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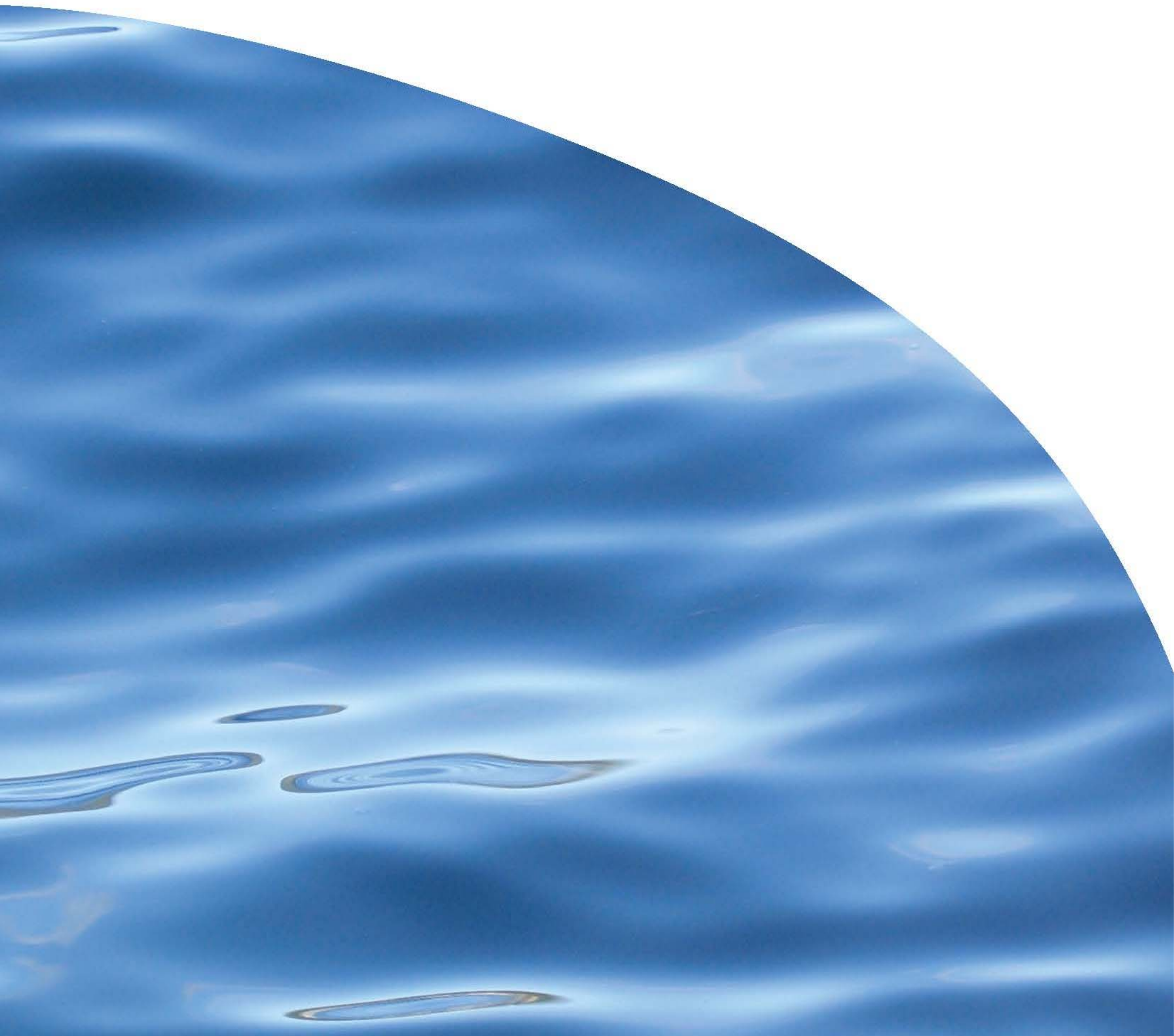
BROAD-SCALE TROUT HABITAT MAPPING IN A BEST PRACTICE DAIRY CATCHMENT



BROAD-SCALE TROUT HABITAT MAPPING IN A BEST PRACTICE DAIRY CATCHMENT

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EXECUTIVE SUMMARY

A catchment-wide trout habitat survey was trialled on the Waikakahi Stream (South Canterbury), which drains a best practice dairy monitored catchment. In total, 8.5 kilometres of the riparian zone and 2.5 kilometres of in-stream habitat were surveyed. Field assistance was offered in kind by Central South Island Fish & Game (CSIFG) and Environment Canterbury (ECan).

An index of adult trout habitat quality that assigns a habitat suitability score to a 20 m stream reach was created to interpret the survey results. The index scores were consistent with expert qualitative assessments of trout habitat quality. Index results are displayed on catchment maps using a traffic light system.

If survey results are compared to historical anecdotes the overall physical habitat condition of the Waikakahi Stream seems to have improved considerably since the stream was fenced. However, the survey and trout habitat quality index results highlighted areas in the upper catchment where improved fencing could further (and most cost effectively) improve stream habitat condition.

The broad-scale trout habitat mapping protocol (BTHMAP) in combination with the adult trout habitat quality index (THQI) shows potential as a method for linking on-farm riparian condition with in-stream physical habitat quality, with a view to achieving best practice and informing stream rehabilitation options.

TABLE OF CONTENTS

1. INTRODUCTION 1
1.1. Habitat mapping 1
1.2. Waikakahi Stream catchment 1
2. METHODS 3
2.1. The broad-scale trout habitat mapping protocol (BTHMP) 3
2.2. Survey methods 3
2.2.1. Riparian survey 4
2.2.2. In-stream survey 5
2.3. Index creation and statistical analysis 6
3. RESULTS 8
3.1. In-stream habitat survey 8
3.2. Trout habitat quality index (THQI) 9
4. DISCUSSION 15
4.1. Overall habitat condition of the Waikakahi Stream 15
4.2. Spawning habitat remains degraded 15
4.3. Performance of the broad-scale trout habitat mapping protocol (BTHMP) 17
4.4. Performance of the adult trout habitat quality index (THQI) 18
4.5. Potential for using the adult trout habitat quality index (THQI) as a diagnostic tool for stream restoration ... 19
5. SCOPE FOR FURTHER WORK 22
6. ACKNOWLEDGEMENTS 23
7. REFERENCES 24
8. APPENDICES 26

LIST OF FIGURES

Figure 1. An example of the overview maps used in the field survey. 4
Figure 2. Scatter plot of the average adult trout habitat quality index and average expert assessment score for each 100 m in-stream habitat survey reach. 9
Figure 3. (a) Average trout habitat quality index scores and average expert assessment scores for adult trout habitat in the 100 m in-stream habitat reaches. (b) The same data but normalised to a common scale by dividing by the maximum value in each data set. 10
Figure 4. Adult trout habitat quality index scores determined by three survey teams for each 20 m sub-reach. 11
Figure 5. Qualitative expert assessment scores for adult trout habitat determined by three survey teams for each 20 m sub-reach. 11
Figure 6. The 100 m in-stream survey reaches within each of the nine segments showing the adult trout habitat quality index scores expressed as categorical colours based on quartiles of the index range. 12
Figure 7. The three 100 m reaches of Segment 9. 13
Figure 8. The three 100 m reaches of Segment 13. 14
Figure 9. Sediment analysis at a potential spawning area. 16
Figure 10. Areas of stock pugging next to the stream at Segment 6. 20
Figure 11. The riparian zone of Segment 12.. 21

LIST OF TABLES

Table 1. Percentage of meso-habitat types for the Waikakahi Stream expressed as an average % of the wetted width of all 20 m sub-reaches. 8
Table 2. Depth category percentages for Waikakahi Stream expressed as an average % of the wetted width of all 20 m sub-reaches. 8
Table 3. Percentage stream-bed cover of the various substrate categories (Wentworth classification system) and aquatic macrophyte beds expressed as an average % of the wetted width of all 20 m sub-reaches. 9
Table 4. Percentage of the in-stream cover types for all survey sub-reaches combined. 9
Table 5. Categorical colours for each habitat type and the associated score. 12

LIST OF APPENDICES

Appendix 1. An example of a riparian survey aerial photo map. 26
Appendix 2. An example of a 100 m in-stream survey photo map. 27
Appendix 3. An example of a completed section of the riparian survey at Segment 13. 28
Appendix 4. An example of a completed survey for a 100 m in-stream habitat reach, showing the base aerial photo map and the acetate overlays: depth and meso-habitat types, cover attributes, substrate characteristics and the subjective expert assessment of trout habitat quality. 29
Appendix 5. Suitability weights for the habitat attribute categories for the adult trout habitat quality index. 30
Appendix 6. Average adult trout habitat quality index and expert assessment scores for each 100 m reach in the survey. 31

1. INTRODUCTION

1.1. Habitat mapping

In 2011 a broad-scale trout habitat mapping protocol (BTHMP) was developed to survey trout habitat at the catchment scale using aerial photography (Holmes & Hayes 2011). The present report describes a field trial of the BTHMP in the Waikakahi Stream (a tributary of the lower Waitaki River) during late February 2012. Field support was provided by Central South Island Fish & Game Council (CSIFGC) staff and an Environment Canterbury (ECan) staff member. The survey results were interpreted by creating an index of adult trout habitat quality (THQI) which assigns a habitat suitability score (from 0-1) to 20 m lengths of a stream.

