Sedimentation in the Styx River Catchment and Brooklands Lagoon

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Executive Summary

This report presents information on sedimentation in the Styx River catchment and Brooklands Lagoon into which the Styx flows. The main issues investigated cover sediment loads and source areas, landuse effects on sediment production, river channel deposition and dredging, the effects of the tidal gates on sedimentation, and sedimentation in the lagoon. It includes a review and analysis of existing information, plus new information on stream sediment loads measured during storms in 1993.

The present average specific sediment yield of the 50 km^2 Styx catchment is somewhere between 6 and 78 t/km^2/yr. The lower figure derives from direct measurements of sediment load made over a relatively benign six months in 1993. The high value derives from data on dredging and deposition in the lower Styx channel from 1967 to 1989, and contains uncertanties mainly to do with the volumes, bulk density, and weed content of the dredged material.

In both the Styx River and its largest tributary, Kaputone Creek, practically all of the sediment load is carried in suspension and comprises both clay and fine sand populations. The organic content of their sediment loads ranged from 10% to 50% and increased as the total suspended solids concentration decreased on storm recessions. Horners Drain and its tributaries carried mainly silt and clay sediment with a high proportion of organic material.

Sub-catchment yields measured during one rainstorm showed that of the total sediment yield at Marshland Road, 48% came from Horners Drain, 36% was from the upper Styx, and 16% was from Kaputone Creek. On a unit area basis, the yield from Horners Drain was significantly higher. The specific yield from Quaids Drain, a largely market-gardening catchment, was a factor-of-ten higher than the yields from the other rural sub-catchments, while the yield from the dominantly residential Horners Drain was 50% larger than those from the rural catchments dominantly in pasture. These landuse effects are expected to be greater with longer and more intense rainstorms.

Future landuse changes involving more market-gardening or more rapid urbanisation would increase the Styx sediment yield. The increase due to urbanisation would be temporary, until the new development 'matured'. The 80 t/km^2/yr yield figures for the 1970's period, which saw the main phase of urban development in the Styx catchment to date, might be a reasonable index of this.

Analysis of cross-section and dredging records for the period 1969-84 showed that in the low-gradient, tidally influenced reach between Radcliffe Road and the tidal gates some 59,000 m^3 of sediment were deposited, 92,000 m^3 were dredged, resulting in a net channel enlargement of 33,000 m^3. Deposition rates over this period were highest (48 mm/yr) in the 2 km-long sub-reach downstream from Radcliffe Road, were 26 mm/yr around the Oruhia Loop, then averaged 19 mm/yr along the 7.5 km long sub-reach down to the tidal gates. The Styx channel upstream from Radcliffe Road experienced little sedimentation (2 mm/yr) and has not been dredged. A smaller number of cross-sections that were surveyed four times between 1967

and 1989 indicate that deposition rates were steady over this period. Considering all available records from dredging and cross-section surveys, it is apparent that the maintenance dredging programme of recent decades in the lower Styx has more-or-less matched sedimentation, with little net change in mean bed levels.

It appears that relatively little sediment passes downstream of the tidal gates. Aquatic weed encourages sedimentation in the long low-gradient reach upstream of the tidal gates reach by slowing flow velocities and 'hiding' sediment.

The Styx channel downstream of the tidal gates over the period 1979-83 showed an irregular pattern of bed-level change, with some sections aggrading, others degrading, and little net change overall. Changes there since then have not been surveyed.

Brooklands Lagoon was occupied by the main Waimakariri River channel earlier this century but since the 1940's has been a quiet tidal backwater, trapping sediment from Waimakariri floodwaters and sand blown and washed over the spit from the coast. Sedimentation rates in the lagoon were high soon after the departure of the Waimakariri but have waned in recent years. Some 1.4 million m^3 deposition was detected by surveys in 1932 and 1969, with average sedimentation rates of 30 mm/yr in the old river channel over this period. Since then, gradual infilling has progressed from the top (south) end of the lagoon, while towards the mouth, localised erosion and deposition has accompanied shifts of tidal channels and bars, resulting in some flushing of sediment. Overall, the recent net changes have been relatively minor, and future average sedimentation rates are inferred to be of the order of a few mm/yr.

