Remote sensing of freshwater Environments: Trial application on the Lower Waikato River

CBER Contract Report 103

A report prepared for
Environment Waikato

by

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List of Abbreviations:

ALOS	Advance Land Observing Satellite
AP	Aerial Photograph
AVNIR-2	Advanced Visible and Near Infra-red Radiometer type 2
CBER	Centre for Biodiversity and Ecology Research
EW	Environment Waikato
GPS	Global Positioning System
HRG	High Resolution Geographic
IHS	Intensity Hue Saturation
LUCAS	Land Use Carbon Analysis System
PAN	Panchromatic
PCA	Principal Component Analysis
PRISM	Panchromatic Remote Sensing Instrument for Stereo Mapping
QB	QuickBird
SAV	Submerged Aquatic Vegetation
TM	Thematic Mapper
UoW	The University of Waikato
VHSR	Very High Spatial Resolution
WRAPS	Waikato Region Aerial Photograph Syndicate

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1. Introduction

High quality remote sensing data is the optimal tool for mapping and monitoring the physicochemical characteristics and ecological condition of areas inundated by freshwater, such as littoral, riparian and floodplain zones. Such habitats are often difficult to work in and inaccessible in their inner reaches. Recent developments in the field of remotely sensed data acquisition result in many different types of available data, but both data processing and spatial resolution may be inadequate for regional or site-specific management decision making. Improved information, and the ability to monitor more detailed changes in vegetation structure and composition, facilitates its monitoring. This is especially relevant as we expect to see shifts in species composition in response to environmental changes induced by climate change.

Environment Waikato wishes to explore the feasibility of mapping the ecological condition along the margins of the large water bodies (lakes and large rivers) using remote sensing. Given the range of remote sensing sensors (from high spatial resolution to hyper-spectral) and techniques currently available (like soft and sub-pixel classifications), the prime interest of this research is to evaluate remote sensing as a cost and time effective tool to map aquatic environments. It is also important to determine the optimum spatial and spectral resolution of remotely sensed data, its accuracy and the repeatability of measurements at different scales that are achievable by the different processing techniques.

1.1. Purpose of the study

The overall goal of this study is to evaluate multi-sensor and multi-spectral satellite data to characterise different freshwater habitat zones of large rivers and lakes of the Waikato region. The earlier evaluation of different sources of remotely sensed data (see Ashraf et al., 2007) suggested the implementation of sub-pixel classification on the QuickBird satellite image of Tongariro River delta region (see Ashraf et al., 2008). The current research is further expanding the same research on other freshwater environments within the Waikato region. This research is directed towards achieving the following objectives;

1. Test subpixel classification and subtractive resolution merge techniques on selected lakes and parts of the lower Waikato River, in particular around whitebait spawning sites to map different habitat types and quantify accuracy of the classification.
2. Acquire in-situ reflectance data of the predominant or important aquatic plant species, including species suitable for whitebait spawning, to enable interpretation of the classification.
3. Conduct detailed field-based plant species map of contrasting lake (e.g., peat and riverine) and riverine (e.g. delta, main channel) environments on the lower Waikato, and relate these to classification accuracy.

1.2. Study area

To achieve the above objectives, the lower Waikato River (Figure 1) and a stretch within Hamilton city were explored where multi-source remotely sensed data (either from SPOT-5, QuickBird-2 satellites, scanned aerial photographs or digital aerial images) are available from different projects and agencies such as LUCAS, KiwImage, WRAPS and Aerial Mapping NZ Ltd.

The lower Waikato is exposed to a range of domestic, agricultural and industrial influences that can affect water quality and plant growth in the river. The depth of the river varies, but is generally around 5-6m; it is subject to tidal fluctuations of up to 15cm at Tuakau Bridge (i.e. 27km upstream from the Port Waikato town and 10cm at Mercer (i.e. 12km further upstream from Tuakau bridge) during high tides and low flows (Cromarty & Scott, 1996).

The climate of the Waikato is generally one of warm humid summers, mild winters and moderate rainfall with a peak in winter. The mean annual temperature is about 12.5°C, with mean monthly temperatures varying by about 10°C. The average annual rainfall is about 1,200-1,600mm.

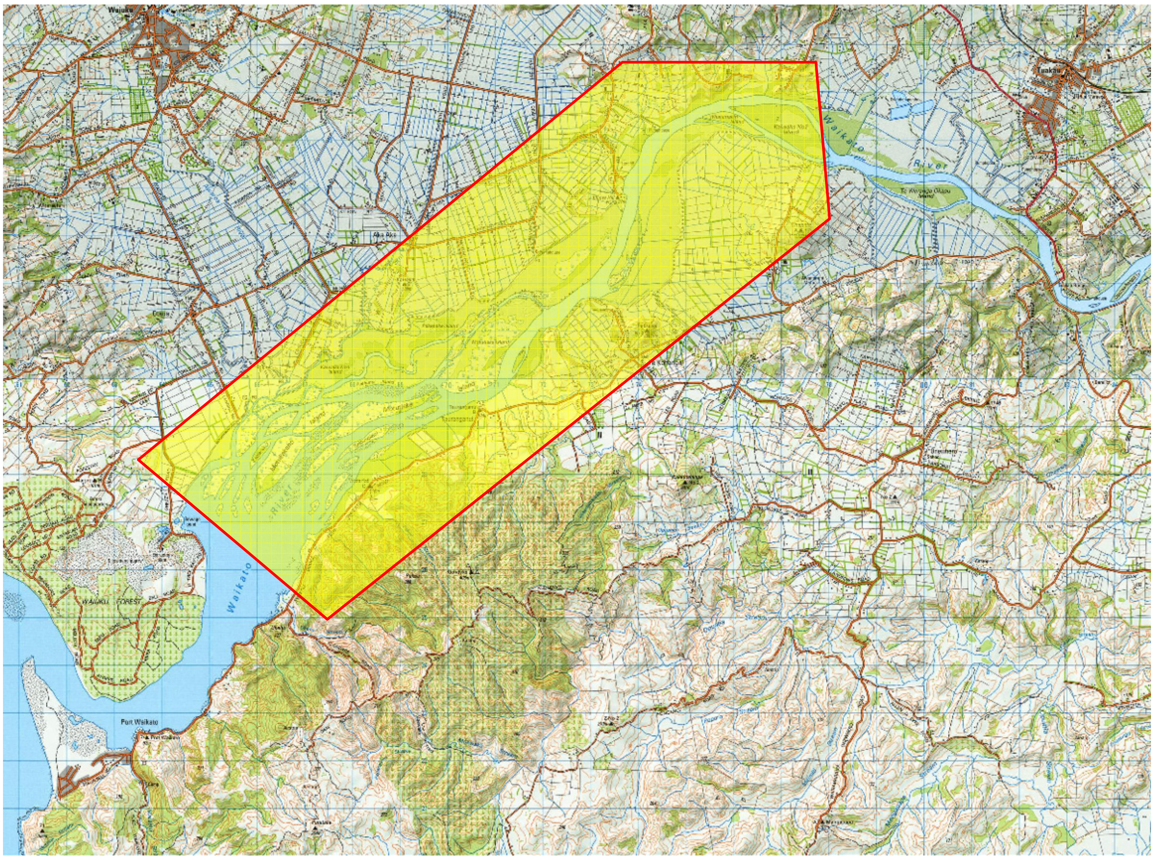


Figure 1: The location of study area (lower Waikato River delta) is shown as the yellow highlighted zone with a red outline)