1.2. Waikakahi Stream catchment

The Waikakahi is one of five Best Practice Dairy Catchments (BPDCs) across the country. The primary purpose of the BPDC programme was to research and monitor the environmental outcomes of implementing Best Management Practices (BMPs) on dairy farms (Wilcock *et al.* 2007).

Anecdotal reports state that the Waikakahi Stream was held in high regard as a small spring-creek brown trout fishery prior to the 1990s (Buxton 2002). It also had indigenous biodiversity values, including eels, upland bully, koura and kākahi. Kākahi are of particular significance, Waikakahi meaning "*the place where kākahi (a fresh water shellfish – specifically mussels) are found*".

Following the development of the Morven-Glenavy-Ikawai irrigation scheme, the Waikakahi catchment was converted from sheep/beef and mixed crops to dairy farming. Unfenced sacrifice paddocks adjacent to the stream (Meredith *et al.* 2003) and overland runoff from the predominantly border dyke irrigation system (Monaghan *et al.* 2009), caused excessive nutrients and fine sediment to enter the Waikakahi Stream. Following conversion to dairy, the stream habitat declined to the point where the trout fishery values of the catchment were considered virtually non-existent (pers. comm. Graeme Hughes, CSIFGC). The population of koura also declined and kākahi are no longer found in the stream.

During 1999 high profile media reports implicated poor riparian management as the cause of the degraded trout fishery in the Waikakahi Stream (Monaghan 2007). The local community took action over the following decade to clean up the stream and a significant effort was made to exclude stock from the waterway. It is reported that approximately 93 % of the stream has been fenced (Hayward 2011).

No extensive physical habitat data was taken before the Waikakahi Stream was fenced. However, water quality monitoring at Glenavy (at the lower end of the catchment) has shown a four-fold reduction in suspended sediment load over the 10 years following 1997 after the stream was fenced (Dodd *et al.* 2009).

2. METHODS

2.1. The broad-scale trout habitat mapping protocol (BTHMP)

The BTHMP is detailed in Holmes & Hayes (2011). In short, it involves a desktop analysis of existing catchment knowledge (as described in Harding *et al.* 2009) followed by ground-truthing habitat features on aerial photos. Survey segments (1000 m long) are picked at random from strata identified during the desktop analysis. The BTHMP is split into two stages at each survey segment:

- Stage 1: Riparian features and potential contaminant sources are surveyed over the entire 1000 m segment
- Stage 2: In-stream assessments of trout habitat are conducted in three 100 m reaches (each split into five 20 m sub-reaches) that are nested within each 1000 m segment.

The following terms are used to describe the different scales at which the survey was conducted:

- Survey segment - refers to a 1000 m length of stream
- Reach - refers to a 100 m length of stream
- Sub-reach - refers to a 20 m reach of stream.

2.2. Survey methods

The Waikakahi Stream was surveyed during base flow conditions between 27 February and 1 March 2012.

Stream stratification (into 5-10 km sections) was not necessary because all but the lower two kilometres of the stream is dominated by dairy farms. Using a generalised random tessellation stratified (GRTS) spatially balanced survey design (Stevens & Olsen 2004), nine stream segments were chosen from a pool of 17 potential segments. A set of aerial photos was then printed out for each segment. Ortho-rectified aerial imagery was sourced from http://gis.ecan.govt.nz/arcgis/services.

Each 1000 m survey segment was marked on an overview aerial photo which served as a base map for the survey team. The segment centre was marked as a red dot. Five perimeter rings were drawn at 100 m increment radii around this central point. These rings, along with a 20 x 20 m grid (NZ map grid) were overlaid on the photo so that field workers could find their position on it using handheld GPS (Figure 1). The upstream and downstream ends of the 1000 m segment were defined by the intersections of the outermost ring with the stream (*i.e.* the blue ring depicted in Figure 1). The three 100 m reaches for the in-stream survey within the 1000 m segment were randomly chosen, and the surveys within these were conducted in 20 m increments.

2.2.1. Riparian survey

For the riparian survey, five aerial photos which encompassed the entire 1000 m segment, were printed at a 1:5000 scale (Appendix 1). For each of the 100 m in-stream reaches a single aerial photo at a 1:750 scale was printed (Appendix 2).

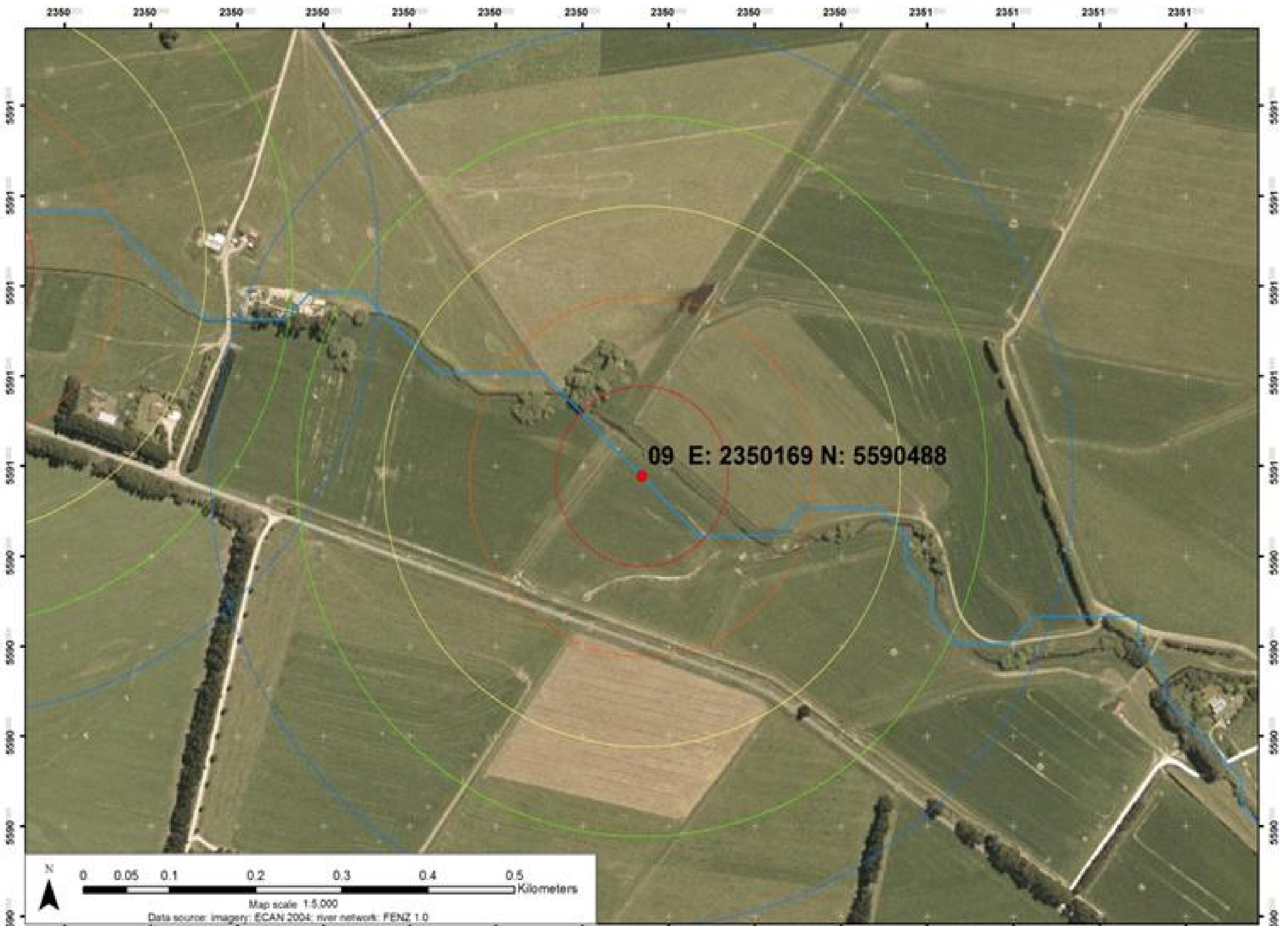

Figure 1. An example of the overview maps used in the field survey. The red dot indicates the centre of the 1000 m survey (Segment 9). The five coloured perimeter rings at 100 m increment radii around the segment centre were used to randomly select three 100 m in-stream survey reaches and to assist field workers navigating the segment.