Since the 1940's, when it was a low, largely unvegetated area of shifting sand, the spit enclosing Brooklands Lagoon has been stabilised by vegetation and is broadening and increasing in elevation. The lagoon shore of the spit near the lagoon mouth is experiencing chronic erosion, partly due to a reduced supply of wind-blown sand across the spit and partly due to shifts in the lagoon channels. The stabilisation of the spit has lessened the likelihood of the Waimakariri channel reoccupying the lagoon and of wind-blows and storm-wave wash-over.

The mouth of the Styx River has been shifting to and fro in recent decades. This instability probably is partly natural and partly related to the shallowing of the lagoon.

Recommendions from this study are:

- A sub-set of the existing cross-section network down the lower Styx channel should be monitored at 5-yearly intervals. These surveys should be used to target dredging. The dredging should be to a design bed profile. The first survey should be within the next year, to fix the channel condition after the 1993 dredging run.
- The volume of spoil left on the banks from the 1993 dredging run should be surveyed as soon as possible and compared with the dredging records to indicate the reliability of the latter.
- The cross-sections in the Styx channel between the tidal gates and Brooklands Lagoon and also those in Brooklands Lagoon should be resurveyed. These surveys should confirm the

assumption that recent deposition patterns have not altered much since the last surveys in the late 1970's to early 1980's.

- Sediment sampling of storm runoff at the Styx at Radcliffe Road site should continue for a further two years in order to get a more representative estimate of the long-term average yield.

Suggested further research includes:

- Measuring the sediment trap-efficiency of the reach upstream of the tidal gates by sampling through a storm runoff event at the up- and downstream ends.
- Establishing an experimental reach in the lower Styx to monitor sedimentation rates after dredging, the density of the channel bed deposits, and the relationships between sedimentation, weed, and hydraulic conveyance.

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1 Introduction

1.1 Study Purpose

This report presents information on sediment loads and sedimentation in the Styx River catchment near Christchurch. The information is required for input to management plans for the river floodplain and Brooklands Lagoon, and as resource material for sediment management policies such as for landuse zoning and river channel dredging.

The tasks of the study were threefold. The first task was to assemble and analyse available information on sedimentation in the Styx channel and Brooklands Lagoon. The second was to collect additional information on stream sediment loads. The final task was to evaluate this information in terms of issues which include: geographic and landuse effects on sediment sources, river channel dredging operations, the effect of the tidal gates, and future sedimentation in Brooklands Lagoon.

1.2 Content of this Report

Following this introduction, Section 2 provides a brief geomorphic description and historical perspective on the Styx catchment. Section 3 reviews information available on sedimentation in Brooklands Lagoon. In Section 4, records of river channel dredging and survey data on cross-section change are analysed to identify net and total rates of sedimentation in the main Styx channel. Section 5 specifically addresses the effect of the tidal gates near Harbour Road and aquatic weed on sedimentation in the lower Styx channel. Section 6 reports on measurements of sediment loads made during two storm events in 1993 in the Styx main stem, Kaputone Creek, and Horners, Rhodes, and Quaids Drains, plus estimates of the long-term average sediment yields of the Styx River and Kaputone Creek. Section 7 synthesises the information from the previous sections in terms of current and future sediment management issues.

1.3 Acknowledgments

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2 Geomorphic Description and Historical Perspective

The Styx River catchment, 55 km^2 in area, lies between the toe of the Waimakariri alluvial gravel fan and the shore of Pegasus Bay. It is bordered to the north by the Waimakariri River channel and to the south by the Avon River catchment (Fig. 2.1). From its spring-fed sources to the north of Christchurch airport, the river's 21 km course passes first over old Waimakariri riverbed gravels, then across a belt of Holocene coastal sands and peats that were deposited as the coastline prograded during the past 6-7,000 years. A kilometre from the coast, its turns northward, running for several km behind the modern coastal dune field until, just south of the Waimakariri channel, it turns east again to exit into Brooklands Lagoon. Its slope decreases markedly, and its bed material changes from gravel to sand, where the Holocene progradational sequence laps over the Waimakariri Gravels.