The soils in this area are primarily brown granular loams and clays, gley (a hydric soil which exhibits a greenish-blue-grey colour due to wetland conditions) and yellow brown earths. Its delta provides a rich habitat for a range of species and contains a number of islands, some of which are vegetated with native kahikatea *Dacrycarpus dacrydioides* and totara (*Podocarpus totara*). Large areas of natural wetland communities occur on the islands in the delta, including New Zealand flax (*Phormium tenax*), raupo (*Typha orientalis*), rushes (*Juncus* spp.), sedges (*Carex* spp.) and submerged plants. The islands also sustain extensive stands of lake club-rush (*Schoenoplectus tabernaemontani*) and marsh club-rush (*Bolboschoenus fluviatilis*), both species that can tolerate some brackish water. Other riparian species include alder (*Alnus glutinosa*), crack willow (*Salix fragilis*), pampas (*Cortaderia selloana*), reed sweet-grass (*Glyceria maxima)* and mingimingi

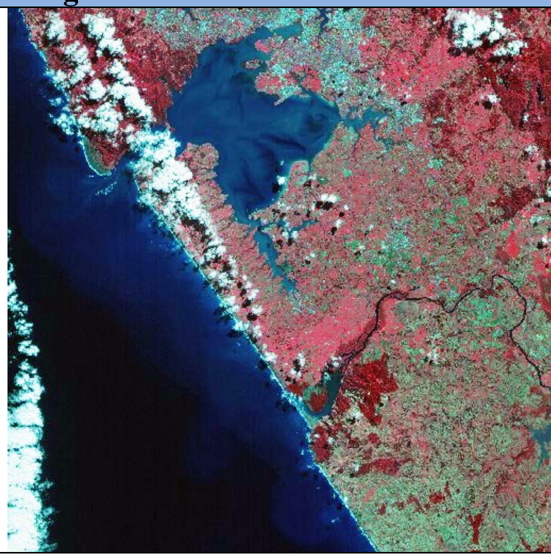
(*Coprosma propinqua*). On the more stable dunes, the native sand-binding plant pingao (*Desmoschoenus spiralis*) is present, along with silvery sand-grass (*Spinifex sericeus*) and marram grass (*Ammophila arenaria*). Cattle grazing occur in places down to the water's edge, causing damage to marginal vegetation (Cromarty & Scott, 1996; Graeme, 2005).

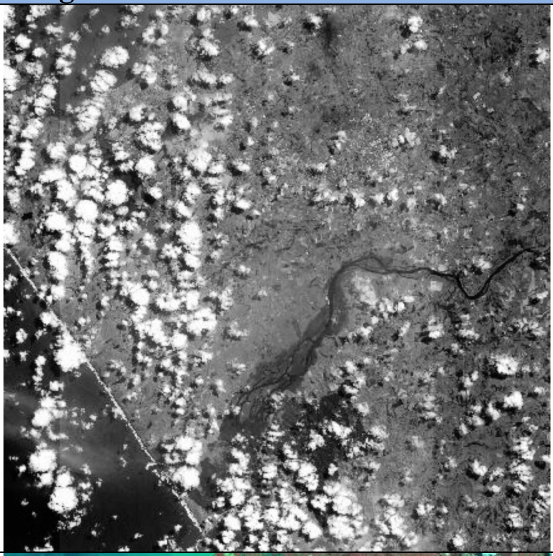
The other site whose aquatic vegetation was assessed using remotely sensed data is Hamilton Lake and the Waikato River within Hamilton city. Most significant vegetation types at the shallow margins of this lake are bottom-rooted emergent plants. These include lake club-rush (*Schoenoplectus tabernaemontani*) and yellow flag reedland (*Iris pseudacorus*) (Johnson and Gerbeaux, 2004).

1.3. Remotely sensed data and processing software

Currently there are many remote sensing (RS) satellites operational which are capable of acquiring optical RS data (mainly in the visible to near infrared part of the electromagnetic spectrum) with varied ranges of spatial, spectral, radiometric and temporal resolutions. However, the availability of preferred data with excellent quality parameters (such as cloud/haze free images captured at high solar elevation and near-nadir satellites' viewing angles) remain low. Three satellites, viz. SPOT-5, ALOS and QuickBird-2, were searched for their archive. Following is the summary of data search. ERDAS Imagine Professional version 9.3 with its sub-pixel classifier module is used for the data processing (Tables 1 and 2).

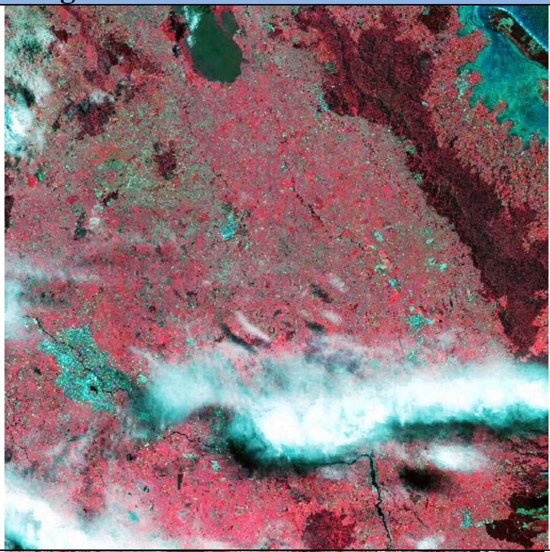
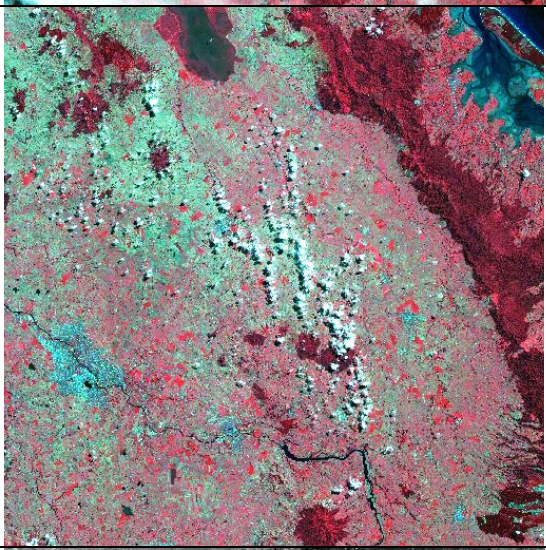
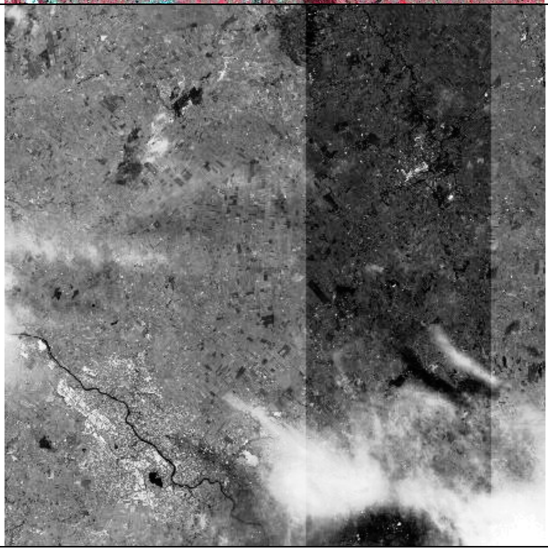
Table 1: Review of available remotely sensed data for the lower Waikato region