Photos and overlays were organised into segment folders for the three two-person survey teams. Habitat information was recorded directly on to the aerial photos (or on acetate overlays) using fine-tipped Stabilo permanent markers.

Information recorded in the riparian survey, conducted over the entire 1000 m segment, included:

- Extent and category types and of riparian vegetation
- Land-use management features (such as stock exclusion fences)
- Potential contaminant sources (such as stock crossings or stock pugging).

An example of a completed section of the riparian survey is shown in Appendix 3. The field guide for the riparian survey, which includes a full description of the riparian survey protocol, is available on request.

2.2.2. *In-stream survey*

For the in-stream survey each 100 m reach was divided into five 20 m sub-reaches. A 20 m rope was laid out next to each sub-reach to measure (or use as a reference for estimating) the length of the various habitat features. Within each 20 m sub-reach meso-habitat types (*e.g.* riffle, run, pool), depths, cover attributes and stream-bed characteristics were visually estimated either as a percentage of the 20 m reach or as areas (m^2). In cases where the features could be distinguished on the aerial photo they were traced and labelled. Wetted widths, depth categories and meso-habitat types were recorded directly onto the aerial photo. Substrate characteristics and cover types were recorded on a separate acetate overlays. A qualitative expert assessment of trout habitat (adult, juvenile, fry, spawning), angling access and aesthetics was also undertaken in each 20 m sub-reach. Each of these assessment categories were assigned a score from 1-4 (1 = poor, 2 = adequate, 3 = good, 4 = excellent) and the scores were recorded on another acetate overlay. The assessors included Graeme Hughes, Mark Webb and Hamish Stevens from CSIFGC, Mary Beech from ECan, John Hayes, Rasmus Gabrielsson and Robin Holmes from the Cawthron Institute (Cawthron). This group of people have over 100 years of combined experience in fisheries research or fisheries management.

An example of a completed section of the in-stream survey is shown in Appendix 4. The field guide for the in-stream trout habitat survey, which includes a full description of the in-stream survey protocol, is available on request.

At one of the nine survey segments (Segment 24) 500 m of the riparian zone and the five 20 m sub-reaches in one of the 100 m in-stream survey reaches were assessed independently by the three survey teams to examine inter-observer variation.

2.3. Index creation and statistical analysis

The THQI was calculated based on the 20 m sub-reach in-stream habitat data. All of the habitat data were entered into an Excel spread-sheet and converted to % wetted area of each 20 m sub-reach before being used for the index calculations.

Scores for each of the three survey categories (depth, cover and substrate composition) were calculated by multiplying the percentage wetted area cover of a category feature by a suitability weighting score. The product of each of these calculations was then summed to give a category score. For example: the suitability weightings for the depth categories are as follows: 0–0.3 m (= 0.0), 0.3-0.5 m (= 0.5), and >1 m (= 1) (Appendix 5). If a 20 m sub-reach was recorded as 40 % 0-0.3 m deep, 30 % 0.3-0.5 deep and 30 %>1 m deep then the depth category score would be: (40 x 0) + (30 x 0.5) + (30 x 1) = 45. The same approach was used to calculate scores for the cover and substrate categories.

To calculate the overall THQI score (for each 20 m sub-reach) depth, cover and substrate composition category scores were summed and divided by the maximum possible combined score to give a number from 0.0 to 1. If a score of 0 was assigned to a depth or cover category then the overall THQI score for that reach was 0 irrespective of scores in the other categories. For the cover category, a score of 0 had to occur in all the cover types and in the depth category >1 m (because deep water can be used by trout as cover) before the other category scores were discounted. A zero score in the substrate composition category was not possible (a nominal value of 0.01 was assigned to ‘unsuitable’ substrate).

Suitability weighting scores for the depth and substrate categories were based on habitat suitability curves for brown trout developed by Raleigh *et al.* (1986) and Hayes & Jowett (1994). Cover suitability weightings were assigned by considering the cover preferences of salmonids described in overseas literature. Weighting scores were adapted for New Zealand trout (which tend to have a larger average size than overseas populations) based on the experience of R. Holmes and J. Hayes. Large wood, undercut banks and vegetation overhanging by >1 m received higher weightings than other cover types. These cover types are known to be favoured by adult trout (Raleigh *et al.* 1986). See Appendix 5 for a list of the various habitat suitability weightings.

No meso-habitat weighting scores were assigned for the adult trout index because the range of water velocities in the Waikakahi Stream are all within acceptable limits to support either drift feeding or benthic foraging by trout. To gather coarse velocity information, a single ‘typical’ fast, medium and slow run was chosen from the lower Waikakahi Stream. The ‘Orange method’ (*i.e.* timing the drift of an orange over a known distance USEPA 2012) was used to estimate water velocities in each of these selected meso-habitats. Each estimate was the average of three drifts. A coefficient of 0.85 was used to convert surface velocity to mean channel velocity (USEPA 2012).

A Spearman's rank correlation was used to test the association of the THQI and expert assessment scores for each 100 m reach in the survey. Pairwise T-test comparisons were used to assess inter-observer variation between the five 20 m sub-reaches that were assessed independently by three survey teams. GIS was used to display the index results on catchment maps.

3. RESULTS

The Waikakahi Stream is approximately 17 kilometres long. Overall, 2470 m (15 %) of the in-stream habitat and 8500 m (50 %) of the riparian zone (both banks) was surveyed. This was achieved by seven field workers over 2.5 days. Due to time and budget constraints, only the in-stream data have been analysed to date.

3.1. In-stream habitat survey

The estimated water velocities for a typical fast, medium and slow run were 0.6 m/s, 0.5 m/s and 0.3 m/s respectively. The water velocity value of the fast run gives an indication of the upper limit of velocities in the Waikakahi Stream (excluding shallow riffles).

Overall the stream averaged 4.7 m wide. 'Slow run' was the dominant meso-habitat type averaging 48 % of the surveyed habitat (Table 1). Deep habitat was rare with water deeper than 1 m making up only 5 % of the in-stream survey area. Combined, the depth categories 0-0.3 m and 0.3-0.5 m made up 72 % of the in-stream survey area (Table 2). Macrophyte beds were a dominant feature of the stream with a mean cover of 38 %. Coarse gravel was the most common substrate category comprising 37 % of the stream bed. Fine sediment and fine gravel together made up 42 % of the stream bed (Table 3). In-stream cover was predominantly overhanging vegetation and emergent and submerged aquatic macrophytes (Table 3). Overhanging banks were also reasonably common making up 13 % of the stream edge. Small amounts of large wood, submerged branches and man-made cover objects were also present (Table 4).

Table 1. Percentage of meso-habitat types for the Waikakahi Stream expressed as an average % of the wetted width of all 20 m sub-reaches.

	Meso-habitat type					
	Pool	**Riffle**	**Slow run**	**Med. run**	**Fast run**	**Backwater**
Mean %	5	4	48	14	28	1

Table 2. Depth category percentages for Waikakahi Stream expressed as an average % of the wetted width of all 20 m sub-reaches.

	Depth category			
	0-0.3 m	**0.3-0.5 m**	**0.5-1.0 m**	**>1 m**
Mean %	34	38	23	5

Table 3. Percentage stream-bed cover of the various substrate categories (Wentworth classification system) and aquatic macrophyte beds expressed as an average % of the wetted width of all 20 m sub-reaches.

