REGIONAL AND SEASONAL PATTERNS OF STREAM SEDIMENT DISCHARGES ALONG NEW ZEALAND COASTS FROM SKYLAB AND LANDSAT SATELLITE IMAGERY

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SUMMARY: Several analytical techniques used on both conventional colour photographs from SKYLAB and the LANDSAT MSS data — in both photographic and magnetic digital tape formats — provide useful sources of information about regional and seasonal patterns of stream sediment discharges along New Zealand coasts. The large area synoptic views from space are superior to aircraft photomosaics. The green visible band (500-600 nm) is the most useful for sediment studies. Band 7 (0.8 - 1.1 μm) sharply defines land-water interfaces. Digital analysis of small sample areas provides additional quantitative information. Better information about patterns is of potential value in coastal geomorphology, coastal engineering applications, and in coastal ecology.

INTRODUCTION

Spacecraft images, for earth resources analyses, have been taken of New Zealand only since 1973. Prior to this the very small scale NIMBUS and other meteorological spacecraft imagery had been taken primarily to aid weather forecasting.

The first satellite photographs of New Zealand were a few 70 mm, oblique, colour photographs taken in 1973 during SKYLAB II and III orbits in the periods May 25-June 22 and July 28-September 25, respectively. These small-scale photographs covered all or almost all of either the North Island or the South Island. However, some of these showed potential hydrological applications: the extent of snow cover as well as patterns of coastal sediments and shallow water areas were clearly portrayed. From December onwards, during the 1973-4 summer until 8 February 1974, while SKYLAB IV was in orbit, some 50 hand-held colour photographs of New Zealand were taken by the astronauts. Many of these were vertical and at much larger scales than those taken of New Zealand on SKYLAB II and III missions. It was possible, therefore, to map directly from such photographs without excessive problems of photo-rectification.

Also, during the summer of 1973-4 the first LANDSAT imagery of New Zealand was obtained. This unmanned satellite recorded radiance values from the earth's surface in four separate wavelength bands (Band 4: 500-600 nm; Band 5: 600-700 nm; Band 6: 700-800 nm; and Band 7: 800-1100 nm). A multispectral scanner (MSS), not a camera, recorded this from an orbital altitude of 915 km. The data was stored on a wideband tape recorder, subsequently transmitted to a North American ground receiving station and reconstituted as either magnetic tapes (computer compatible tapes—CCTs) or as photographic images. For additional technical details about the Earth Resources Observation Satellite (EROS) LANDSAT spacecraft and applications to which the imagery has been put see Cochrane (1974, 1975a, b, 1976).

During December 1973, some 20 LANDSAT-I images were taken of New Zealand. Shortly after this the tape recorder ceased to operate. Subsequently, since the launching of LANDSAT-II in January 1975, more LANDSAT satellite imagery has been acquired of New Zealand. To date there have been some 56 sets of data taken of New Zealand by LANDSAT I and II. The repetitive cover is valuable for comparative mapping purposes.

Both the vertical SKYLAB colour photographs and the LANDSAT images provide synoptic views of large areas acquired at one instant of time under uniform light conditions. The standard photographic format of LANDSAT photographs is at a scale of 1 : 1 000 000 showing a surface area of 32 400 km (12 500 sq. miles).

Broad regional patterns of geological, geomorphic, hydrologic, ecological and landuse features can be seen and mapped without the masking, distortion or other modifications inherent in aircraft photographic mosaics taken over a range of time and lighting conditions and subject to variations in subsequent processing and printing. Thus, spacecraft images are useful for mapping patterns of sediment discharges along New Zealand coasts.

Within New Zealand research workers have studied mostly stream gauging or detailed surveys of small areas of coast or harbours. Little attention has been paid to the New Zealand regional patterns and to the seasonal changes in sediment discharges over large areas.

This paper is a statement of research in progress. It reports results from a selected range of SKYLAB, LANDSAT-I and LANDSAT-II satellite data. Methods of analysis employed include conventional photo interpretations as well as optical processes, electronic techniques of densitometry, colour enhancement and enlargement, and digital processing of LANDSAT MSS magnetic tape data.

METHODS

1. PHOTOGRAPHIC – OPTICAL – ELECTRONIC

A. SKYLAB

All SKYLAB colour photographs of New Zealand were viewed either as colour positive transparency enlargements or as 70 mm contact colour positive transparencies. The oblique photographs were used to obtain a qualitative assessment of sediment patterns. Because of the small and varying scale on these oblique images no attempt was made to map accurately the patterns shown. Sixteen SKYLAB IV 70 mm colour positive transparencies were selected subsequently for detailed analysis. Suspended sediments showed as a range of pale blues, with palest for maximum concentration. Clear water showed as dark blue. This pattern was very noticeable in the South Island lakes as well as in the coastal waters. Standard photo interpretation techniques employed included (a) viewing images over a light table with a wide field magnifier, (b) with 10 x Lupes, (c) projecting the images on to large-scale maps for comparison and plotting, and (d) producing enlarged colour prints for direct photo plotting.

Two vertical photographs, SL-4 137-3615 and 3616, of the Otago coast had sufficient overlap to be viewed stereoscopically.

