown trout. Transactions of the American Fisheries Society 129: 315-332.

Heggenes J, Bagliniere JL, Cunjak RA 1999. Spatial niche variability for young Atlantic salmon (Salmo salar) and brown trout (S-trutta) in heterogeneous streams. Ecology of Freshwater Fish 8 (1): 1-21.

Hubble TCT, Docker BB, Rutherfurd ID 2010. The role of riparian trees in maintaining riverbank stability: A review of Australian experience and practice. Ecological Engineering 36 (3): 292-304.

Jellyman DJ, Unwin MJ, James GD 2003. Anlgers' percetptions of the status of New Zealand lowland rivers and their trout fisheries. Prepared for NIWA 122. 61 p.

Jonsson B, Jonsson N 2009. A review of the likely effects of climate change on anadromous Atlantic salmon Salmo salar and brown trout Salmo trutta, with particular reference to water temperature and flow. Journal of Fish Biology 75 (10): 2381-2447.

Jowett IG 1992. Models of the abundance of large brown trout in New Zealand rivers. North American Journal of Fisheries Management 12: 417-432.

Jowett IG 1997. Instream flow methods: A comparison of approaches. Regulated Rivers-Research & Management 13 (2): 115-127.

Jowett IG 1998. River hydraulics and habitat simulation, RHYHABSIM computer manual, second edition. National Institute of Water and Atmopheric Research (NIWA) Report. Hamilton, New Zealand: 61.

Jowett IG, Hayes JW, Duncan MJ 2008. A guide to instream habitat survey methods and analysis. 121 p.

Kaller MD, Hartman KJ 2004. Evidence of a threshold level of fine sediment accumulation for altering benthic macroinvertebrate communities. Hydrobiologia 518 (1-3): 95-104.

Kawaguchi Y, Nakano S 2001. Contribution of terrestrial invertebrates to the annual resource budget for salmonids in forest and grassland reaches of a headwater stream. Freshwater Biology 46 (3): 303-316.

Lisle TE 1987. Using 'Residual Depths' to monitor pool depths independently of discharge. Prepared for US Dept of Agriculture. 1-4 p.

Louhi P, Maki-Petays A, Erkinaro J 2008. Spawning habitat of atlantic salmon and brown trout: General criteria and intragravel factors. River Research and Applications 24 (3): 330-339.

Maddock I 1999. The importance of physical habitat assessment for evaluating river health. Freshwater Biology 41 (2): 373-391.

Matthaei CD, Weller F, Kelly DW, Townsend CR 2006. Impacts of fine sediment addition to tussock, pasture, dairy and deer farming streams in New Zealand. Freshwater Biology 51 (11): 2154-2172.

McCleary RJ, Hassan MA 2008. Predictive modeling and spatial mapping of fish distributions in small streams of the Canadian Rocky Mountain foothills. Canadian Journal of Fisheries and Aquatic Sciences 65 (2): 319-333.

McDowall RM 1990. New Zealand freshwater fishes: a natural history and guide. Heinemann Reed, Auckland, New Zealand. 553 p.

Meredith A, Smith Z, Lavender R 2003. Waikakahi Stream: assessment of water quality and ecosystem monitoring, 1995 to 2002. Prepared for Environment Canterbury. 67 p.

Milner NJ, Hemsworth RJ, Jones BE 1985. Habitat evaluation as a fisheries management tool. Journal of Fish Biology 27: 85-108.

Modde T, Ford RC, Parsons MG 1991. Use of a habitat-based stream classification system for categorizing trout biomass. North American Journal of Fisheries Management 11: 305-311.

Mossop B, Bradford MJ 2006. Using thalweg profiling to assess and monitor juvenile salmon (Oncorhynchus spp.) habitat in small streams. Canadian Journal of Fisheries and Aquatic Sciences 63 (7): 1515-1525.

Mouton AM, Alcaraz-Hernández JD, De Baets B, Goethals PLM, Martínez-Capel F 2011. Data-driven fuzzy habitat suitability models for brown trout in Spanish Mediterranean rivers. Environmental Modelling & Software 26 (5): 615-622.