	Substrate category							
	Weed beds	**Clay/mud/ silt/sand**	**Fine gravel**	**Coarse gravel**	**Small cobble**	**Large cobble**	**Boulder**	**Bed rock**
Mean %	38	23	19	37	18	4	0	0

Table 4. Percentage of the in-stream cover types for all survey sub-reaches combined (UB = Undercut Bank, OV = Overhanging Vegetation, LW = Large wood, SB = Submerged Branches, MM = Man-Made cover). LW, SB and MM are average % stream-bed cover of the wetted width of all 20 m sub-reaches. UB and OV are average % linear cover of a 40 m edge (*i.e*. both banks of a 20 m sub-reach).

	Cover category								
	UB 0-0.3 m	**UB 0.3-0.5 m**	**OV 0-0.3 m**	**OV 0.3-0.5 m**	**OV 0.5-1 m**	**OV >1 m**	**LW**	**S B**	**M M**
Mean %	8	5	30	24	4	4	0.4	1	0.4

3.2. Trout habitat quality index (THQI)

A visual comparison of the relationship between the THQI and the expert assessments of adult trout habitat is shown in Figure 2. A Spearman's rank correlation coefficient of 0.76 (P = <0.01) indicates a positive correlation between the 100 m reach THQI scores and corresponding expert assessments of adult trout habitat.

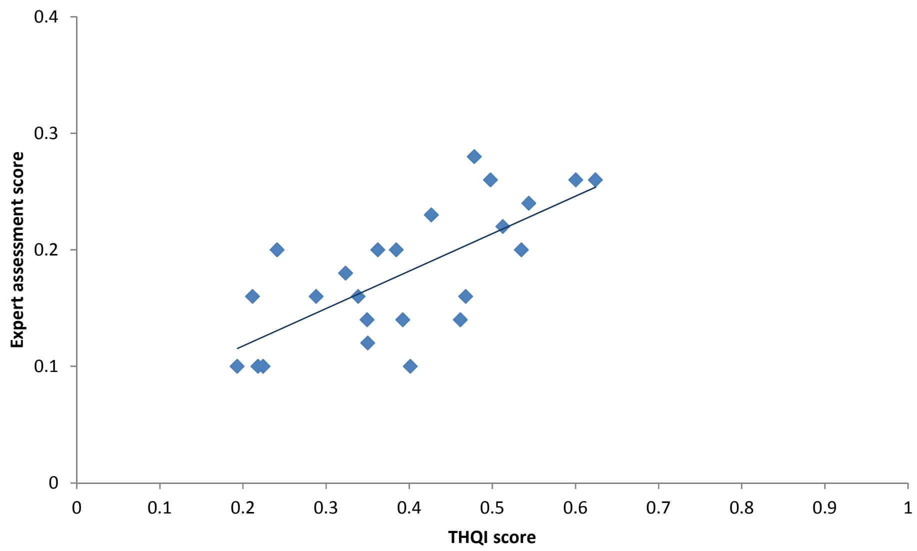

Figure 2. Scatter plot (with trend line) of the average adult trout habitat quality index (THQI) and average expert assessment score for each 100 m in-stream habitat survey reach (n = 24). The tributary reaches 2a and 2b are omitted because flow was partially subterranean in these reaches.

Figure 3 shows the average adult THQI scores and expert assessment scores of adult habitat for each 100 m reach. Figure 3 b shows the data on a normalised scale by dividing by the maximum value in each data set to better compare the two assessments.

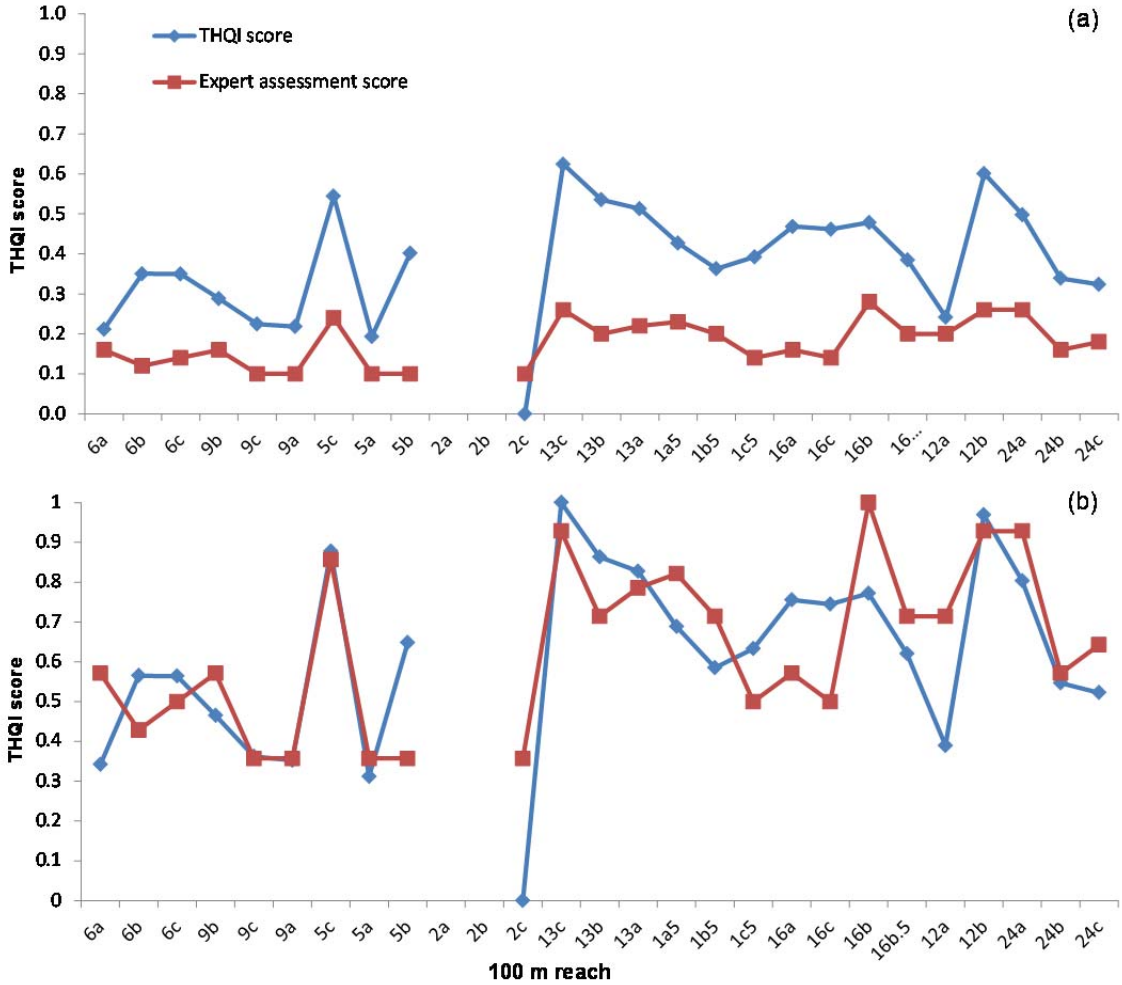

Figure 3. (a) Average trout habitat quality index (THQI) scores (blue diamonds) and average expert assessment scores for adult trout habitat (red squares) in the 100 m in-stream habitat reaches. The reaches are ordered from upstream to downstream, left to right. Numbers indicate the survey segment and letters correspond to the 100 m reaches within the segments. (b) The same data but normalised to a common scale by dividing by the maximum value in each data set. The tributary reaches 2a and 2b are omitted because flow was partially subterranean in these reaches.

Trout habitat quality index (THQI) scores were similar for the five 20 m in-stream habitat sub-reaches (Segment 24b) that were surveyed independently by three survey teams (Figure 4). Subjective assessments of adult trout habitat quality differed by no more than 25 % (one increment on the 0.1-0.4 Likert scale, Figure 5). Pairwise T-test comparisons showed no significant difference between trout habitat scores derived from the different survey teams using either the THQI (*P*= 0.86) or expert assessment methods (*P*= 0.77).

The greatest difference in the THQI score (0.22 points) occurred between survey teams 2 and 3 for sub-reach 2. Index scores for the remaining sub-reaches differed by less than 0.08 points (Figure 4). The average maximum difference between the three survey team scores for each of the five sub-reaches was 0.07 points. Average THQI scores for the same 100 m reach were 0.28, 0.30 and 0.25 for the survey teams 1, 2 and 3 respectively.