Brooklands Lagoon was originally part of the mouth system of the Waimakariri River. Although the position of the Waimakariri mouth has been stable since the 1940's, prior to then it showed great instability: the mouth often migrated southwards along much of the lagoon's length, with the river flowing behind a wave-built spit. Occasionally, usually during floods, the river would force a new mouth through the spit. Then, as with the current mouth situation, the lagoon would be temporarily abandoned by the river.

The pre-European landscape of the Styx catchment, compiled from the 1856 'black maps' (Fig. 2.2), was largely one of raupo swamp and grassland, over-run near the coast by a belt of mostly unvegetated sand dunes (Wilson, 1989; Blakely and Mosley, 1987). Today, the Styx remains a dominantly rural catchment, but with the native vegetation largely replaced by pasture, market gardens , and orchard and the dune areas stabilised by plantations. The southwestern corner of the catchment has been built over by the northern suburbs of Christchurch. Small settlements near the coast include Spencerville and Brooklands. The soils near the coast are loamy sands; further inland they are peaty, silty, and sandy loams, and eventually become gravelly and sandy on the old Wamakariri surfaces.

The main tributary streams are the upper Styx, Smacks Creek, and Kaputone Creek (Fig. 2.1). These have spring-fed baseflows (Daglish, 1985) and drain the largely rural areas to the north of Christchurch and the Harewood/Belfast area. The northern suburbs of Papanui, Northcote, and Redwood contribute storm water through a network of drains, the largest being Horners Drain which enters the Styx a short distance upstream from Kaputone Creek.

Drainage work affecting the Styx catchment commenced in the late 1800's. Soon after its establishment in 1875, the Christchurch Drainage Board constructed a number of drains to lead stormwater from the north of the city into the Styx River, thereby increasing the Styx catchment by some 16 km^2 (Scott, 1963). The Christchurch Drainage Board took over responsibility for the remainder of the Styx catchment in 1952 and then embarked on a programme of drain improvement and dredging.

Tidal influence on water levels extends upstream to Marshlands Road. Salt water penetration currently stops just upstream from the tidal gates near Harbour Road. The tidal gates were installed in 1934 by the North Canterbury Catchment Board, mainly to keep out flood waters from the Waimakariri River. The gates were replaced in 1981. They currently open to drain Styx runoff when the upstream water level is 100 mm higher than the downstream level.