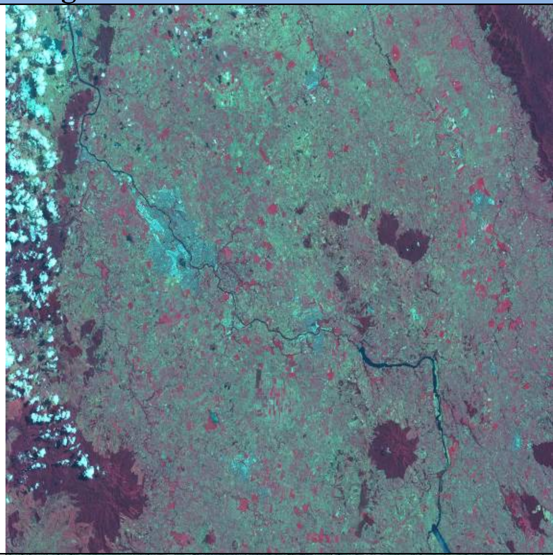
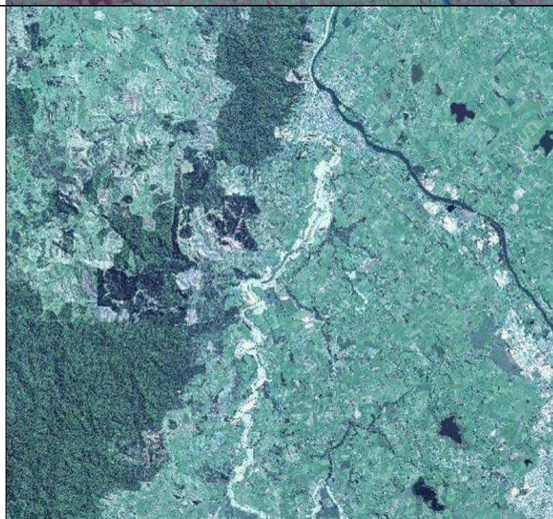
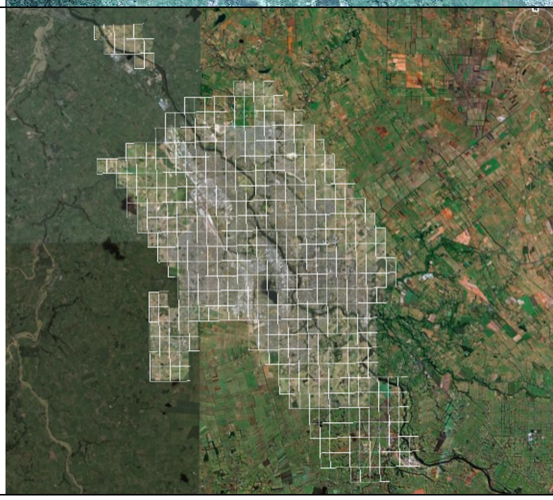
Sensor/Image Details	Image Preview
Satellite: ALOS Sensor: AVNIR-2 Acquisition Date: 10-03-2008 Acquisition Time: 10:24 Spatial Res: 10m Spectral Res: B, G, R, NIR Viewing Angle: 0° Data Quality: Cloud cover over Waikato delta. Its panchromatic image is not captured simultaneously.	

Sensor/Image Details	Image Preview
Satellite: ALOS Sensor: PRISM Acquisition Date: 26-01-2009 Acquisition Time: 10:26 Spatial Res: 2.5m Spectral res: PAN Viewing Angle: 1.2° Data Quality: Cloud cover over Waikato delta. No simultaneous multispectral data acquisition.	
Satellite: SPOT-5 Sensor: HRG Acquisition Date: 04-01-2007 Acquisition Time: 10:26 Spatial Res: 10m Spectral res: G, R, NIR, MIR Viewing Angle: 8.1° Data Quality: Slightly high tide image, missing simultaneously acquired 2.5m res PAN band.	
Satellite: QuickBird-2 Sensor: Multispectral Acquisition Date: 01-04-2009 Spatial Res: 0.6m, 2.4m Spectral res: PAN, B, G, R, NIR Viewing Angle: 14° Data Quality: Lowest tide, late summer image but high incidence angle.	

Sensor/Image Details	Image Preview
Satellite: QuickBird-2 Sensor: Multispectral Acquisition Date: 25-06-2007 Spatial Res: 0.6m, 2.4m Spectral res: PAN, B, G, R, NIR Viewing Angle: 10° Data Quality: High tide, late autumn/winter season but low incidence angle.	
Satellite: QuickBird-2 Sensor: Multispectral Acquisition Date: 18-04-2004 Spatial Res: 0.6m, 2.4m Spectral res: PAN, B, G, R, NIR Viewing Angle: 12° Data Quality: Low tide, late summer season, old archive.	
Source: WRAPS Scanned Aerial Photo Camera: Large format photographic plate Acquisition Season: Summer 2007/08 Spatial Res: 0.6m Spectral res: B, G, R Viewing Angle: 0° Data Quality: Low tide, low image contrast, poor spectral resolution, summer season, high solar elevation.	

Table 2: Review of available remotely sensed data for the Hamilton city region

Sensor/Image Details	Image Preview
Satellite: ALOS Sensor: AVNIR-2 Acquisition Date: 23-12-2008 Acquisition Time: 10:22 Spatial Res: 10m Spectral Res: B, G, R, NIR Viewing Angle: 0° Data Quality: Cloud cover over south Hamilton, high solar elevation.	
Satellite: ALOS Sensor: AVNIR-2 Acquisition Date: 07-02-2009 Acquisition Time: 10:22 Spatial Res: 10m Spectral Res: B, G, R, NIR Viewing Angle: 0° Data Quality: Good solar elevation.	
Satellite: ALOS Sensor: PRISM Acquisition Date: 23-12-2008 Acquisition Time: 10:22 Spatial Res: 2.5m Spectral res: PAN Viewing Angle: -1.2° Data Quality: Cloud cover over south Hamilton, high solar elevation.	

Sensor/Image Details	Image Preview
Satellite: SPOT-5 Sensor: HRG Acquisition Date: 18-01-2008 Acquisition Time: 10:33 Spatial Res: 10m Spectral res: G, R, NIR, MIR Viewing Angle: 30.1° Data Quality: Missing simultaneously acquired 2.5m res PAN band, very high incidence angle.	
Satellite: QuickBird-2 Sensor: Multispectral Acquisition Date: 04-03-2004 Spatial Res: 0.6m, 2.4m Spectral res: PAN, B, G, R, NIR Viewing Angle: 15° Data Quality: Covering northern Hamilton city, high river flow as well as incidence angle.	
Source: NZ Aerial Mapping Ltd Camera: Digital UltraCam X Acquisition Season: Jan 2008 Spatial Res: 0.125m, 0.285m Spectral res: PAN, B, G, R, NIR Viewing Angle: 0° Data Quality: Very high spatial resolution, good spectral resolution, summer season, high solar elevation	

A recently launched cluster of five similar Earth Observation satellites (RapidEye1-5) was also considered and the archive data queried for Waikato region images. They have no archive data for the Waikato region for the time being whereas their online data search system is not fully developed. The low cost images of ALOS satellite (2.5m resolution) for Hamilton city can be evaluated to study submerged aquatic vegetation (SAV) however; its available coverage for the lower Waikato River has a disadvantage of either missing panchromatic or multispectral data at the time of data acquisition. Alternatively, a recently acquired QuickBird-2 image of the lower Waikato River is an excellent data source captured at very low tide. Availability of QB data through KiwImage initiative was also queried. KiwImage is in process of completing maps in the immediate north of the Waikato River delta so it is plausible that the latest acquired image on April 01, 2009 will be available free of cost through KiwImage.

In terms of aerial based RS data, WRAPS 2007/08 scanned imagery of the Port Waikato region shows poor contrast and TerraLink Ltd is in the process of its reacquisition. In contrast, very high resolution (12.5cm) multispectral images of the Waikato River within Hamilton city offer visually explicit details of SAV along the river bank. Its acquisition for the entire Waikato region is highly unlikely; however it can be used as a reference image to gauge the classification accuracy from medium to high resolution satellite images such as ALOS, SPOT and QB whose images are available for different parts of Hamilton city. New Zealand Aerial Mapping Ltd. has been asked to provide few scenes for further investigation.

2. Methodology & Results

The current study focuses on three main aspects of aquatic vegetation mapping using remotely sensed data. Of particular significance are i) investigation of a subtractive resolution merging technique, ii) collection of the *in-situ* reflectance signatures of different aquatic vegetation types, and iii) application of classification techniques such as supervised and subpixel classifier on the available data.

All these aspects are performed with some initial investigation about the technique and the progress so far has been discussed below.