Two further images, one of Hawke Bay (SL-4 137-3641) and one of the Otago coast (SL-4 137-3700) were selected for intensive photographic interpretation by electronic processing, namely (a) isodensitometry, (b) colour enhancement processes and (c) selective enlargement using a Spatial Data Systems Colour Isodensitometer at PEL, DSIR. Subtle tonal differences in the photograph not able to be detected by the human eye can be scanned electronically and recognised as 32 discrete gray levels thereby providing a greatly increased range of values. Such density slicing can be further modified by colour enhancement. Specific colours are introduced for each gray level recognised. Areas of specific interest were subsequently greatly magnified to obtain maximum detail of the density-sliced, colour-enhanced image.

B. LANDSAT

All LANDSAT images have been inspected in at least two different forms, (a) as individual black and white narrow-band images either as positive transparencies, or as positive prints or as both at scales of 1 : 1 000 000 and (b) as colour composites of three different bands at scales of 1 : 1 000 000. Comparisons have been made between images showing low flow and high flow sediment discharge conditions. In all cases Band 4 images embracing the green visible light wavelength bands (500-600 nm) proved the most useful for recognising sediments. Selected Band 4 images have been used for direct mapping.

Colour isodensitometer analysis was employed on several LANDSAT images. In addition use was made of the I_2S Mini Addcol Colour Additive Viewer at PEL, DSIR, to process the four separate 70 mm black and white positive transparencies of several LANDSAT images.

Each transparency is projected with either a blue, green or red filter, or white light. Light through each projector can have a range of 10 different light intensities. Each projected transparency is exactly registered and superimposed. It is possible thereby to enhance various densities and emphasize patterns that cannot be recognised readily or even at all by the unaided human eye.

2. DIGITAL PROCESSING BY COMPUTER

Two small areas selected from a Band 4 LANDSAT image, (E-2192-05311) of 2 August 1975, of the Canterbury coast have been used to illustrate digital analysis techniques. Radiance values for each picture element or "pixel"—corresponding to a surface area 79 m x 59 m — are recorded on the LANDSAT multispectral scanner (MSS) for each of the four wavelength bands. These can be printed out from computer compatible tapes (CCTs). Thus, areas with similar densities of suspended sediments record similar radiance values. Boundaries between suspended sediment-laden stream discharges and clear sea water are very sharp.

Following a printout of absolute radiance values from the LANDSAT Band 4 CCT for the test areas a histogram evaluation was run to establish classes of radiance values. A clustering programme was then implemented to provide the line printout maps. These provide greatly enlarged and much more detailed information of patterns than can be derived from photo interpretation of the LANDSAT image. The patterns present, such as those on Fig. 5 of the Hurunui River discharge can be viewed simply as a line printout map. These patterns become more obvious if the diagram is viewed from arm's length.

On Fig. 6, of the Waimakariri River discharge, the line print symbols have served as the basis for mapping using map symbols. The detailed pattern shown presents a greater amount of information than can be derived from photographic analysis. Comparison of Fig. 3, a photographic product; Fig. 4, a map derived from colour enhanced densitometry analysis; and Fig. 6, a map derived from computer processing, of a LANDSAT Band 4 CCT clearly illustrates the progressive information gain possible when processing from optical through electronic to digital analytical techniques.