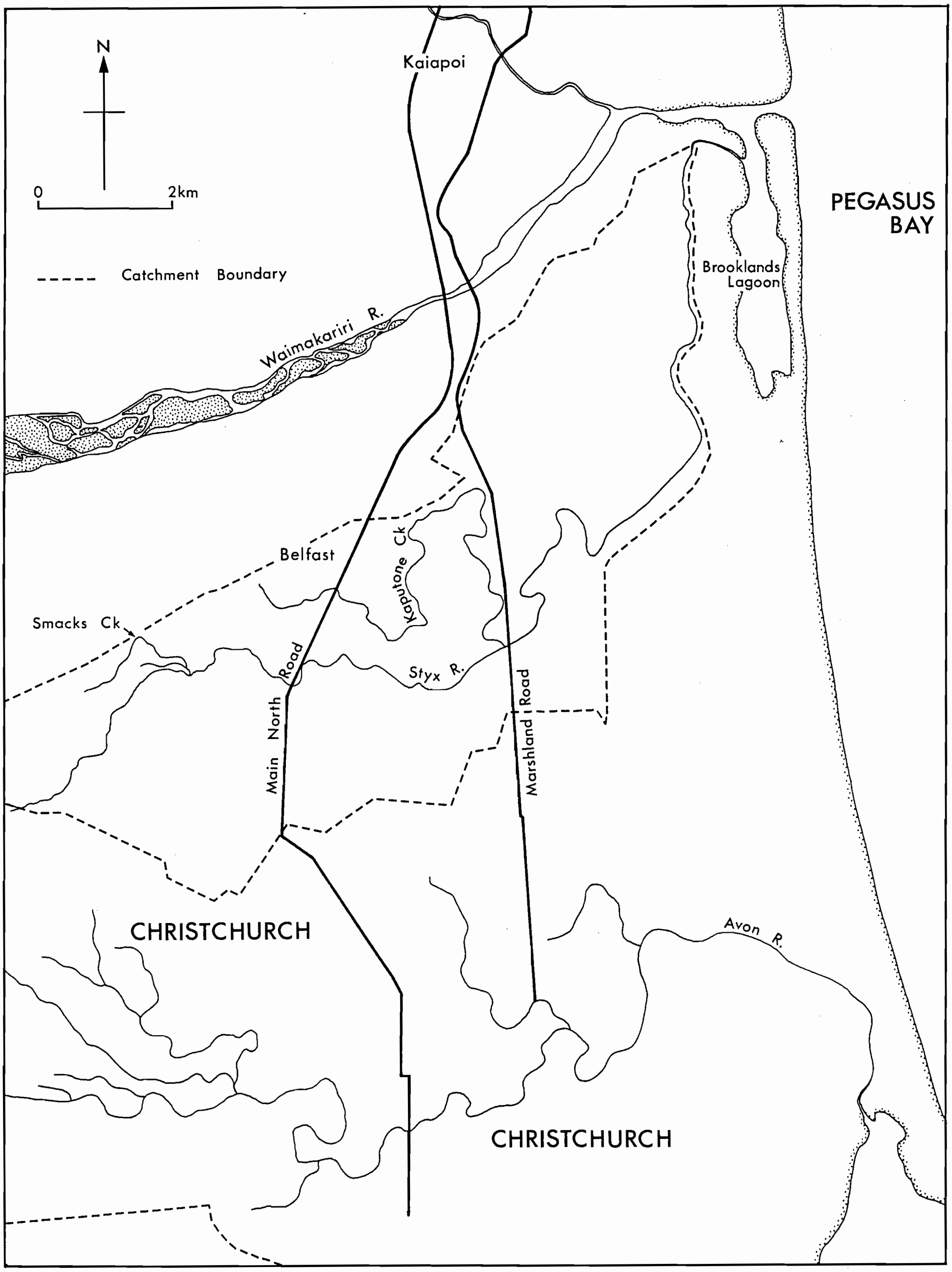

Figure 2.1 Location map showing Styx catchment to north of Christchurch.