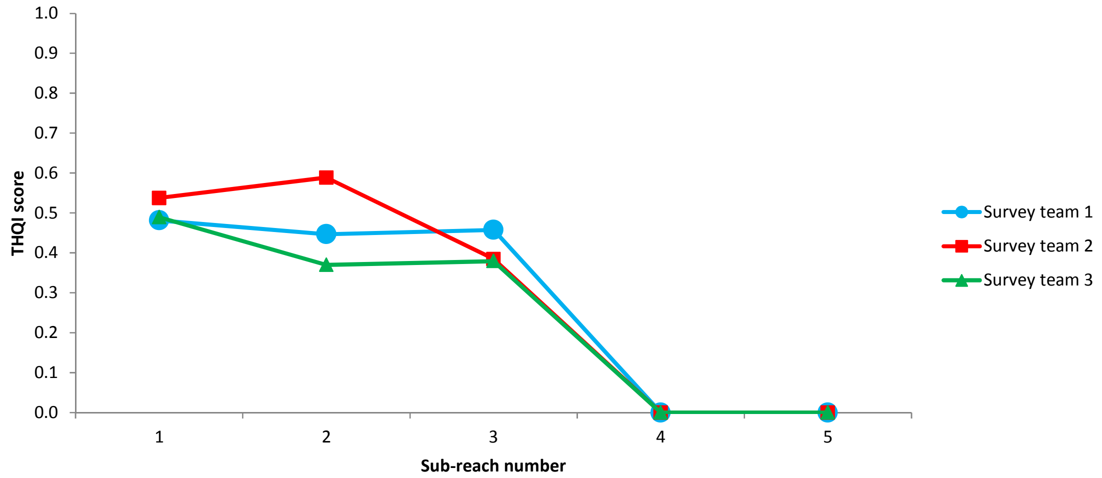

Figure 4. Adult trout habitat quality index (THQI) scores determined by three survey teams for each 20 m sub-reach (100 m reach b, at Segment 24).

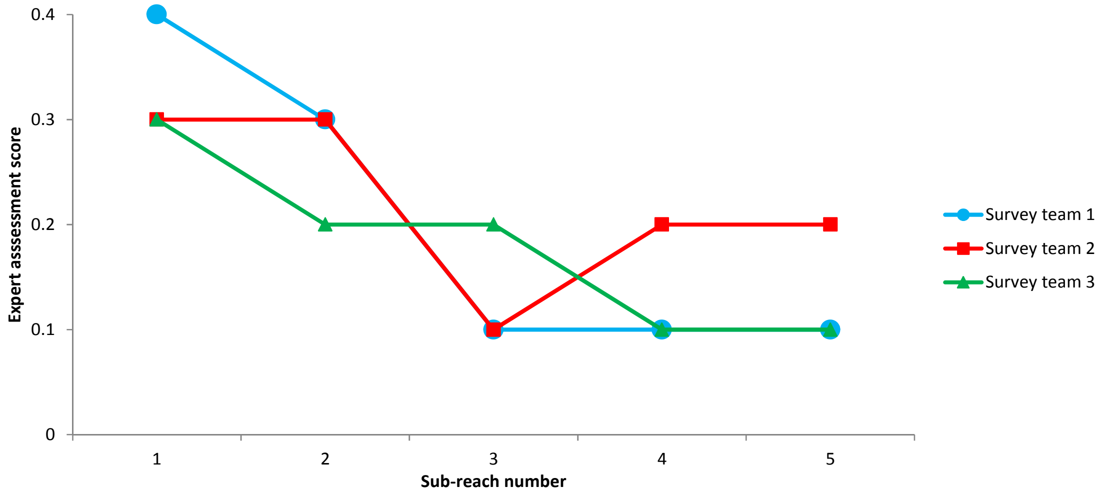

Figure 5. Qualitative expert assessment scores for adult trout habitat (0.1-0.4 Likert scale) determined by three survey teams for each 20 m sub-reach (100 m reach b, at Segment 24).

Figure 6 shows a catchment overview of the positions of the survey reaches. Average THQI scores for each 100 m reach are expressed as categorical colours based on quartiles of the index range:

No 'excellent' habitat was identified in the Waikakahi Stream according to the THQI (Table 5). Segment 2 (in the middle of the catchment, Figure 6) which received the lowest index score, was a small spring-fed tributary, too shallow to support adult trout.

Table 5. Categorical colours for each habitat type and the associated score.

Categorical colour	Habitat type	Score
Red	Poor	0.0-0.25
Yellow	Adequate	0.26-0.50
Green	Good	0.51-0.75
Blue	Excellent	0.76-1

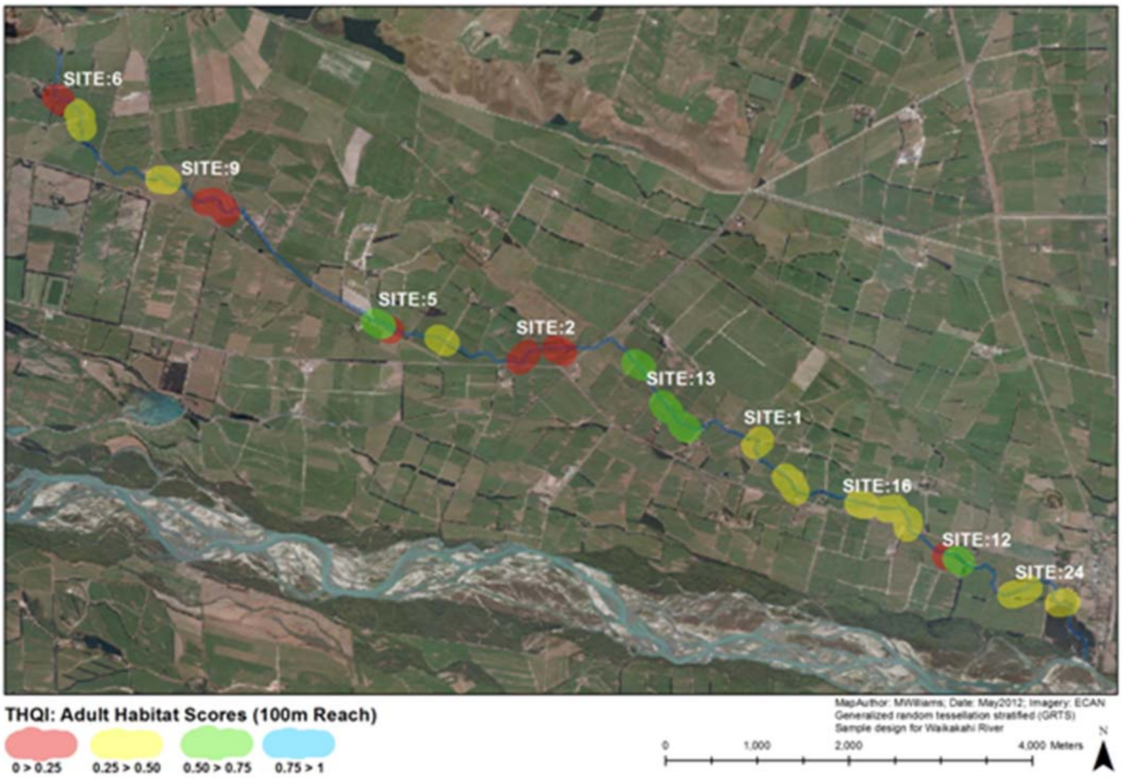

Figure 6. The 100 m in-stream survey reaches within each of the nine segments showing the adult trout habitat quality index (THQI) scores expressed as categorical colours based on quartiles of the index range.

The following figures show close-up views of segments which indicate the habitat quality according to the THQI scores; *e.g.* the segment which had the second lowest score; Segment 9 (Figure 7) and the best survey score; Segment 13 (Figure 8). The individual 20 m sub-reaches and their assigned THQI scores can be seen, as well as the locations of the 100 m reaches in relation to various farm landmarks. These maps highlight areas where protection (Segment 13) or restoration (Segment 9) measures should be considered.

Figure 7. The three 100 m reaches of Segment 9. Trout habitat quality index (THQI) scores are expressed as categorical colours based on quartiles of the index range. The thickness of the internal line indicates the relative width of the stream at each 20 m sub-reach.