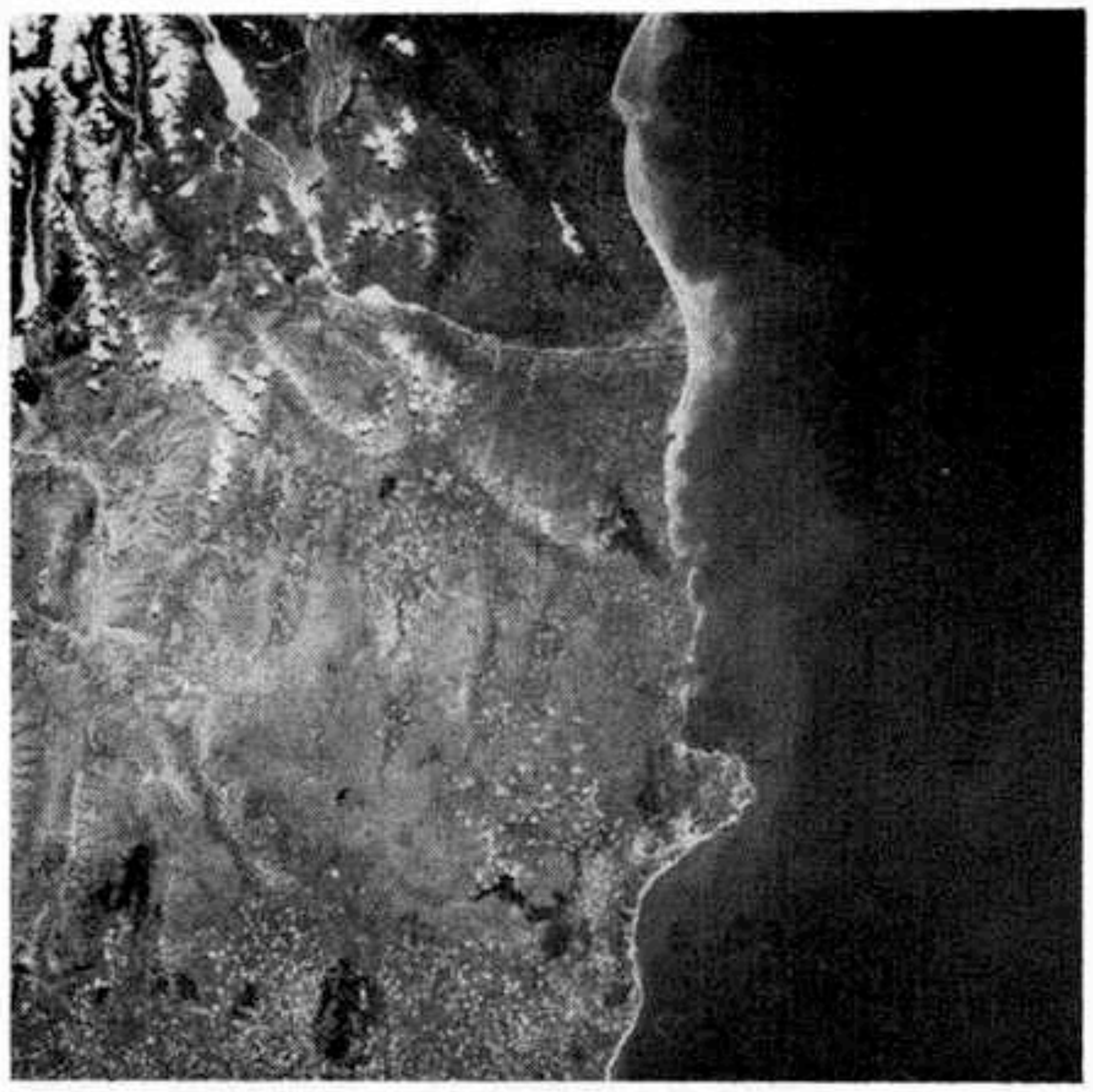

FIGURE 1. *Black-and-white copy of a SKYLAB-IV colour photograph of Otago and the Otago coastline. Lighter grey tones show patterns of suspended sediment movements out and along the coast. Note the difference between sediment concentrations and movement at the Waitaki delta and those from the Waimakarua and Shag Rivers.*

DISCUSSION

It has not been possible to reproduce imagery in colour in this paper. Consequently, much of the information recorded on the original colour imagery is lost, therefore, in the black and white reproductions. Nevertheless, the following figures illustrate something of the range of information available, from Spacecraft data, for mapping sediment patterns in New Zealand coastal areas. The increased information that can be derived from colour isodensitometry in comparison with conventional photo interpretation is illustrated in Figs. 1 and 2.

SKYLAB PHOTOGRAPHS

Fig. 1 is an panchromatic copy of part of a SKYLAB IV colour space photograph of Otago and its' coast from just north of Shag River to the Rangitata River mouth. Moeraki Head, Waitaki River, Timaru, and the complex of hydro lakes are all clearly shown. Patterns of sediment concentrations (shown as a range of pale blues on the colour photo) can be seen as different gray scale densities. These are densest, i.e. highest suspended sediment concentrations, (whitest) near the coast especially seawards and northward of the Waitaki River mouth. Another zone extends up to 15 km offshore. A third zone extends irregularly to over 35 km offshore.

Greatly increased detail of these patterns was achieved with electronic processing of the SKYLAB IV colour transparency. The three zones recognisable on the positive photograph transparency were subsequently subdivided into 14 zones through the use of colour isodensitometry analysis. Careful inspection of the range of grey scale densities shown on Fig. 2—a panchromatic copy of a colour isodensitometer image—illustrate a progressive zonation of suspended sediment concentrations. The patterns of discharge seawards from the mouth of the Waitaki River showed sharp but narrower zones than those from the Shag river and Clutha river discharges further south. A strong northerly movement several kilometres out from the coast was much more apparent with discharges from the southern rivers. As noted earlier such patterns, shown as different colours, are much more readily recognised on the original colour enhanced imagery than on the black and white reproduction shown in this paper.

A similar range of 11 classes of concentrations of suspended sediments were noted in the colour isodensitometer analyses of SKYLAB IV colour photographs of the Hawke Bay area.

Inspection of Figs. 1 and 2 shows that although there is a loss of resolution with the colour isodensitometry process (compare the detail of features on the land) there is a great increase in total inform-