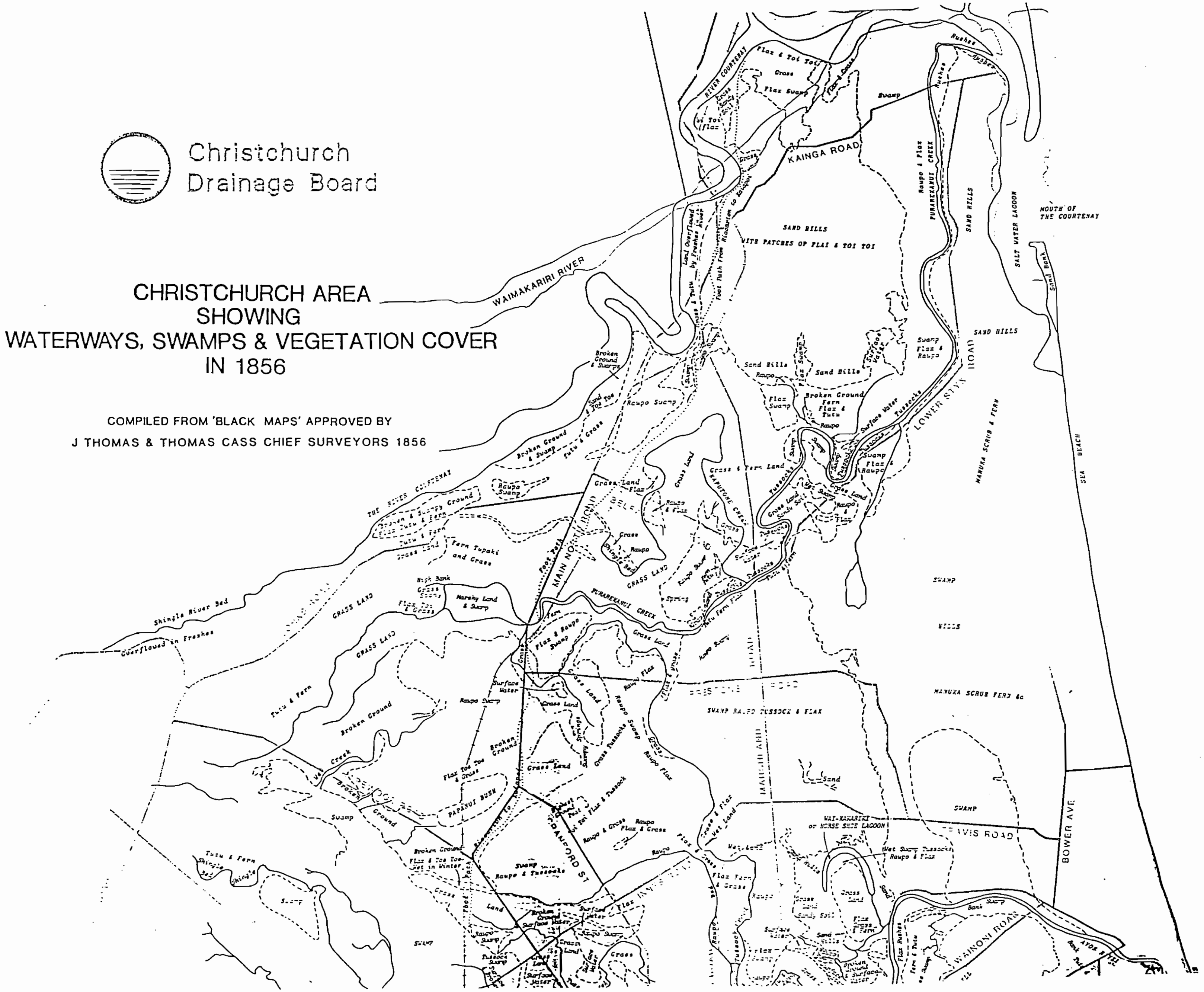

Figure 2.2 Pre-european landscape and vegetation of Styx catchment compiled from 'Black Maps' (from Wilson, 1989).

3 Sedimentation in Brooklands Lagoon

3.1 Introduction: a dynamic setting

Brooklands Lagoon owes its origin principally to the interaction of the large, powerful, and sediment-laden Waimakariri River and a predominantly southerly longshore drift along the prograding Pegasus Bay coast. Superimposed on these controls are the effects of sand blowouts and inflows from the Styx River. Man has also had an influence, in stabilising the Waimakariri mouth and sand-dune blowouts.

Left to its own devices, the Waimakariri River mouth would likely migrate from somewhere just north of its current position to the south end of Brooklands Lagoon. There would be a cycle of the river breaking through the spit near the location of the current mouth during a large flood, with the mouth then moving southwards again under the influence of the longshore drift, and the lagoon deepening to accommodate the flow as the mouth moved south. When a breakout occurred the lagoon would be left as a deep backwater which would quickly infill with sediment spilled from the river, blown over the sand spit by the prevailing northeasterly wind, or washed over by storm waves. Even with the present lagoon configuration, the Styx River likely exerts only a small influence on lagoon sedimentation processes, mainly in reworking the lagoon sediments towards the mouth, and then generally only when the tide is low. The supply of sediment to the lagoon from the Styx catchment is small compared to the amount that circulates in and out with Waimakariri water.

In this section, we review the recent history of change at Brooklands Lagoon, look at the evidence for sedimentation recorded on cross-section surveys, and assess how future sedimentation might progress.

3.2 Recent History

The lower reaches of the Waimakariri River and the Brooklands Lagoon area have changed dramatically in the last 140 years through a combination of natural events and river control works (Knox et al., 1978; Blakely and Mosley, 1987; Owen, 1992). Maps and photographs show the changes well. An 1865 map attributed to Doyne (Fig. 3.1a) shows the lagoon with a very wide mouth between spits built from north and south. A map dated 1880 shows only a short spit attached at the north and no lagoon at all (Fig. 3.1b). A further map dated 1928 (Fig. 3.1c) shows a configuration similar to that of 1865.