Mouton AM, Jowett I, Goethals PLM, De Baets B 2009. Prevalence-adjusted optimisation of fuzzy habitat suitability models for aquatic invertebrate and fish species in New Zealand. Ecological Informatics 4 (4): 215-225.

Näslund I 1993. Migratory behaviour of brown trout, Salmo trutta L: importance of genetic and environmental influences. Ecology of Freshwater Fish 2 (2): 51-57.

Niyogi DK, Simon KS, Townsend CR 2004. Land use and stream ecosystem functioning: nutrient uptake in streams that contrast in agricultural development. Archiv Fur Hydrobiologie 160 (4): 471-486.

Northcote T 1992. Migration and residency in stream salmonids- some ecological considerations and evolutionary consequences. Nordic journal of freshwater research (67): 5-17.

O'Connor WCK, Kennedy RJ 2002. A comparison of catchment based salmonid habitat survey techniques in three river systems in Northern Ireland. Fisheries Management and Ecology 9 (3): 149-161.

Parkyn S, Wilcock B, Harding J, Mosley P, Pearson C, Sorrell B 2004. Impacts of agricultural land use. In: ed. Freshwaters of New Zealand. New Zealand Hydrological Society, Christchurch. Pp 34.1-34.16.

Parsons M, Thoms MC 2007. Hierarchical patterns of physical-biological associations in river ecosystems. Geomorphology 89 (1-2): 127-146.

Platts WS, Shirazi MA, Lewis DH 1979. Sediment particle sizes used by salmon for spawning with methods for evaluation. U.S. Environmental Protection Agency, Corvallis Environmental Research Laboratory, Corvallis, Oregon.

Quinn JM 2000. The effects of pastoral development. in: New Zealand stream invertebrates: Ecology and implications for management. Caxton Press, Christchurch, New Zealand.

Quinn JM 2009. Riparian Managment Classification Reference Manual. National Institute of Water and Atmospheric Research, Environment Canterbury.

Quinn JM, Cooper AB, Davies-Colley RJ, Rutherford JC, Williamson RB 1997. Land use effects on habitat, water quality, periphyton, and benthic invertebrates in Waikato, New Zealand, hill country streams. New Zealand Journal of Marine and Freshwater Research 31: 579-597.

Quinn JM, Stroud MJ 2002. Water quality and sediment and nutrient export from New Zealand hill-land catchments of contrasting land use. New Zealand Journal of Marine and Freshwater Research 36 (2): 409-429.

Rabeni CF, Doisy KE, Zweig LD 2005. Stream invertebrate community functional responses to deposited sediment. Aquatic Sciences 67 (4): 395-402.

Raleigh RF, Zuckerman LD, Nelson PC 1986. Habitat suitability index models and instream flow suitability curves: brown trout, revised. Prepared for U.S. Fish and Wildlife Service.

Riley RH, Townsend CR, Niyogi DK, Arbuckle CA, Peacock KA 2003. Headwater stream response to grassland agricultural development in New Zealand. New Zealand Journal of Marine and Freshwater Research 37: 389-403.

Robertson BM, Gillespie PA, Asher RA, Frisk S, Keeley NB, Hopkins GA, Thompson SJ, Tuckey BJ 2002. Estuarine Environmental Assessment and Monitoring: A National Protocol. Prepared for Councils and the Ministry for the Environment, Sustainable Management Fund. Cawthron Report No. 5096. Part A. 93p. Part B. 159p. Part C. 40p plus field sheets.

Roni P, Beechie TJ, Bilby RE, Leonetti FE, Pollock MM, Pess GR 2002. A review of stream restoration techniques and a hierarchical strategy for prioritizing restoration in Pacific northwest watersheds. North American Journal of Fisheries Management 22 (1): 1-20.

Roni P, Hanson K, Beechie T 2008. Global review of the physical and biological effectiveness of stream habitat rehabilitation techniques. North American Journal of Fisheries Management 28 (3): 856-890.