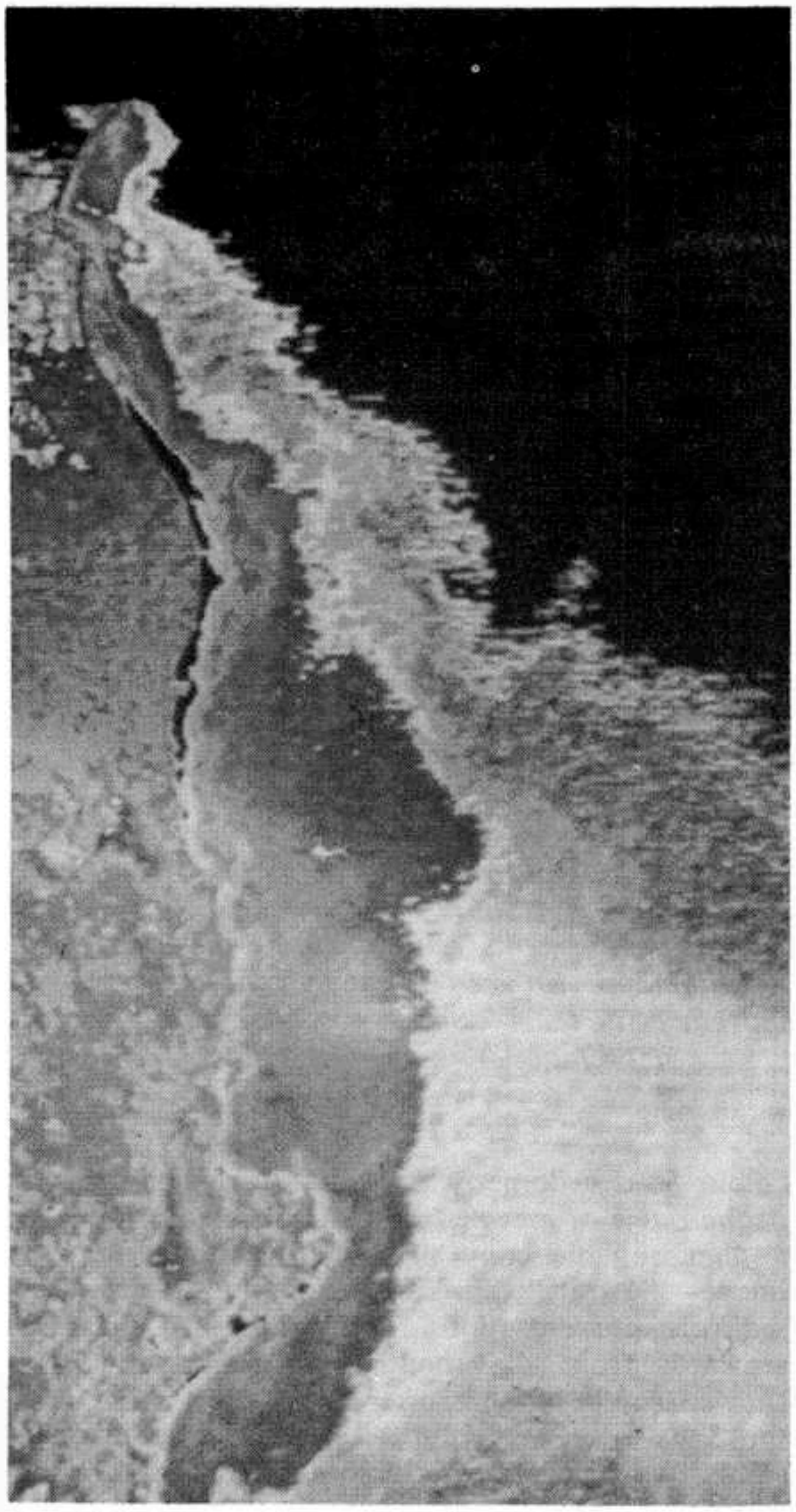

FIGURE 2. *Black-and-white copy of a colour isodensitometer image of the SKYLAB-IV colour photograph of Figure 1. Each of the grey tones from the coast seawards represents a different colour tone on the original. These bands or zones represent a gradation of densities of suspended sediments from maximum near the coasts and river mouths to minimum out to sea.*

ation content. This is inherent in most electronic colour enhancement processes. Fig. 2 provides a greatly increased display of areas of equal density: it shows a much more subtle recognition, therefore, of zones of different densities of suspended sediments. Such zones are merged together in the colour photograph and are not recognisable by the unaided human eye without colour enhancement.