2.1. Subtractive Resolution Merge Technique

Image fusion is one of the most promising issues in the remote sensing with the sole object in mind to enhance its interpretability. It combines low resolution multispectral and high-resolution panchromatic images using different algorithms. The well-known techniques are, for example, transformation based fusion, arithmetic combination based fusion, and wavelet based fusion. Among these fusion techniques, transformation based fusion, such as, the IHS (Intensity, Hue, Saturation) and PCA (Principal Component Analysis) techniques have become the most popular. Other significant techniques include different arithmetic operations of multiplication, division, addition and subtraction or their combination in different ways to achieve a better fusion effect (Jing and Cheng, 2009). Brovey transformation, synthetic variable ratio (SVR) and ratio enhancement (RE) techniques are among successful arithmetic based fusion methods. Brovey transformation uses addition, division and multiplication for the fusion of multispectral bands. Its concept is described with the following equations;

$$Fused_i = \frac{Multi_i}{Multi_{Sum}} \times Pan$$

with i = band numbers whereas;

$$Multi_{Sum} = \sum_{i=1}^{n} \frac{Multi_i}{n}$$

and n = number of bands per image

It is a three step process; i) add all the multispectral bands together for a sum image, ii) divide each multispectral band by the sum image, iii) multiply each quotient by a high resolution panchromatic (Zhang, 2002). The SVR and RE techniques are similar but involve more sophisticated calculations for the sum image (Chavez et al., 1991; Welch and Ehlers, 1987; Siddiqui, 2003; Zhang, 1999). Arithmetic fusion techniques such as SVR function well in pure pixels of low resolution multispectral image, while the problem arises in mixed pixels. The extent of this problem depends upon the amount of mixed pixels and the nature of this mixture (i.e., which objects are present on that pixel and what are their reflectance characteristics) (Rahman and Csaplovics, 2007).

Subtractive Resolution Merge is a relatively new fusion method using arithmetic based fusion with no citation about its performance and its calculation method. The concept is similar to the HPF merge technique (see Ashraf et al., 2008) but it derives the high frequency component using a different method. Below is a rough outline of what the subtractive resolution merge is doing behind the scenes (personal communication, Zehner, 2009):

Step One: Derive the high frequency (HF) component from pan by subtracting a synthetic pan (synpan) image from a pan image. The synpan image is created from a normalised weighted sum of the MS image. Synpan is upsampled prior to the subtraction using a bilinear method followed by a 5x5 low pass filter. For the merge to work well, the synpan image needs to closely match the radiometric characteristics of the pan image. The pan image is sharpened using 3x3 sharpening filter.

Step Two: Add the high frequency information into the MS image. Scale the HF to each MS band based on a ratio. The ratio is the standard deviation (SD) of a MS Band divided by the SD of the degraded pan image.

The most significant segment of this fusion technique is its determination of weights for the sum of individual multispectral bands (Table 3). This model works only for the selected sensors such as QB, IKONOS and Formosat whose weights are mentioned below.

Table 3: Weights of individual bands of high resolution satellites for subtractive resolution merge

Weights	Quick Bird	IKONOS	FORMOSAT
Band 1	0.20	0.20	0.60
Band 2	0.70	0.70	0.80
Band 3	1.20	1.00	0.20
Band 4	1.40	1.60	1.50

Moreover, this technique accepts only RS data with pixel geometry of 1:4 for the panchromatic and multispectral bands. Other satellites, such as SPOT-5 and ALOS also follow the same 1:4 pixel geometry, cannot be used unless the weights of their multispectral data are not determined. Customisation of this fusion technique is under way in order to determine band weights for any multi-sensor data such as WRAPS colour aerial photo to be merged with SPOT-5 multispectral data. Figure 2 shows the method of calculating normalised weighted sum and band statistics before performing fusion.

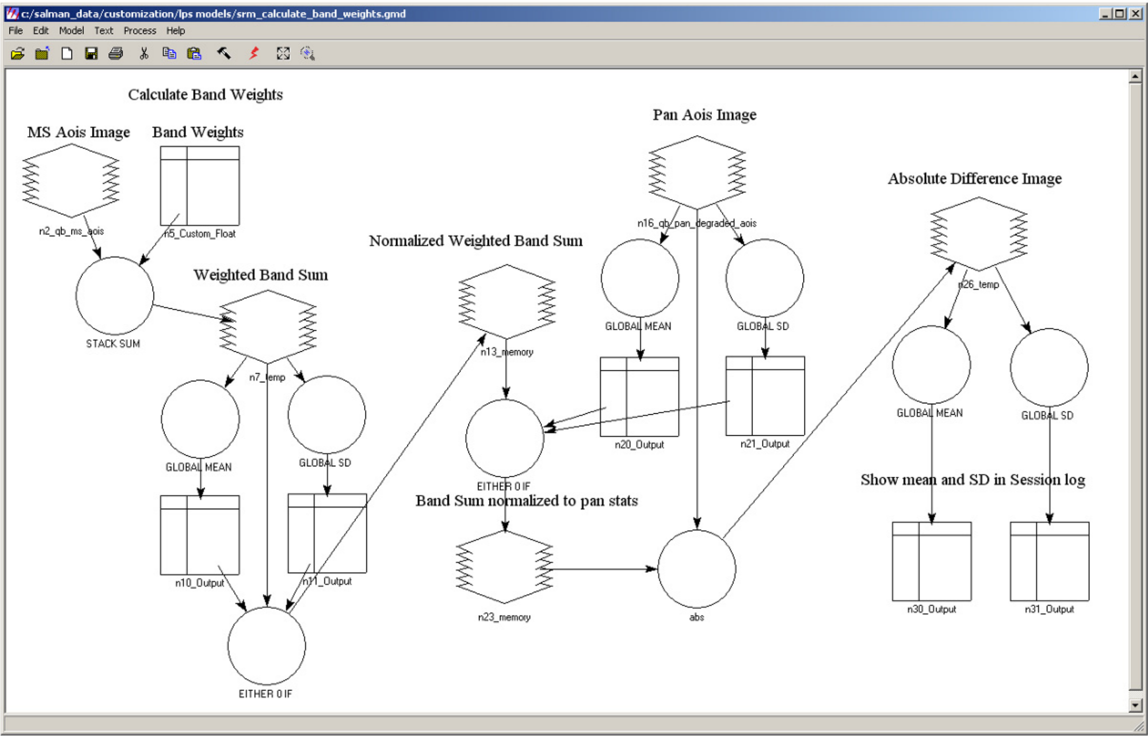


Figure 2: Model diagram to determine the normalised weighted sum of multispectral image

2.2. *Reflectance signature of aquatic vegetation*

Development of spectral libraries for wetland vegetation is a key component of wetland data collection efforts, and facilitates advanced techniques to monitor wetlands (Zomer et al., 2006). In keeping with this objective, a significant component of this contract is to acquire *in-situ* reflectance data of the predominant or important aquatic plant species in large rivers and lakes of the Waikato region to achieve higher accuracy towards satellite image classification. In order to do so, an Ocean-Optics USB2000 digital spectrometer was used to collect the irradiance/reflectance of different aquatic plant species.

2.2.1. Equipment calibration

Spectrometers are constantly experiencing changes in temperature and pressure; thus they undergo mechanical stress and optical decay which result in the gradual degradation of the designed critical performance parameters. Spectrometers thus require recalibration on a regular basis to ensure reliable and accurate results. Calibration is the comparison of its performance to a known standard of accuracy. For the USB2000 spectrometer, wavelength monitoring and recalibration requires the use of a reference light source that emits well-defined wavelengths. High purity gas or vapour lamps (such as HG-1 Mercury Argon light source) are the primary standards recommended for testing wavelength accuracy. For the wavelength recalibration, 50µm diameter fibre optics cable is suggested, however due to its non-availability, a 400µm diameter cable was used. The result of irradiance of lawn grass is shown in Figure 3 which clearly shows the shift of its peak from the blue to the green-yellow region in pre- and post-calibration formations.