In 1930, in an attempt to lessen the risk of flooding, engineers made a cut in the sand hills to create a new direct course to the sea to the south of the current opening. The river continued to use the natural mouth until 1940 when it shifted 3 kilometres north to its current position during a flood (Fig. 3.1d). Rock bank protection on the north bank of the river opposite Brooklands Lagoon probably

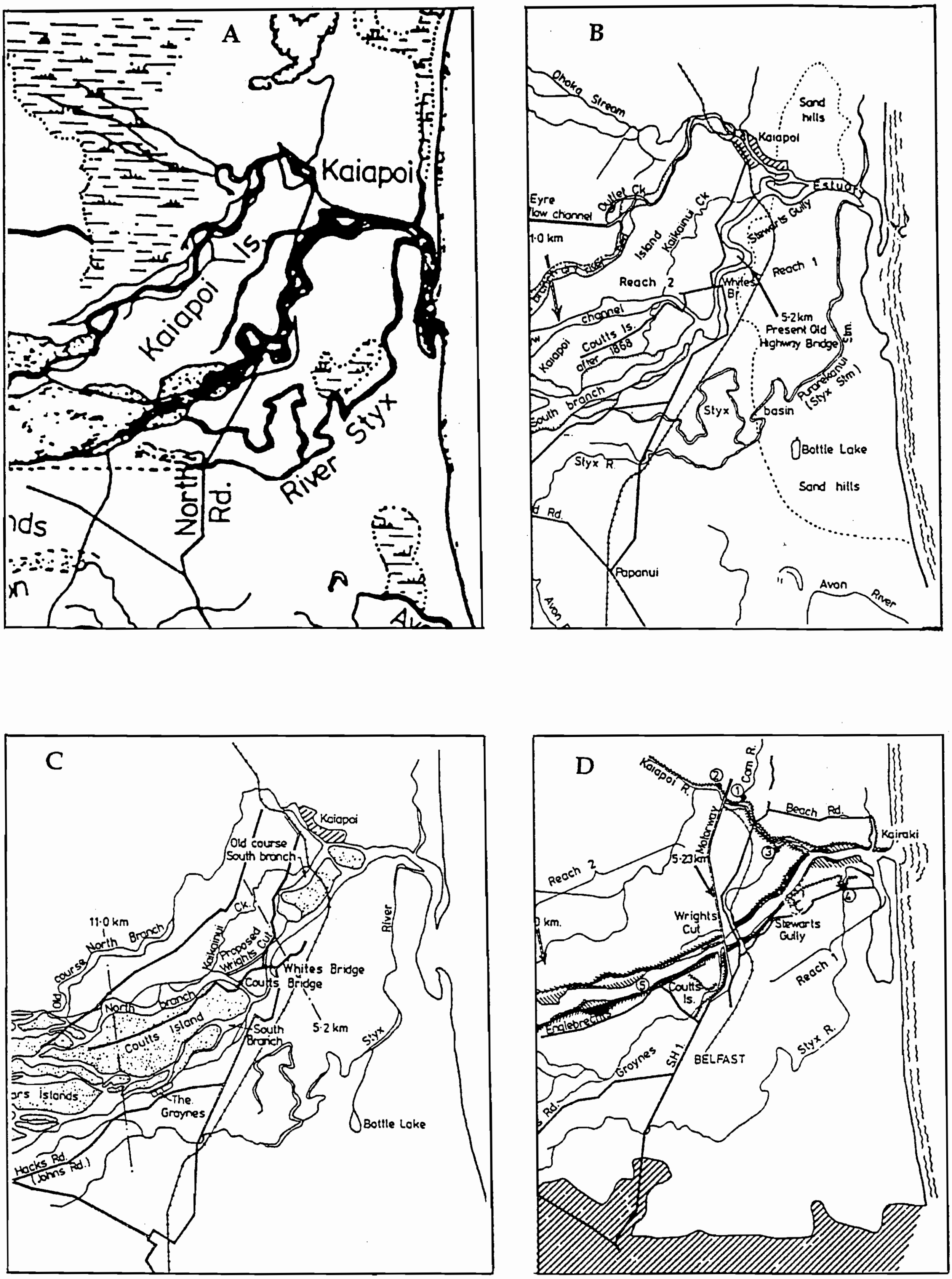

Figure 3.1 Lower Waimakariri River and Brooklands Lagoon as they were: A in 1865, B in 1880, C in 1928, D in 1982 (from Blakely and Mosley, 1987).

encourages the mouth to maintain its present position.