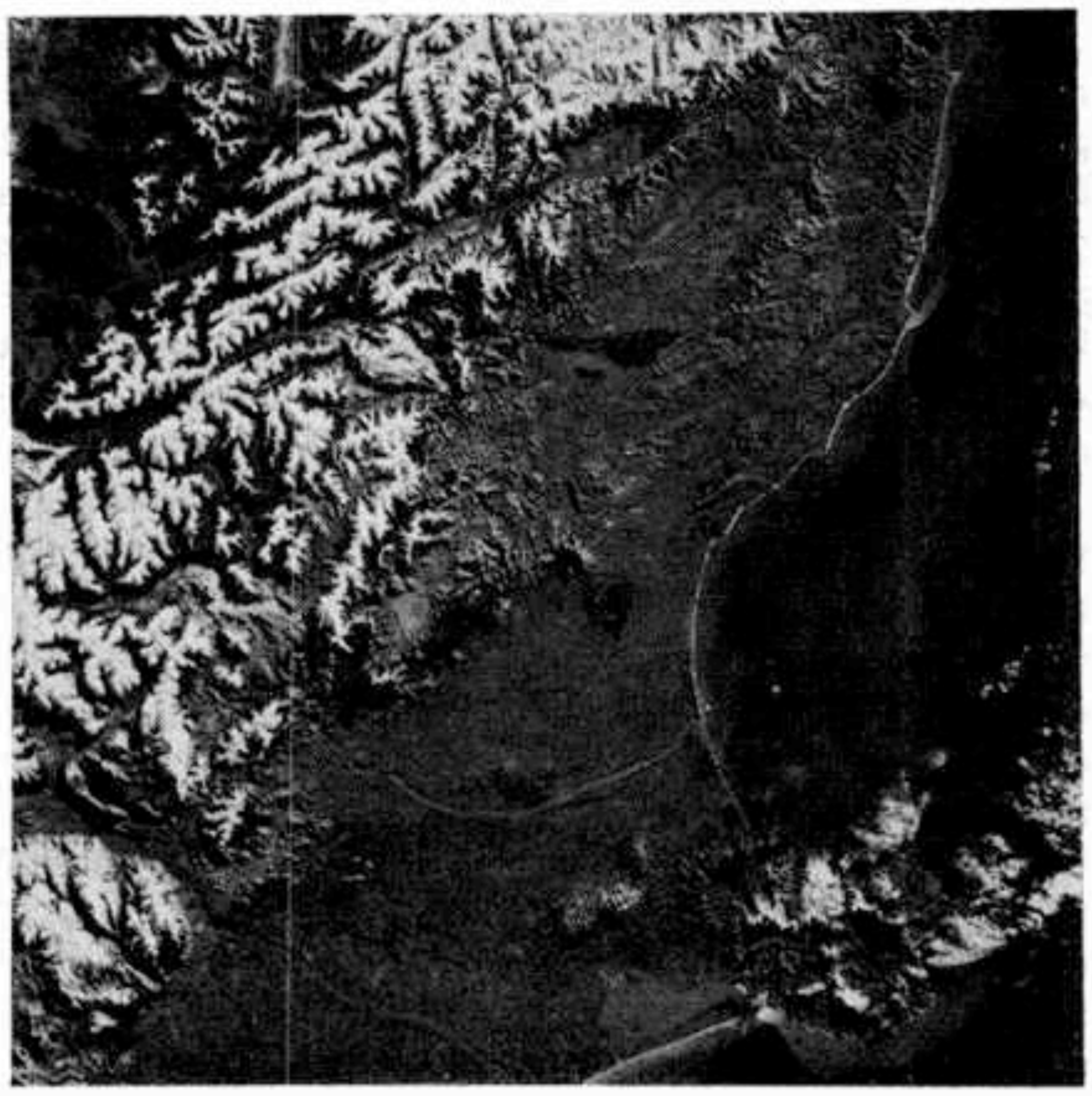

FIGURE 3. *LANDSAT MSS Band 4 image at scale 1:1 000 000 of Canterbury and coastal waters on 2 August 1975. This image shows patterns of high concentrations of sediment discharges. A strong northward drift is apparent along the Kaikoura coast and around Banks Peninsula.*

LANDSAT DATA – IMAGERY

The 2 August 1975 LANDSAT-II photograph shown as Fig. 3 provides an excellent example of the broad synoptic view possible from satellites. The patterns of sediment movement in the ocean from near the Rakaia mouth to beyond Kaikoura are well portrayed during this period of high discharge. Imagery showing low discharge still indicate a prevailing northward movement. Analysis of a range of LANSAT imagery of this area shows that seasonal fluctuations in the amounts of suspended sediments discharged into the sea can be readily observed as can the source and dispersal patterns of individual discharge plumes. The seaward extent of suspended sediment movement can be readily plotted. Studies of LANDSAT imagery of other coastal areas of New Zealand show a similar range of information.

DENSITOMETRY

The area of Pegasus Bay north of Banks Peninsula was selected for more detailed study using a colour isodensitometer. Colour slides were made of colour isodensitometer images. These were subsequently projected on to a base map and boundaries drawn around the colour classes. Fig. 4 shows a map of sediment patterns of Pegasus Bay derived from density slicing and colour enhancing the LANDSAT-II Band 4 positive transparency of the area shown as Fig. 3.

Five classes of sediment density were more readily recognised than from the photograph. Additionally, both the intricate pattern and evidence of a south flowing current near shore causing a marked discontinuity in the gradation of sediment concentration with increasing distance from shore were readily distinguished. The colour isodensitometer image also showed that the main influence of the southward current is about one km offshore from the Waimakariri river mouth. The major movement northward of the Southland current was clearly demonstrated on both the photograph and the isodensitometer image.

The major sediments of Pegasus Bay, an actively prograding plain, are derived from the rivers, particularly the Waimakariri River. Much of the sediment is sand and fine grades of sediment which allows for easy suspension (Blake, 1967 and Burgess, 1968). This easy suspension facilitates wide dispersal by coastal currents. This is clearly seen in Fig. 3 whilst Fig. 4 shows the direction and position of the major influence of the Southland current and its southward flowing eddy bifurcation inshore along Pegasus Bay.

DIGITAL PROCESSING

While the LANDSAT-MSS imagery is useful for portraying broad patterns, colour isodensitometry can provide a three- to fourfold increase in the zonations present. Further substantial increase in detailed information can be achieved with computer analysis of digital data tapes. Two small areas have been selected to illustrate this technique. One illustrates a strong sediment discharge plume moving northwards with sharp boundaries: the other is a weaker discharge with a more diffuse pattern. The two samples selected for computer analysis in this paper are:
(1) an area approximately 10 km x 6 km of the Hurunui River discharges clearly seen on Fig. 3 and (2) the area shaded as Computer Printout on Fig 4. This is a narrow strip approximately 15 km x 6 km showing discharges north and south from the Waimakariri River. Part of the former area is shown as Fig. 5 and part of the latter as Fig. 6.