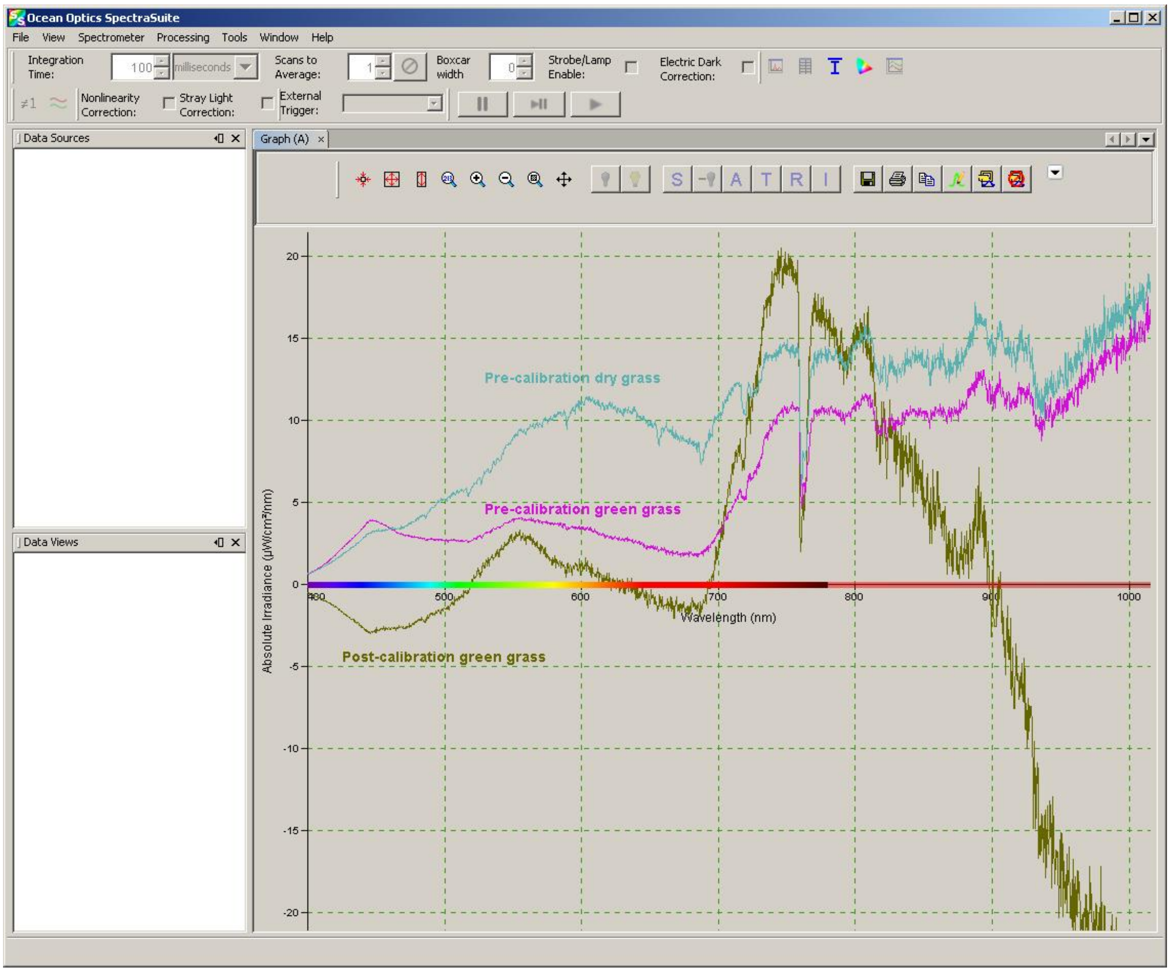


Figure 3: Irradiance curve of vegetation, before and after wavelength calibration

In order to calculate an absolute irradiance (irradiance is the amount of energy at each wavelength emitted from a radiant sample), radiometric calibration is needed each time the unit accessories are disengaged from each other, such as removal of the fibre optics cable from the spectrometer or detachment of the cosine corrector from the fibre line etc. During the new calibration for absolute irradiance, a calibration lamp (such as LS-1 CAL light source) with known spectral output (microwatts per square centimetre per nanometre) is required. A dark spectrum is achieved by simply blocking the light source of the fibre optics. A lamp calibration file thus updates the radiometric calibration file by incorporating the reference and dark spectra as well as the collection area parameters of the used fibre optics or a cosine corrector.

The image below represents the radiometric calibration curve of the cosine corrector (Figure 4). After the calibration, the reflectance curve of the light source at e.g. 600nm is 0.010840µW/cm^2/nm which matches with the provided lamp calibration data, i.e. 0.010826µW/cm^2/nm, clearly indicating its accuracy for absolute irradiance data capture.

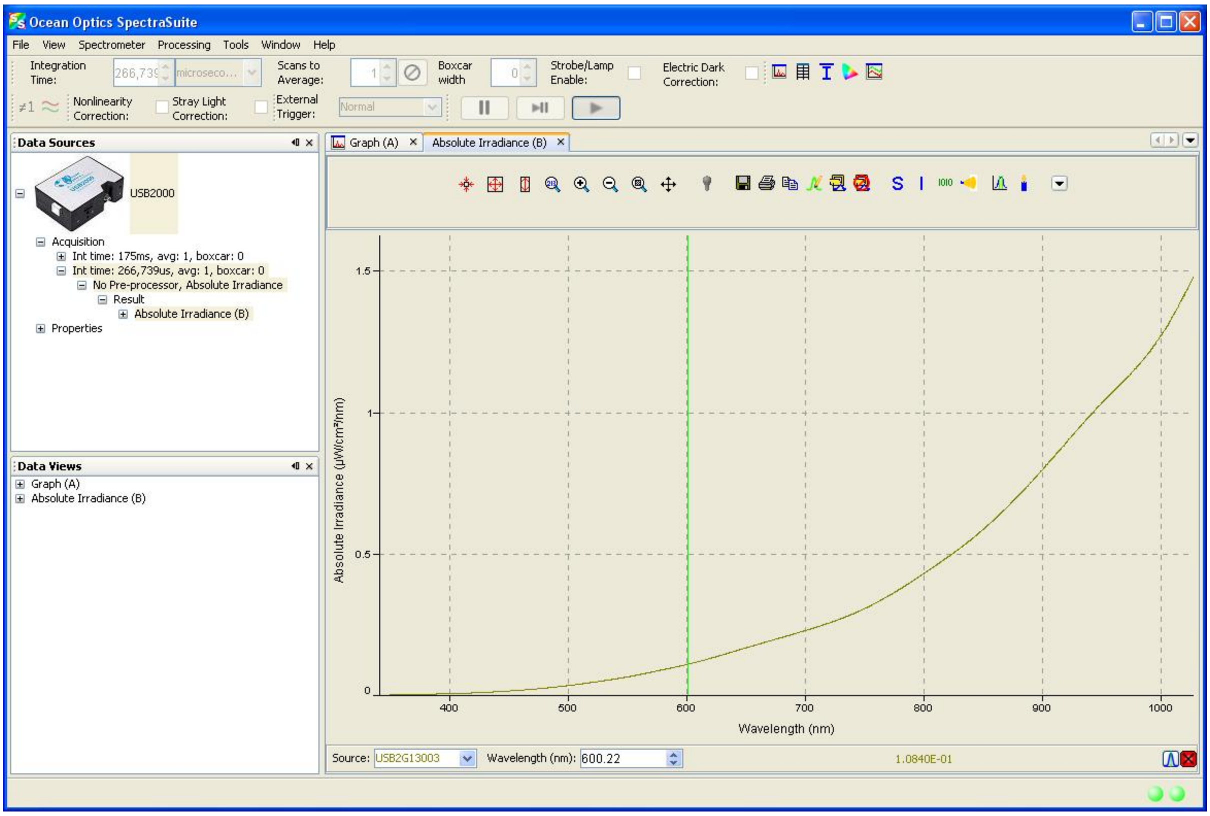


Figure 4: The calibration curve of the spectrometer

2.2.2. Reflectance data collection

In order to acquire reflectance signature of any given species or feature on the ground, its reflected energy is measured against a Lambertian or diffused (instead of specular) reflectance standard (an isotropic surface that exhibits an almost perfect reflectance in the visible to NIR range of incident energy). It is scattered such that the apparent brightness of the surface to an observer is the same regardless of the observer's angle of view. Its ratio is recorded as reflectance in percentage. Calculating an absolute irradiance is a more accurate method but may require very precise steps (such as maintaining similar distance from the object, and consistent solar illumination, time of capture and solar angle) to capture absolute irradiance which is not always possible to maintain in the field.