Photographs from 1940 show the current spit area as a broad expanse of water and shifting sand bars with little vegetation and lagoon openings at the centre and north end. A 1983 aerial photograph shows dramatic changes, with vegetation on the spit and north bank of the Waimakariri (Blakely and Mosley, 1987). The present vegetation coverage is more extensive still, with large trees covering more of the spit than is evident in the 1983 photo (Owen, 1992). Thus, what was a desolate area of shifting sand bars and lagoon mouths before 1940 has now been transformed into a relatively stable, vegetated environment.

Although Owen (1992) reports (p. 103) that the southern end of the lagoon was silting-up even in the 1930's, the lagoon appears to have filled substantially since the 1940's, both with silt and sand from the Waimakariri River and sand blown and washed from the open coast.

In 1978, storms widened a narrow low point in the spit at the site of the old (1930's) river mouth, and over the space of a few weeks a 250 metre wide gap appeared in the dunes. Sand flooded into the lagoon on the high tides and with the prevailing north-easterly wind. The foredune here has since rebuilt with the help of fencing (Owen, 1992).

The mouth of the Styx River has been slowly but constantly shifting, at least in recent decades. Boyle (1984) reported that from 1971 to 1979 the left bank was eroding as the Styx channel migrated laterally towards the Waimakariri. This trend reversed from 1979 to 1983. Currently the Styx River is eroding its left (northeast) bank again. This instability of the Styx may partly reflect its attempts to maintain its conveyance in the face of a shallowing lagoon.

The sandspit is eroding on its Brooklands Lagoon bank from opposite the Styx mouth to the confluence of the Lagoon with the Waimakariri River, in the region where the sandspit is widest. From Boyle's (1984) report, this erosion appears to have continued since the 1970's. There are two likely explanations. Firstly, there is a wide band of large *Pinus radiata* trees on the north end of the spit which effectively filter out any wind blown sand, so there is no replacement of any sand eroded away. Secondly, the Styx River is building a shallow delta where it enters the lagoon, which appears to have forced the tidal channel in this narrow part of the lagoon eastwards against the spit.

3.3 Sedimentation rates: past and future

The changes in Brooklands Lagoon have been measured with surveys of thirteen cross-sections spaced between 188 and 408 metres apart along the long axis of the lagoon (Fig. 3.2). Surveys of nearly all cross-sections were made in 1932, 1969 and 1977, with additional surveys at the mouth in 1973, 1978 (section H only) and 1984. Data presented by Knox et al. (1978) on mean bed level change at these cross-sections shows considerable deposition between 1932 and 1969, with close to 1 m of average deposition in the old Waimakariri channel through the lower third of the lagoon (Fig. 3.3). We calculate that for the lagoon as a whole some 1.4 million m^3 were deposited over this period, which amounts to a 53% decrease in the spring tidal prism volume (Fig 3.4). Presumably,