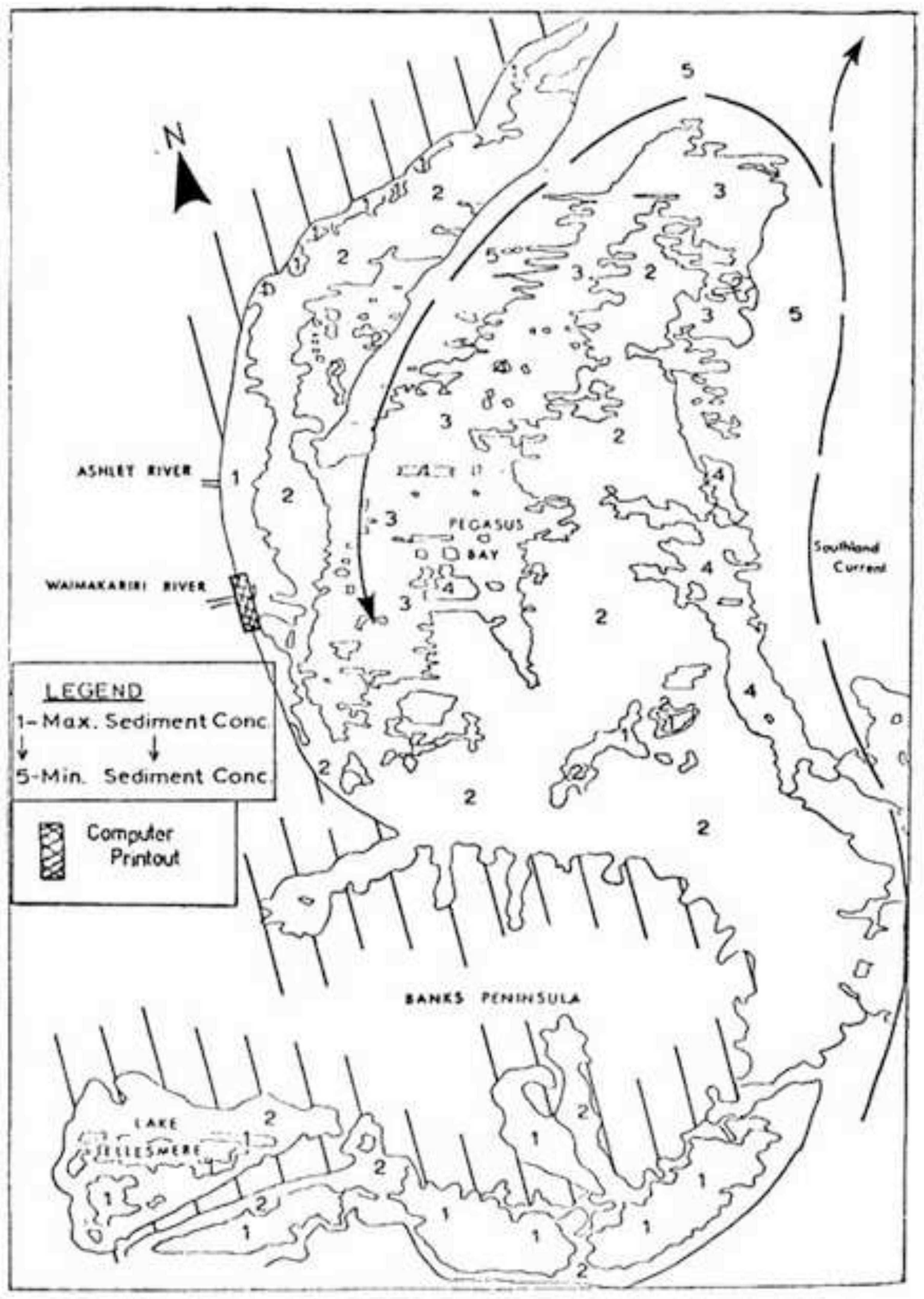

FIGURE 4. *Map of Pegasus Bay showing patterns of suspended sediment densities as derived from electronic processing of a LANDSAT Band 4 positive transparency. Density slicing and colour enhancement techniques were employed to delineate zones and major paths of ocean currents.*

Comparison of Fig. 3 and the computer printout map, Fig. 5, of the Hurunui River discharges clearly indicates the greatly increased range of information available and the much larger scale possible using computer compatible tapes to produce the information. Each individual symbol represents information about a surface area 79 m x 59 m. A west to east line across the upper third of this map clearly shows six density zones seaward of the coastline and nearshore zone (shown as white in the map). Immediately east from the headland a different range of zones is present. Yet another pattern of zones is present across the base of the map. Detailed inspection of the photograph cannot provide this information. Photographic enlargement to this scale would merely produce a blurred grainy film image with resolution lost.

In Fig. 6 of the Waimakariri River mouth suspended sediment discharges, a complex pattern of great detail showing five classes of suspended sediment density as well as sandy beach and gravel lagoon have been derived from computer analysis of CCTs. From a printout map similar to that shown in Fig. 5 the zones of similar computer printout symbols have been replaced by graded density map symbols.

REGIONAL PATTERNS OF SUSPENDED COASTAL SEDIMENTS

Using all available earth resources oriented satellite imagery of New Zealand coastal areas plus the range of analytical techniques outlined, maps of regional and seasonal patterns of suspended sediment movement are being compiled. Limited field sampling has also been carried out.