Most of the species signature data collection was performed in the irradiance mode due to the non-availability of reflectance standard. These curves for different species are shown in Figure 5 (see also Figure 6).

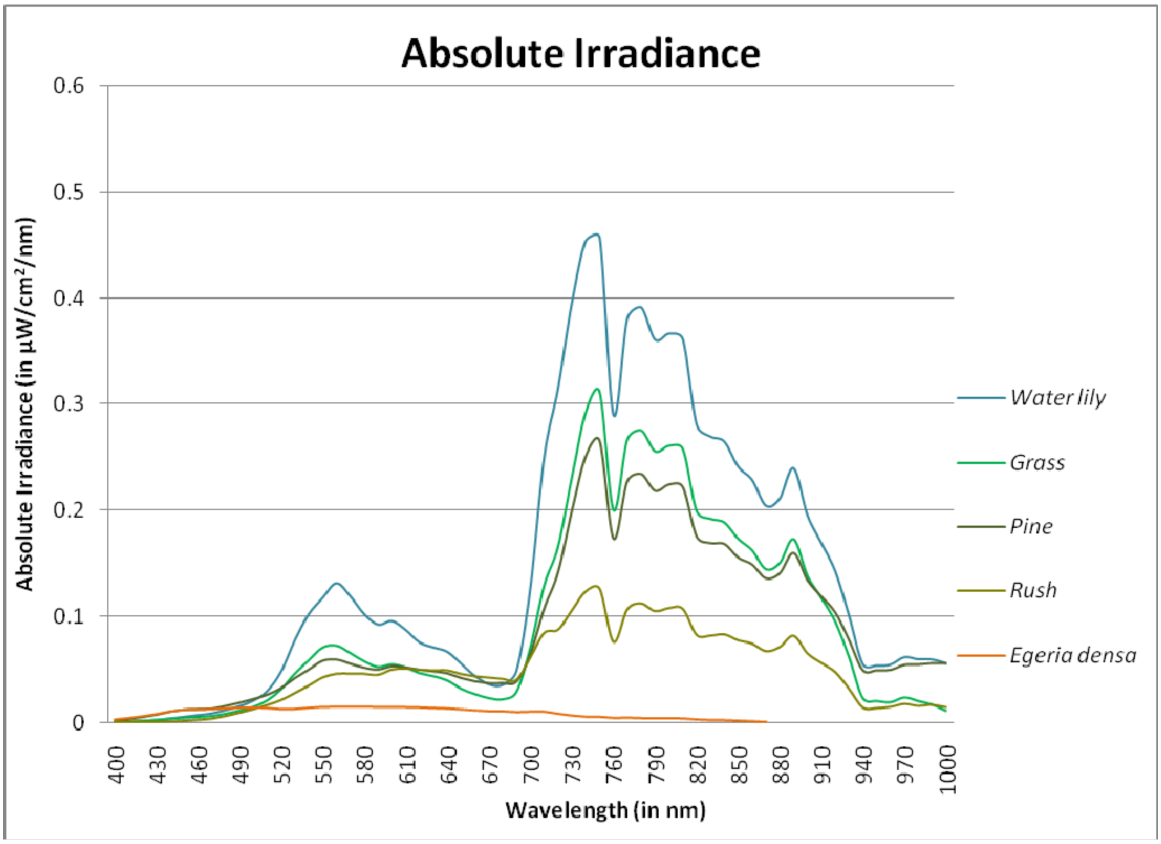


Figure 5: Absolute irradiance curve of different species

Figure 6: Images show different vegetation types whose irradiance data is captured

Alternative to absolute irradiance, most cited work records species reflectance in percentage units so it can be analysed with satellite images. To proceed with this method, a diffused reflectance standard tile (Barium Sulphate surface) was borrowed from AgResearch. Using this tile, reflectance curves of a leaf of Karamu (*Coprosma robusta*) shrub are generated. Its unprocessed reflectance curves are shown below which highlight its high reflection in the NIR zone.

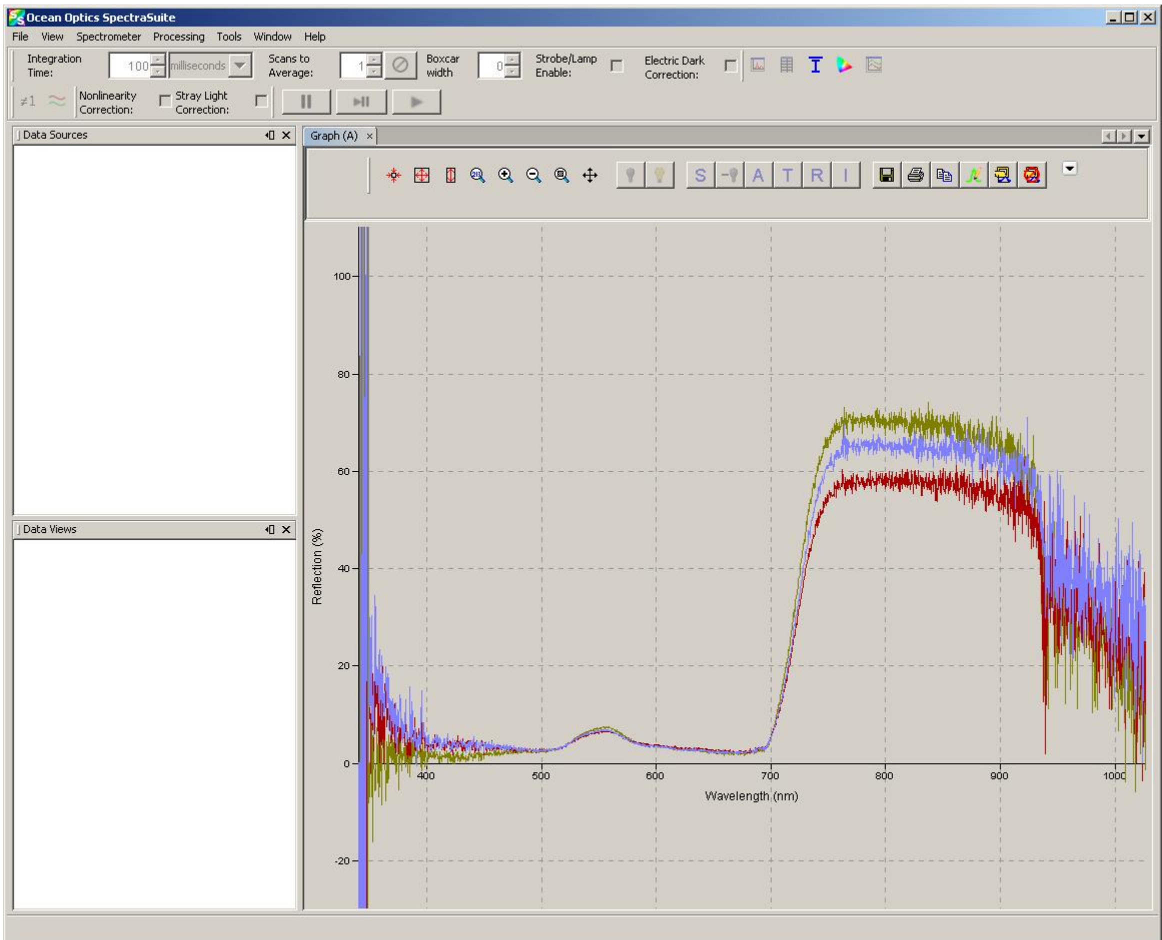


Figure7: Reflectance of curve of Karamu (*Coprosma robusta*) species

2.3. Classification of SPOT data

The most widely used method for extracting information on surface cover from remotely sensed data is image classification. With this technique, each image pixel is allocated exclusively to one of a small number of categories, producing image-containing thematic information.