Figure 8. The three 100 m reaches of Segment 13. Trout habitat quality index (THQI) scores are expressed as categorical colours based on quartiles of the index range. The thickness of the internal line indicates the relative width of the stream at each 20 m sub-reach.

4. DISCUSSION

4.1. Overall habitat condition of the Waikakahi Stream

The Waikakahi Stream was degraded by poor riparian management practises in the late 1980s and early 1990s. Following conversion to dairy, the stream was highly turbid and had excessive amounts of fine sediment covering the stream bed (Meredith *et al.* 2003). Our survey results suggest that a considerable improvement in the general physical condition of the Waikakahi Stream has occurred since the stream was fenced. Gravel now dominates the substrate. Furthermore, large areas of the lower Waikakahi Stream provide adequate or good adult trout habitat (Figure 6). However, fine sediment in the streambed is still an issue, particularly in the upper catchment. Overall, the Waikakahi Stream had an average of 23 % fine sediment cover. This is above Clapcott *et al.'s* (2011) recommended upper-limit guideline of 20 % fine sediment cover to protect biodiversity and salmonid spawning values.

4.2. Spawning habitat remains degraded

A survey conducted eight years previously, identified low trout-embryo survival rates in the Waikakahi Stream (Hay 2004). Hay (2004) implicated excessive amounts of fine sediment and/or high nitrate levels as the cause for the low survival rates.

The present survey results imply that fine sediment continues to reduce the suitability of spawning habitat in the Waikakahi Stream. Experts most commonly rated the Waikakahi survey reaches as 'poor' spawning habitat (75 % of the 130 survey sub-reaches received a 'poor' rating). Good or excellent scores were given to only 5 % of the 135 sub-reaches in the survey. The predominantly poor rating (by expert assessment) of spawning habitat in the Waikakahi was due in part to experts noting high levels of surface and/or intra-gravel fine sediment at potential spawning areas (Figure 9a and 9b). Fine sediment inhibits the percolation of water through salmonid redds. Gentle intra-gravel water flow through trout redds is required to flush out metabolites and deliver oxygen to developing trout embryos (Louhi *et al.* 2008).

Figure 9. Sediment analysis at a potential spawning area. Note: (a) The gravel in front of John Hayes (Cawthron) appears to be an ideal trout spawning location (*i.e*. gravel and coarse gravel in 'knee-deep' water at the tail of a pool. (b) A fine sediment plume is dislodged from the substrate when disturbed showing that the sub-surface gravel is laden with fine sediment which reduces its suitability for trout spawning.

Large amounts of interstitial fine sediment in the Waikakahi Stream are a legacy of dairy conversion and poor farming practices through the 1990s, with poor practices on some farms continuing to the present day. Spring-fed streams such as the Waikakahi typically have low flood power. Even if the human inputs of fine sediment are reduced in spring-fed streams the existing fine sediment may take decades (or more) to be flushed from the stream-bed (Rosgen & Silvey 2006).

Irrigation in the Waiakakihi catchment has altered the annual hydrograph so that the stream now experiences high flows in summer. These enhanced flows have increased stream power and will have helped to flush accumulated fine sediment from the surface of the bed. However, even larger flows would be required to flush fine sediment from within the stream bed. Flood flows sufficient to disturb the amour layer by definition are very infrequent in spring-fed streams such as the Waikakahi. In order to achieve significant reduction in fine sediment levels within the gravels, targeted rehabilitation is probably required.

A promising option is removal of fine sediment by suction pump. The Sand Wand^{TM} is an example and is commonly used for stream-bed rehabilitation in the U.S.A. (http://www.streamsideenvironmental.com/sediment-removal-services/). This technology was recently imported to New Zealand by Fish & Game New Zealand – North Canterbury Region. Mechanical removal of fine sediment could be targeted to potentially good spawning areas identified by the survey.

4.3. Performance of the broad-scale trout habitat mapping protocol (BTHMP)

Overall, the BTHMP was well received by the F&G staff who participated in the Waikakahi survey. It was noted that the concept shows promise as a method for long-term monitoring of riparian and in-stream habitat condition (pers.comm. Mark Webb, CSIFGC). In particular, it was also noted that the BTHMP could be used to monitor cumulative effects of land use development on small-stream trout fisheries.

The ECan staff member who participated in the Waikakahi survey (Mary Beech) considered that the survey could be useful as a means for Fish & Game NZ to help regional councils achieve targets for maintaining and enhancing recreational fisheries. For example, one of ECan's water management recreational amenity targets is; "A positive trend in the availability and/or quality of fresh water angling opportunities (by 2015)". The supporting document for the water management targets acknowledges that there is an information gap on the quality and use of freshwater recreational amenities (Annex 2010).

Several areas where the survey could be improved were noted during the field trial and these are being incorporated into the BTHMP. The most important lesson from the field trial was that the scale of investigation must be matched to the resolution of the aerial photos. The poor quality aerial photos that were available for the Waikakahi catchment did not allow the survey to be undertaken at the level of precision that was required. Every fine-scale in-stream observation had to be converted to an average percentage cover of each 20 m sub-reach during processing of the data. Nevertheless, in catchments where higher resolution photos are available there is potential to obtain spatially accurate 2-dimensional measurements of in-stream habitat features. The Waikakahi Stream was chosen for this trial, despite the lack of high quality aerial photos, because it is a BPDC with a previous history of intensive scientific investigation. In addition, the catchment has an active community group genuinely interested in the protection and enhancement of the stream.

The information was collected and transcribed directly onto hard copy aerial photos in the field. The issue with this method is the lengthy time required to digitise the survey information at a later date (*e.g.* it is likely to take approximately 3-5 working days to enter the complete riparian survey data set into Arcmap GIS). If data were recorded directly into technology (capable of running ArcPad mobile data collection software) in the field, then this data-processing time/cost would be considerably minimised.

4.4. Performance of the adult trout habitat quality index (THQI)

Visual estimates of habitat features vary between observers which is a problem for most rapid habitat assessments (Bauer & Ralph 2001). However, there was little variation in the THQI scores between three survey teams for the same 100 m reach.

We acknowledge that the data for comparing inter-observer variation were limited (five sub-reaches assessed by three survey teams). The low sample size means detecting a significant difference between the assessments of the three survey teams is unlikely, unless differences were large. Nevertheless, the results are promising. The apparent low variation in THQI scores between survey teams suggests that the BTHMP will deliver consistent assessments of habitat quality even when undertaken by different survey teams (and probably individuals). The one qualifier is that survey staff are experienced in-stream research or management and preferably receive some training in use of the protocol. Training involves only a few hours of reading, instruction and field demonstration.

The expert assessors held similar opinions about what constitutes good or poor adult trout habitat in the Waikakahi Stream (Figure 5). Furthermore, the scores given by the expert assessments were similar to the THQI scores for the same reaches throughout the stream (Figures 2 and 3). This suggests that the expert assessors were keying into the same features as the index (*i.e.* depth, sediment quality and cover) when assessing habitat. This result also supports the suitability weightings given to the various in-stream features in the THQI (*i.e.* they were appropriate for the Waiakahi Stream).

The THQI scores appear less variable between survey teams than the expert habitat assessments. This justifies the more quantitative approach of combining estimates/measurements of separate habitat features into an index-based assessment (*i.e.* it forces observers to make more consistent assessments of habitat quality). Furthermore, the THQI scores were correlated with expert assessments of trout habitat quality. This indicates that any field team with some training in the BTHMP, irrespective of their experience with salmonid ecology, can use the BTHMP and the THQI to assess the quality of adult trout habitat as competently as an expert.

Further refinement of the BTHMP could be achieved by including a water velocity component in the index. This could involve developing a river-specific set of mean water velocities for the various meso-habitat categories listed in the BTHMP. Once these relationships are established for a stream, meso-habitat type could be used as a proxy for water velocity. The percentages of meso-habitats in a 20 m sub-reach could be multiplied by a meso-habitat weighting factor based on velocity suitability curves from the literature (*e.g.* Raleigh *et al.* 1986). The meso-habitat/water velocity suitability score could then be included as a category type in the THQI calculations. For the present survey this was not possible as accurate water velocity measurements were not taken. However, inclusion of a water velocity component in the THQI calculations for the Waikakahi Stream would not influence the scores appreciably because water velocities, wherever depth was sufficient, were suitable for adult trout throughout the stream.