FIGURE 5. *Computer printout map from LANDSAT-II Band 4 computer compatible tape of the Hurunui River discharge. Compare with photographic image, Figure 3.*

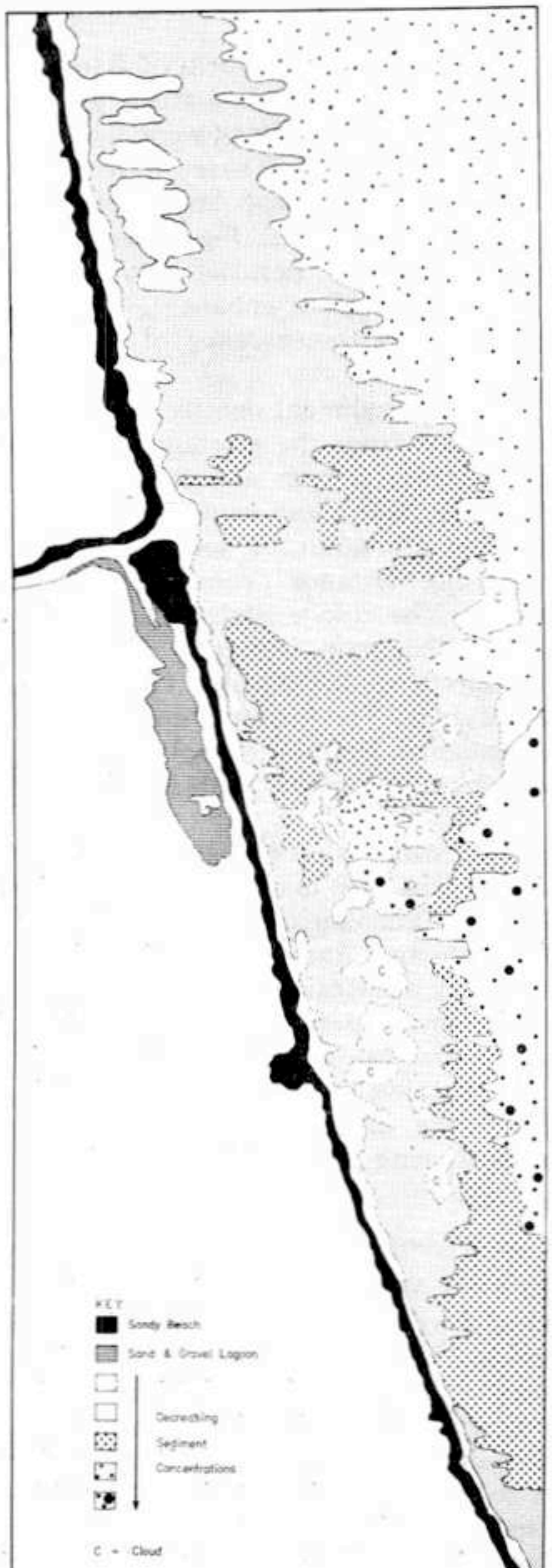

FIGURE 6. *Map showing classes of suspended sediments from Waimakariri River. Density classes derived from computer printout data. Compare scale and detail with Waimakariri River discharges shown on Figure 3.*