The existing land-cover map (LCDB-2) (Figure 8) shows deciduous hardwoods (land-cover ID# 68) as the most dominant generalised vegetation type. Typically willow and poplar species growing adjacent to inland water and rivers belong to this category. This class also includes stands of planted exotic deciduous hardwoods, such as Oak (*Quercus spp*.), Ash (*Fraxinus spp*.) and Elm (*Ulmus spp*.) species. In actual, there is high variability within these broadly delineated polygons and the resulting thematic map from the classification of SPOT data is used to estimate different vegetation types within this generalised class.

Figure 8: Display of LCDB polygons against WRAPS2007 aerial photographed

2.3.1. Unsupervised classification

The unsupervised classification process uses "Iterative Self-Organizing Data Analysis Technique Algorithm" (ISODATA) which repeatedly performs an entire classification (outputting a thematic raster layer) and recalculates statistics. "Self-Organizing" refers to the way in which it locates the clusters that are inherent in the data. The ISODATA clustering method uses the minimum spectral distance formula to form clusters. It begins with either arbitrary cluster means or means of an existing signature set, and each time the clustering repeats, the means of these clusters are shifted. The new cluster means are used for the next iteration.

SPOT-5 10m multispectral data were used for the physiognomic level classes. The resultant image was classified into 50 clusters which were visually compared with WRAPS aerial photographs and were re-coded into 8 different thematic types.

2.3.2. Supervised classification

Maximum likelihood classification (MLC) is the most common supervised classification method which classifies the pixels in an image to one of the cover types or classes. It is achieved through training the sample data. Knowledge of the data, and of the classes desired, is required before classification. The supervised classification process was performed without any field investigation, and thus its results are preliminary and require improvement.

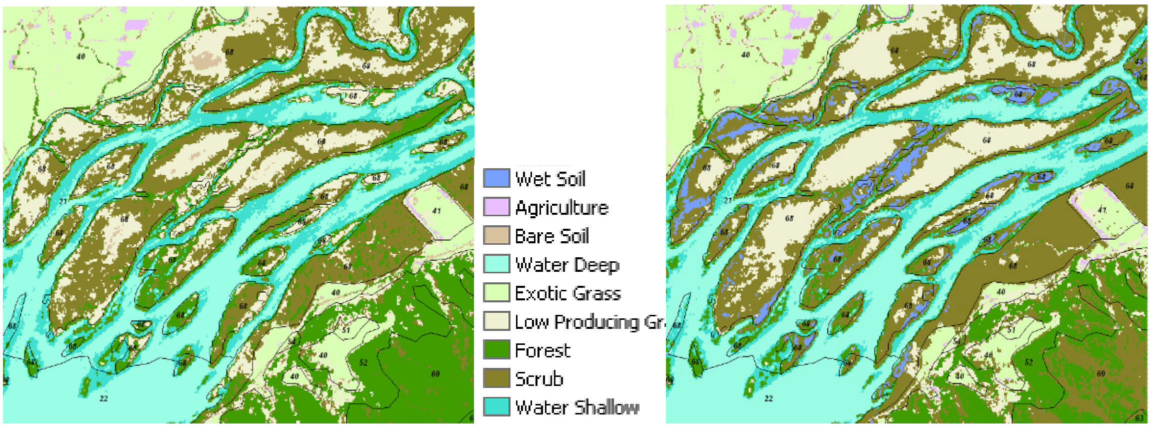


Figure9: ISODATA (left) and supervised classification (right) of SPOT-5 multispectral data

2.3.3. Classification accuracy assessment

Initial classification results were compared with LCDB-2. The following table defines the equivalence of classification classes with LCDB-2.

Table 4: Different landcover types as determined using ISODATA and ML classification techniques

LCDB ID	LCDB-2 Type	ISODATA Classification	ML Classification
1	Built-up Area	Bare soil	Bare soil
3	Surface Mine	Bare soil	Bare soil
21	River	Water (deep)	Water (deep)
22	Estuarine Open Water	Water (deep)	Water (deep)
	Not defined	Water (shallow)	Water (Shallow)
30	Short-rotation Cropland	Agriculture	Agriculture
32	Orchard and Other Perennial Crops	Agriculture	Agriculture
40	High Producing Exotic Grassland	Exotic grass	Exotic grass
41	Low Producing Grassland	Low producing grass	Low producing grass
45	Herbaceous Freshwater Vegetation	Low producing grass	Wet soil
51	Gorse and Broom	Exotic grass	Exotic grass
52	Manuka and or Kanuka	Forest	Forest
54	Broadleaved Indigenous Hardwoods	Forest	Forest
56	Mixed Exotic Shrubland	Scrub	Scrub
63	Afforestation (imaged, post LCDB 1)	Forest	Forest
64	Forest Harvested	Bare soil	Bare soil
65	Pine Forest - Open Canopy	Forest	Forest
66	Pine Forest - Closed Canopy	Forest	Forest
67	Other Exotic Forest	Forest	Forest
68	Deciduous Hardwoods	Scrub	Scrub
69	Indigenous Forest	Forest	Forest

2.3.4. Subpixel classification

Availability of 12.5cm very high spatial resolution (VHSR) multispectral digital image of Hamilton Lake has provided great opportunity to perform subpixel level classification of any given medium to high resolution satellite image and determine its accuracy using ocular assessment (see Figures 10 and 11).

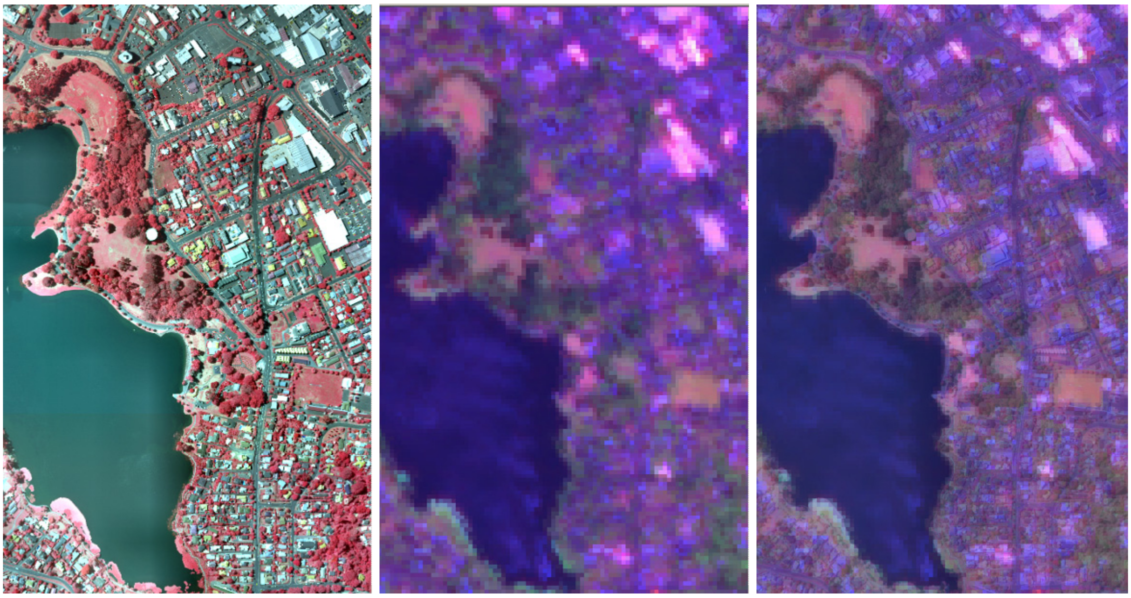


Figure 10: VHSR (12.5cm) CIR image (left), SPOT-5 XS image (middle) and display of both datasets (right)

Figure 11: A close-up of VHSR image (left) showing water lily community on Hamilton lake, SPOT-5 XS data of the same site (middle), and display of SPOT XS data with QB (right) that determines sub-pixel proportion of the corresponding mixed features

SPOT XS image is plotted against VHSR data where it is possible to identify pure and mixed pixels. Aerial Mapping New Zealand has been requested to provide images for the river to locate SAV along its banks. Aerial images captured at such high spatial resolution enable detection of SAV along the river banks (Figure 12) and can be used as training data to perform supervised and subpixel level classification from SPOT data.