Substrate embeddedness is another potentially important habitat attribute that is not included in the BTHMP. Clapcott *et al.* (2011) suggests that the United States Environmental Protection Agency's (USEPA) visual embeddedness assessment method is the most appropriate for New Zealand streams. Alternatively, 'the shuffle index' would also indicate the degree of substrate embeddedness. This method involves disturbing the stream-bed with your feet for 10 seconds and visually gauging the suspended sediment plume that is generated (Clapcott *et al.* 2011). An embeddedness assessment was omitted from the BTHMP to reduce the time required to complete a reach. An increase in the complexity of the BTHMP procedures reduces the survey's potential spatial coverage of a stream.

We consider that the sediment particle size and fine sediment cover information collected from the Waikakahi Stream adequately assesses the quality of stream substrate in relation to free-swimming trout life-history stages. However, to improve the survey's potential for assessing trout spawning habitat, the BTHMP could be altered to include a shuffle test at potential spawning areas such as those depicted in Figure 9 (*i.e.* at pool tail-outs and riffle crests). A shuffle test will also indicate how armoured or impacted the stream-bed is, factors that can also limit the suitability of spawning gravels.

4.5. Potential for using the adult trout habitat quality index (THQI) as a diagnostic tool for stream restoration

The index results suggest that Segments 6 and 9 had some of the poorest habitat quality in the Waikakahi Stream. Excessive fine sediment and shallow water relative to the stream average were the reasons for the low THQI scores. Segments 6 and 9 (across the three 100 m reaches) had average fine sediment covers of 63 % and 36 %, respectively, compared to the catchment average of 23 %.

The riparian survey of Segments 6 and 9 reported areas where the riparian strip was ≤ 1 m wide, 'bad' stock pugging, unfenced laneways, areas of partially grazed riparian zone and stock inside the riparian zone. Stock damage to the stream banks (evident in Figure 10) may be causing excess sedimentation leading to infilling and widening of the channel reducing the potential of Segments 6 and 9 to support trout.

Figure 10. Areas of stock pugging next to the stream at Segment 6. This segment had the highest average fine sediment cover of any survey segment.

The highest index scores occurred in the mid to lower segments (Figure 3 and 6, Appendix 6). An informal analysis of the riparian data suggests that riparian management practices in the lower catchment are of a higher standard than those at Segments 6 and 9 (in the upper catchment). For example, Segment 12 had a relatively wide riparian buffer strip, generally in excess of 3 m, with established riparian vegetation providing stable stream banks (Figure 11). Furthermore, no potential sources of contaminants (fine sediment or nutrients) were noted in the Segment 12 riparian survey.

At Segment 13 the riparian strips were predominantly 2-5 m wide. In addition, there were few incidences of bank slumping (19 m in total) and no incidences of stock pugging. Segments 12 and 13 both contained 100 m reaches with the highest THQI scores recorded in the entire survey (Appendix 6). Segment 12(b) did receive a 'red' score for one of the 100 m reaches (Figure 6). However, a breakdown of the index score for this sub-reach showed that it was a fast run that was too shallow to support adult trout. The survey results suggest that improving the riparian fences in the upper catchment would probably be the most cost effective mitigation action in the Waikakahi Stream to further improve stream habitat quality.

Figure 11. The riparian zone of Segment 12. This riparian area was in excess of 3 m wide on both banks with established vegetation and had no evidence of recent stock activity.

5. SCOPE FOR FURTHER WORK

Demonstrating linkages between farming practices and environmental effects is considered by Dairy NZ's environmental policy managers to be the best outcome of all the research that has been undertaken on the BPDCs (Scarsbrook 2011). Farmers need clear 'cause and effect' relationships on the environmental outcomes of mitigation measures. Once these relationships are established, the economics of implementing mitigation measures (such as improved fencing) can be balanced against the level of environmental impact that is acceptable to the wider community. Linkages between implementing BMPs and improved water quality have been demonstrated in all of the BPDCs (Wilcock *et al.* 1999; Wilcock *et al.* 2006; Monaghan *et al.* 2007; Monaghan *et al.* 2009). However, evidence of BMPs leading to improved physical stream habitat quality in the BPDCs is largely based on inference from water quality data or anecdotal reports. The riparian and in-stream data set collected as part of this survey in combination with the THQI shows promise as a means of linking on-farm practices that affect riparian condition with in-stream habitat quality.

Trout have been identified through community workshops as a key value of the Waikakahi catchment (Monaghan *et al.* 2007). In part, this is why the BTHMP and THQI were tested in this stream. However, the survey data could be interpreted to assess the quality of stream habitat in relation to other stream values. For instance, an eel habitat index could be created using the same method as THQI by altering the suitability weightings according to eel habitat preferences (*i.e.* more weight placed on cover and less weight placed on depth).

The development of the BTHMP and THQI was part of the NIWA-led Aquatic Rehabilitation Programme (ARP). One of the ARP aims is to provide research-based tools that help communities achieve tangible restoration outcomes. To this end, we intend to present the results of the Waikakahi survey to the farmers of the catchment together with the most cost efficient mitigation actions identified by the survey (*i.e.* improved fencing in the upper catchment).

Fish & Game NZ support is vital to the success of this project. We will continue to correspond with Fish & Game Councils regarding the development of the BTHMP and THQI. It is intended that these tools will assist Fish & Game Councils in identifying management priorities to maintain or enhance freshwater fishery values in pasture streams.

Future steps for the BTHMP and THQI as part of the ARP could include:

- Investigating apparent links between on-farm riparian condition and physical in-stream habitat quality by comparing the Waikakahi THQI results with the riparian survey data.

- Using the Waikakahi in-stream survey data to create habitat quality indices for other key trout life-history stages (spawning/egg incubation, trout-fry and juvenile trout). These indices combined with the adult trout THQI will generate a picture of the overall health of the Waikakahi fishery and provide a basis for a limiting factor analysis.
- Adding embeddedness and water velocity assessments to the BTHMP and developing a method to incorporate these habitat attributes into the THQI calculations.
- Trialling the BTHMP using (tablet style) field computers to collect field data.
- Applying the (improved) BTHMP to other streams in BPDCs or elsewhere.

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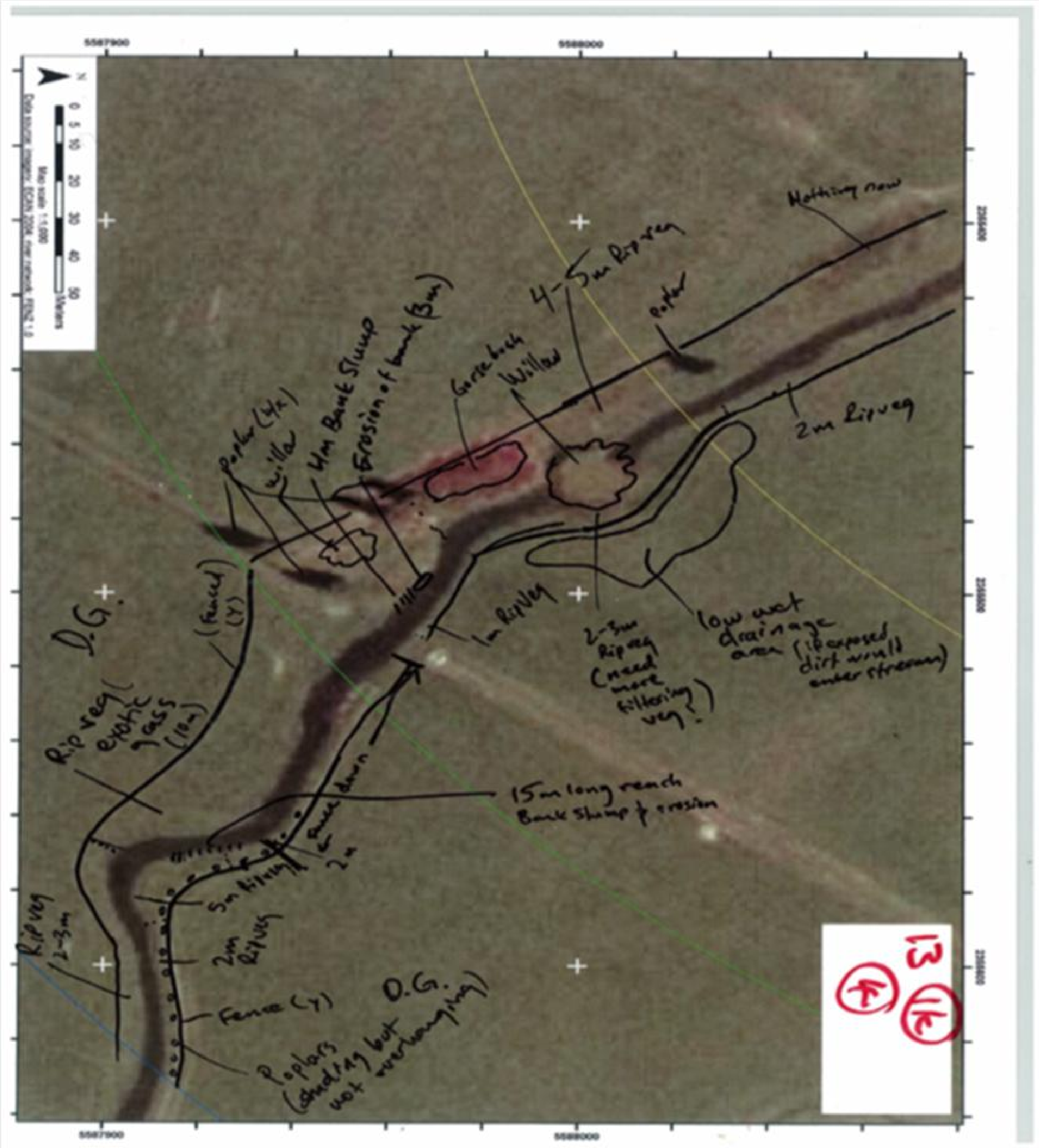
8. APPENDICES