Roper BB, Kershner JL, Archer E, Henderson R, Bouwes N 2002. An evaluation of physical stream habitat attributes used to monitor streams. Journal of the American Water Resources Association 38 (6): 1637-1646.

Scrimgeour GJ, Kendall S 2003. Effects of livestock grazing on benthic invertebrates from a native grassland ecosystem. Freshwater Biology 48 (2): 347-362.

Shearer K, Hayes J 2011. Invertebreate drift and trout growth potential in the Taharua and Upper Mohaka Rivers: an investigation of the effects of dairy farming across three seasons. Prepared for Hawke's Bay Regional Council and Hawke's Bay Fish and Game. Cawthron Report No. 1832. 55 p.

Shearer KA, Stark JD, Hayes JW, Young RG 2003. Relationships between drifting and benthic invertebrates in three New Zealand rivers: implications for drift-feeding fish. New Zealand Journal of Marine and Freshwater Research 37: 809-820.

Shirazi MA, Seim WK 1979. A stream systems evaluation : an emphasis on spawning habitat for salmonids. Prepared for U.S. Environmental Protection Agency. 1-36 p.

Shirazi MA, Seim WK 1981. Stream system evaluation with emphasis on spawning habitat for salmonids. Water Resourses Research 17 (3): 592-594.

Shupryt M, Stelzer R 2009. Macrophyte beds contribute disproportionately to benthic invertebrate abundance and biomass in a sand plains stream. Hydrobiologia 632 (1): 329-339.

Slavik K, Peterson BJ, Deegan LA, Bowden WB, Hershey AE, Hobbie JE 2004. Long-term responses of the Kuparuk River ecosystem to phosphorus fertilization. Ecology 85 (4): 939-954.

Smith CM, Wilcock RJ, Vant WN, Smith DG, Cooper AB 1993. Towards sustainable agriculture: freshwater quality in New Zealand and the influence of agriculture. Prepared for MAF Policy. 1-208 p.

Sutherland AB, Meyer JL, Gardiner EP 2002. Effects of land cover on sediment regime and fish assemblage structure in four southern Appalachian streams. Freshwater Biology 47 (9): 1791-1805.

Townsend CR, Arbuckle CJ, Crowl TA, Scarsbrook MR 1997. The relationship between land use and physicochemistry, food resources and macroinvertebrate communities in tributaries of the

Taieri River, New Zealand: A hierarchically scaled approach. Freshwater Biology 37 (1): 177-191.

Townsend CR, Doledec S, Norris R, Peacock K, Arbuckle C 2003. The influence of scale and geography on relationships between stream community composition and landscape variables: description and prediction. Freshwater Biology 48 (5): 768-785.

Wang L, Lyons J, Kanehl P 1998. Development and Evaluation of a Habitat Rating System for Low-Gradient Wisconsin Streams. North American Journal of Fisheries Management 18 (4): 775-785.

Wankowski JWJ 1979. Morphological limitations, prey size selectivity, and growth response of juvenile atlantic salmon, Salmo salar. Journal of Fish Biology 14: 89-100.

Whitacre HW, Roper BB, Kershner JL 2007. A comparison of protocols and observer precision for measuring physical stream attributes. Journal of the American Water Resources Association 43 (4): 923-937.

Wood PJ, Armitage PD 1997. Biological effects of fine sediment in the lotic environment. Environmental Management 21: 203-217.

Wood PJ, Armitage PD 1999. Sediment deposition in a small lowland stream - Management implications. Regulated Rivers-Research & Management 15 (1-3): 199-210.

Yamada H, Nakamura F 2002. Effect of fine sediment deposition and channel works on periphyton biomass in the Makomanai River, northern Japan. River Res Appl 18 (5): 481-493.

Yuan YP, Bingner RL, Locke MA 2009. A Review of effectiveness of vegetative buffers on sediment trapping in agricultural areas. Ecohydrology 2 (3): 321-336.

Zhang XY, Liu XM, Zhang MH, Dahlgren RA, Eitzel M 2010. A review of vegetated buffers and a meta-analysis of their mitigation efficacy in reducing nonpoint source pollution. Journal of Environmental Quality 39 (1): 76-84.