Figure 12: VHSR image highlighting dark feature as SAV (right), while elevated nadir image from the Victoria bridge (21-6-2009) shows its detailed extent

3. Discussion and Recommendations

There are three major objectives of this study which have been initiated and their progress has been discussed in the previous section. Conclusive results have not been achieved so far because some of the highlighted data have only been captured very recently; such as latest QuickBird-2 image of the lower Waikato River. Similarly, the VHSR aerial images of Hamilton city are required and have been requested from New Zealand Aerial Mapping Ltd. to provide some sample data for the analytical purposes. A favourable response from US Marine Corps Intelligence Activity (MCIA) for sharing the concept and know-how behind subtractive resolution merging technique is definitely an advantage towards its customisation according to our own circumstances. This includes merging of WRAPS aerial data with LUCAS SPOT-5 multispectral images or this technique can be modified to test the merging of VHSR aerial panchromatic and multispectral data. As far as *in-situ* reflectance data collection in the field is concerned, it can be started as from the coming spring season, as all the major issue related with its acquisition technique has been resolved.

We recommend the following work to ensure the meaningful conclusion of this research;

1. Acquire latest QB satellite data (minimum size 50km^2) of the lower Waikato River, and perform a land-cover classification to validate the accuracy of the existing land-cover classification
2. Acquire ALOS satellite data as well as raw digital aerial images from New Zealand Aerial Mapping for Hamilton city to modify the subtractive resolution merging technique for the non-existent sensor types. The improvement of spatial context, while maintaining the spectral integrity of the RS data, will ensure its useful induction for landcover analysis of SAV along the Waikato River.
3. Acquire in-situ reflectance data of the predominant or important aquatic plant species using diffused reflectance standard from October onward. To measure the reflectance from the canopy of both monospecific and mixed species/landcover type samples, readings should be obtained above the canopy of the plant community which may require the use of a bucket truck to reach over large trees, marsh and thicket (Zomer et al., 2006), as shown in Figure 13.

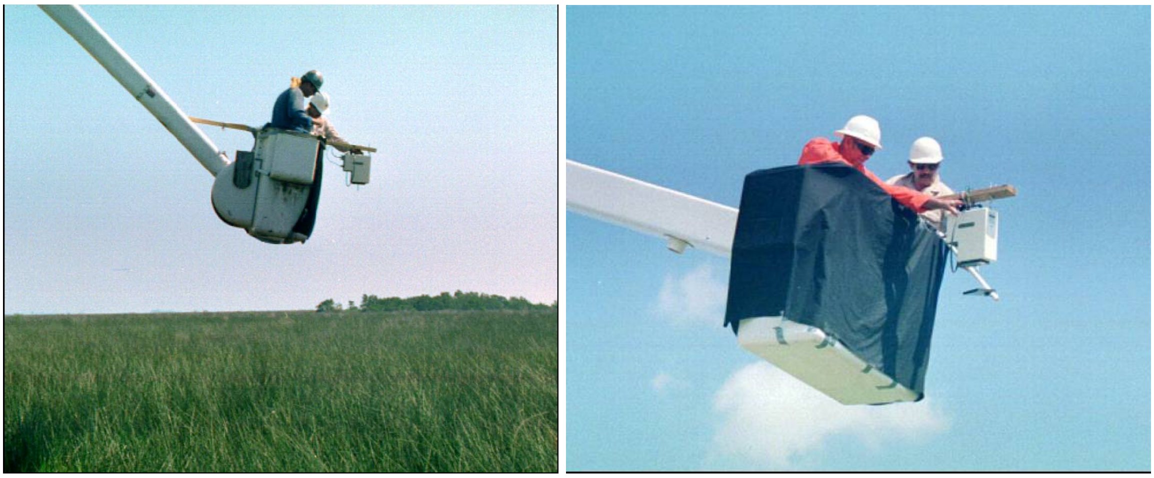


Figure 13: Collection of spectra above the canopy of salt marsh (left) and calibrating the spectrometer using a Spectralon reflectance standard for reference. A dark cloth is used on the bucket to suppress scattered light.

4. Conduct a field trip to the lower Waikato region to acquire ground-truthed data to confirm the accuracy of results from combining the multispectral data in #1 with the reflectance data in #3

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References:

Ashraf, S., Brabyn, L. and Hicks, B., 2008. Evaluating remote sensing data classification techniques for mapping freshwater habitats: Trial application in Tongariro River delta, Lake Taupo - CBER Contract Report 87. A report prepared for Environment Waikato. Centre for Biodiversity and Ecology Research, Department of Biological Sciences, School of Science and Engineering, The University of Waikato, Hamilton.

Ashraf, S., Brabyn, L. and Hicks, B., 2007. Remote sensing of freshwater habitats for large rivers and lakes of the Waikato region using sub-pixel classification - CBER Contract Report 63. A report prepared for Environment Waikato. Centre for Biodiversity and Ecology Research, Department of Biological Sciences, School of Science and Engineering, The University of Waikato, Hamilton.

Chavez, P.S., Sides, S.C. and Anderson, J.A., 1991. Comparison of three different methods to merge multiresolution and multispectral data: Landsat TM and SPOT panchromatic. Photogrammetric Engineering and Remote Sensing, 57(3): 295-303.

Congalton, R.G., Birch, K., Jones, R. and Schriever, J., 2002. Evaluating remotely sensed techniques for mapping riparian vegetation. Computers and Electronics in Agriculture, 37(1-3): 113-126.

Cromarty, P. and Scott, D.A., 1995. A Directory of Wetlands in New Zealand. Department of Conservation, Wellington, New Zealand, 394 pp.

Jing, L. and Cheng, Q., 2009. Two improvement schemes of PAN modulation fusion methods for spectral distortion minimization. International Journal of Remote Sensing, 30(8): 2119-2131.

Johnson, P. and Gerbeaux, P., 2004. Wetland Types in New Zealand. Department of Conservation, Wellington, 184 pp.

Rahman, M.M. and Csaplovics, E., 2007. Examination of image fusion using synthetic variable ratio (SVR) technique. International Journal of Remote Sensing, 28(15): 3413-3424.

Siddiqui, Y. 2003. The Modified IHS Method for Fusing Satellite Imagery. In: ASPRS 2003 Annual Conference Proceedings.

Welch, R., and Ehlers, M., 1987. Merging multi-resolution SPOT HRV and Landsat TM Data, Photogrammetric Engineering and Remote Sensing, 53, 301-303.

Zehner, K.R., 2009. Personal communication on subtractive resolution merging technique. Commanding Officer at Marine Corps Intelligence Activity, Quantico, VA.

Zhang, Y., 1999. A new merging method and its spectral and spatial effects. Int. J. Remote Sensing, 20(10): 2003-14.

Zhang, Y., 2002. Problems in the fusion of commercial high-resolution satellite as well as Landsat 7 images and initial solutions, Symposium on Geospatial Theory, Processing and Applications. ISPRS, Ottawa, pp. 6.

Zomer, R.J., Trabucco, A. and Ustin, S.L., 2006. Building spectral libraries for wetland landcover classification and hyperspectral remote sensing, Proceedings of GlobWetland: Looking at Wetlands from Space, Frascati, Italy.