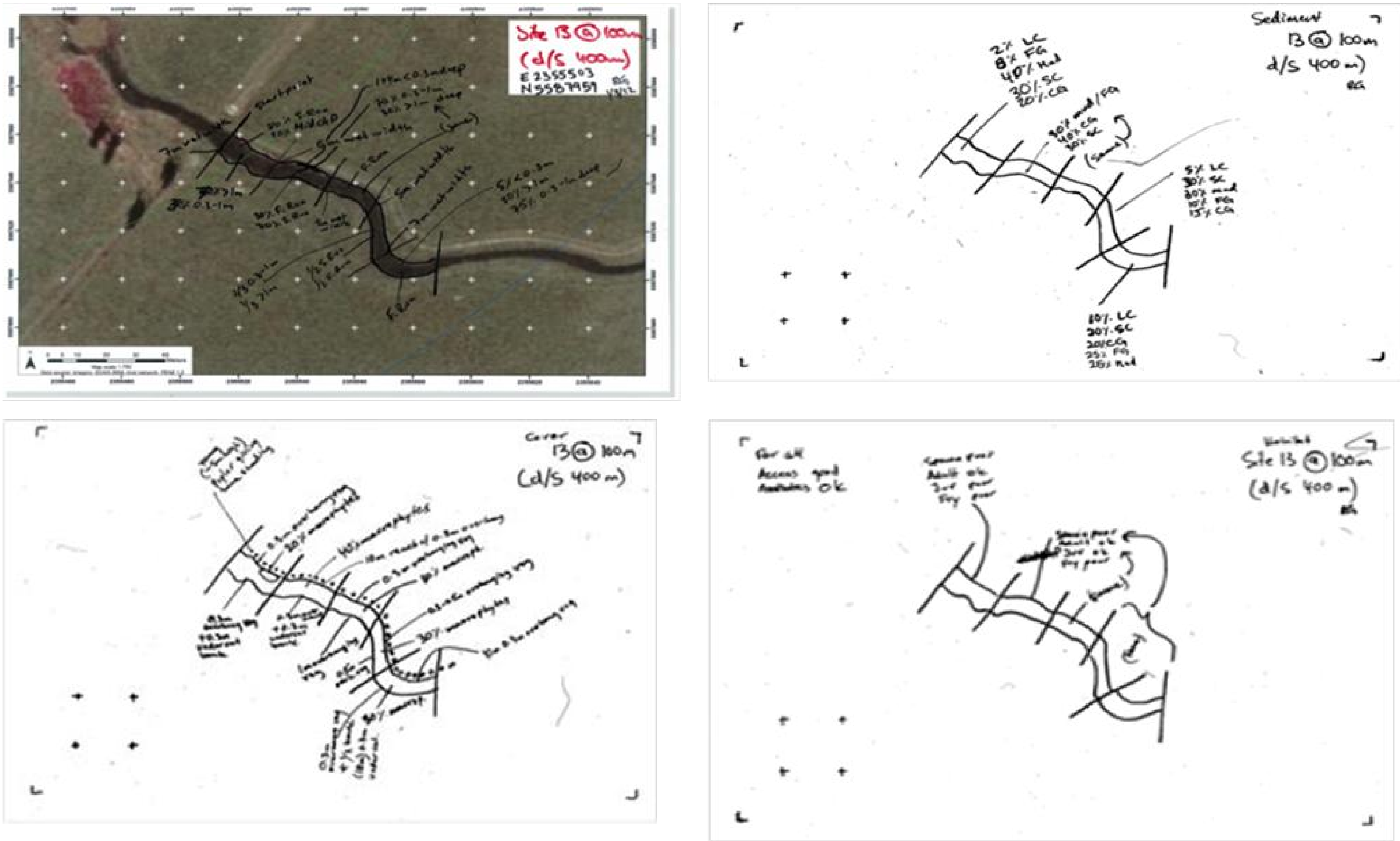
Appendix 1. An example of a riparian survey aerial photo map (one of the five photos used to map this segment).

Appendix 2. An example of a 100 m in-stream survey photo map.

Appendix 3. An example of a completed section of the riparian survey at Segment 13 (one of the five aerial photos used to survey this segment).



Appendix 4. An example of a completed survey for a 100 m in-stream habitat reach, showing the base aerial photo map and the acetate overlays: depth and meso-habitat types (top left), cover attributes (top right), substrate characteristics (bottom left) and the subjective expert assessment of trout habitat quality (bottom right).



Appendix 5. Suitability weights for the habitat attribute categories for the adult trout habitat quality index (THQI). Where possible, weights were derived from habitat suitability curves in the literature (see colour coding). Cover weights were derived by considering overseas literature.

Habitat type/category	Suitability weights
Depth (m)	
0-0.3	0
0.3-0.5	0.5
0.5-1	0.8
≥ 1	1

Source (colour coded)
Hayes & Jowett 1994
Raleigh *et al.* 1986
Bovee 1978
Authors opinion

Substrate	
Silt/mud/sand	0.01
Fine gravel	0.4
Course gravel	0.8
Small cobble	0.9
Course cobble	1
Boulder	1
Bedrock	1

Cover	
Over-hanging vegetation 0-0.3	0.1
Over-hanging vegetation 0-0.5	0.4
Over-hanging vegetation 0.5-1m	0.5
Over-hanging vegetation ≥ 1m	1
Under-cut bank 0-0.3	0.5
Under-cut bank 0.3-0.5	0.8
Large wood	1
Bedrock/boulders	1
Submerged branches	0.1
Manmade (bridges, riprap *etc.*	1
Submerged aquatic macrophytes	0.5

Meso-habitat type	
riffle	0
fast run	n/a
slow run	n/a
run	n/a
pool	n/a
backwater pool	n/a

Appendix 6. Average adult trout habitat quality index (THQI) and expert assessment scores for each 100 m reach in the survey. Stream segments are listed in order from upstream to downstream down the table.

Reaches	Adult THQI scores	Expert assessment scores for adult trout habitat
6a	0.2	0.2
6b	0.4	0.1
6c	0.3	0.1
9b	0.3	0.2
9c	0.2	0.1
9a	0.2	0.1
5c	0.5	0.2
5a*	0.2	0.1
5b	0.4	0.1
2a*	0.0	0.1
2b*	0.0	0.1
2c*	0.0	0.1
13c	0.6	0.3
13b	0.5	0.2
13a	0.5	0.2
1a5	0.4	0.2
1b5	0.4	0.2
1c5	0.4	0.1
16a	0.5	0.2
16c	0.5	0.1
16b	0.5	0.3
16b.5#	0.4	0.2
12a*	0.2	0.2
12b	0.6	0.3
24a	0.5	0.3
24b	0.3	0.2
24c	0.3	0.2

* Denotes reaches that were naturally too shallow to support trout.
# Denotes a side channel that was included as a separate survey reach.