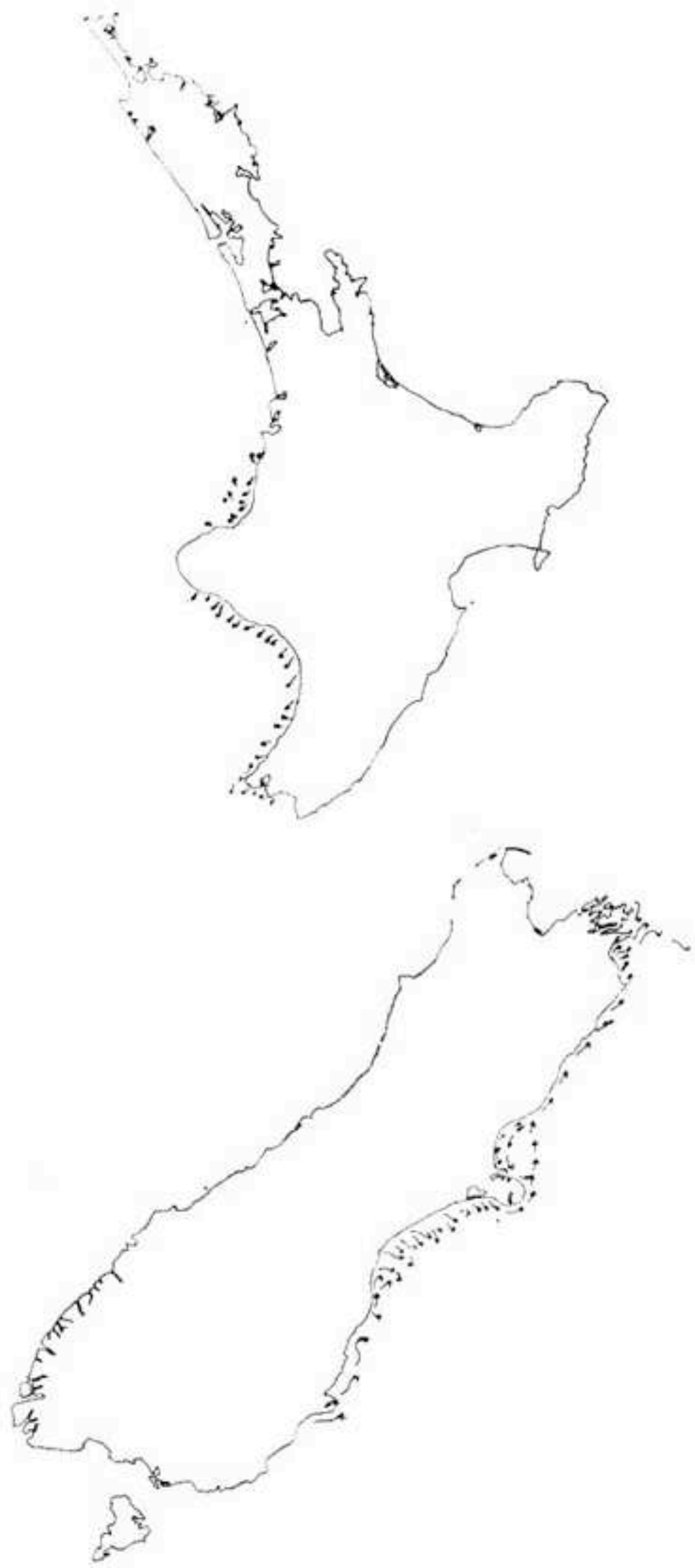

FIGURE 7A AND B. *Generalised map of major areas and direction of suspended sediment movement in the North Island (7a) and South Island (7b) as mapped from SKYLAB and LANDSAT I and II imagery.*

Figs. 7a and b are preliminary generalised maps of the major directions of movements of suspended sediments in parts of the New Zealand coast as plotted from satellite imagery. Not all areas have been surveyed yet. Patterns observed for Westland, Hawke Bay, and Firth of Thames have not been included on these maps. Studies from a single LANDSAT-II image suggest that movement of suspended sediments from both the Manukau and Kaipara harbours is primarily offshore, highly localised and soon dispersed.

Analysis of a single LANDSAT-II image plus sampling with a Secchi dish in the Hauraki Gulf indicates that the numerous Gulf islands exert a major sheltering effect and strongly control suspensate movements within the Waitemata harbour.

A dominant northward movement outwards in the Firth of Thames is strongly influenced by the geological structure of this estuary. Localisation of major discharges in the southeastern corner plus tidal movements modify this simple pattern.

In the South Island (Fig. 7b) there is a strong northward movement of suspended sediments along the east coast. This is particularly apparent at times of high flow from rivers. Movement of sediments extends well offshore in the southern areas but is nearer inshore further north where it closely parallels the Kaikoura coast. Subsequent deflection, eddying, merging and mixing occurs in the Cook Strait where sediments appear to reach across to mingle with North Island sediments near Wellington.

There are secondary patterns such as (a) the circular eddy patterns of Pegasus Bay and (b) direct offshore migration especially at times of low flow although a northerly movement is still present.

Only one LANDSAT image of the west coast of the South Island has been closely studied. Colour isodensitometer studies showed seven densities of suspended sediments from Westland rivers. Movement is mostly offshore and subsequently dispersing.

In the North Island (Fig. 7a) of the areas studied suspended sediments in coastal waters are predominantly offshore in a broadening fan especially on the west coast. Some southward movement is apparent on both coasts near Wellington.

Both offshore movement and a broad northerly eddy movement have been noted in Hawke Bay, the latter probably a result of the coastal configuration.

CONCLUSIONS

Although this is a report of research in progress and the results are only preliminary ones the following observations can be made.

1. Satellite imagery provides a useful tool for mapping patterns of suspended sediments.
2. The analytical techniques outlined facilitate analysis from very broad small scale (photographic) through to detailed large scale sampling (Computer analysis).
3. Seasonal fluctuations in amounts of sediments can be easily observed.

4. The source and dispersal patterns of individual discharge plumes can be observed. This gives a good indication of the erosional quality of catchment areas.
5. Current patterns are important in influencing patterns of coastal suspended sediment movements.
6. Sediment movements extend much further seaward than was anticipated when this study began.
7. There is a strong northward movement offshore on the east coast of the South Island.
8. Elsewhere suspended sediment movement is primarily offshore in a fanlike dispersal pattern with increasing dilution with seawater.
9. Numerous local secondary patterns occur influenced primarily by coastal configuration of headlands and bays e.g. Banks Peninsula and Pegasus Bay and Hawke Bay eddy patterns.
10. Information about seasonal and regional patterns of suspended sediments has practical value for engineers, coastal ecologists, planners and offshore submarine mining. For example, with offshore mining for gold knowledge of major patterns of sediment discharge from the Clutha River would narrow down areas required for surveys for bathymetry, sonar studies and sample bottom coring.
11. Possibly the most useful feature of this survey is its potential broader application into many fields of investigation. Although this study has focussed upon the utility of satellite data for mapping suspended sediments the same techniques can be applied to any feature — vegetation, landuse, forest, crops, extent of snow cover, landform features, catchment properties and so on — where radiance values of the components are measurably different. The senior author and his students are currently applying similar analytical techniques for mapping vegetation, geomorphology, and landuse in parts of New Zealand (Cochrane *et al.*, 1976).

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