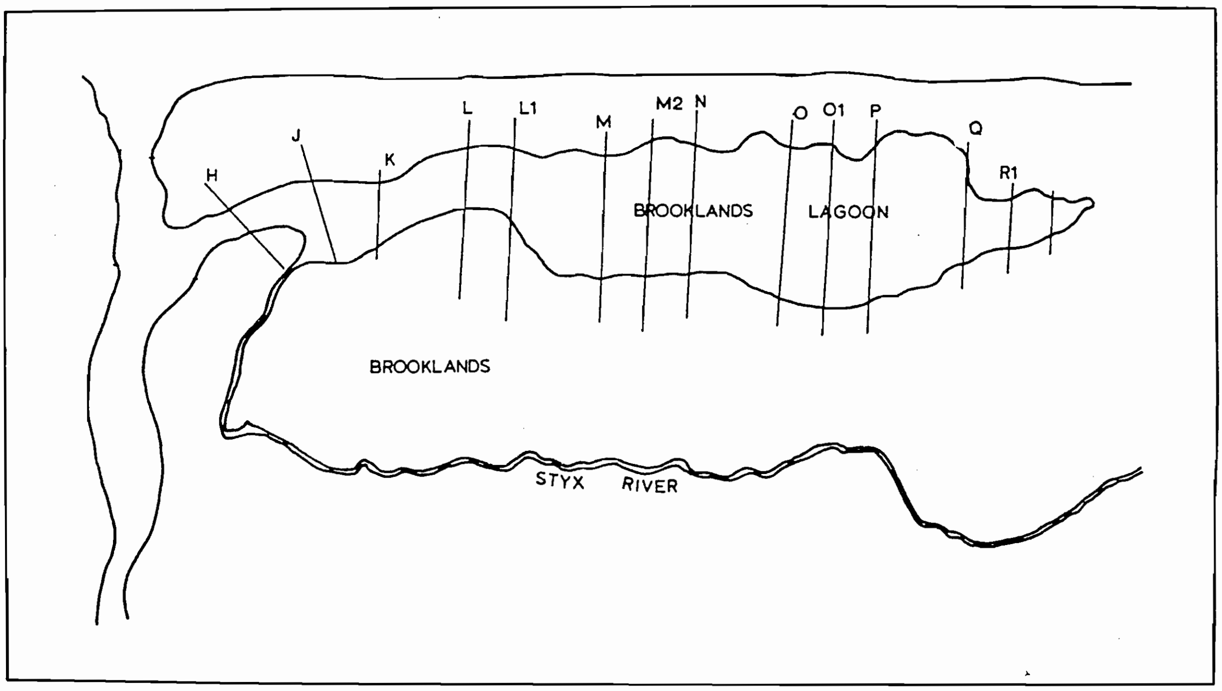

Figure 3.2 Brooklands Lagoon showing locations of cross-sections.

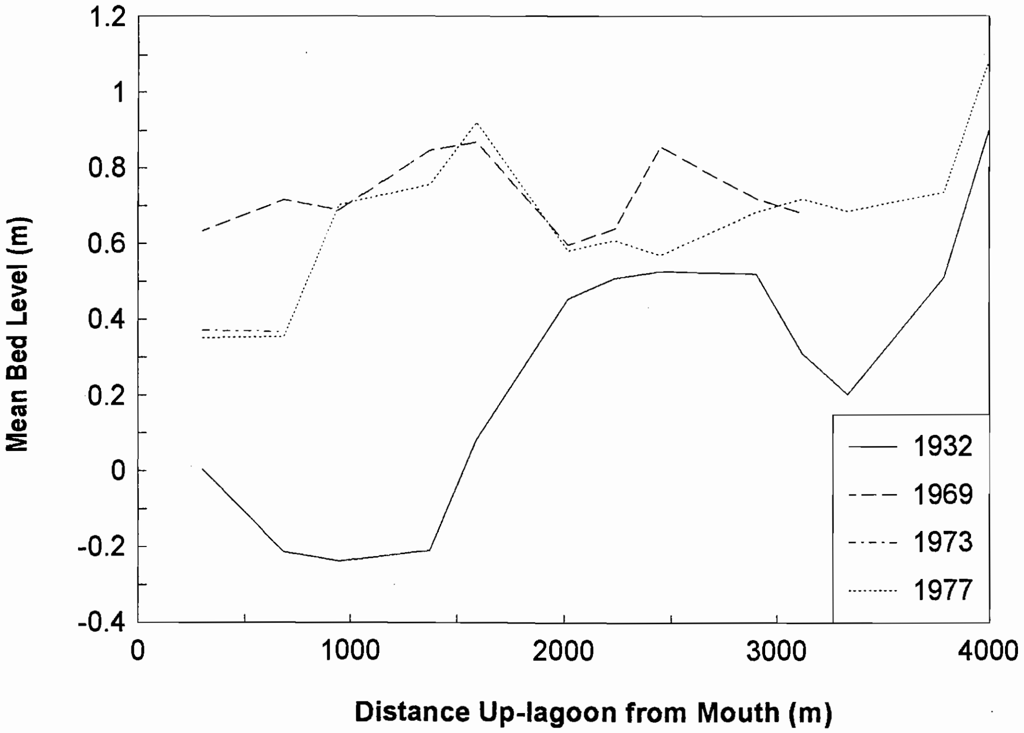

Figure 3.3 Mean bed level profiles of Brooklands Lagoon, 1932 to 1977 (from data presented by Knox et al., 1978).

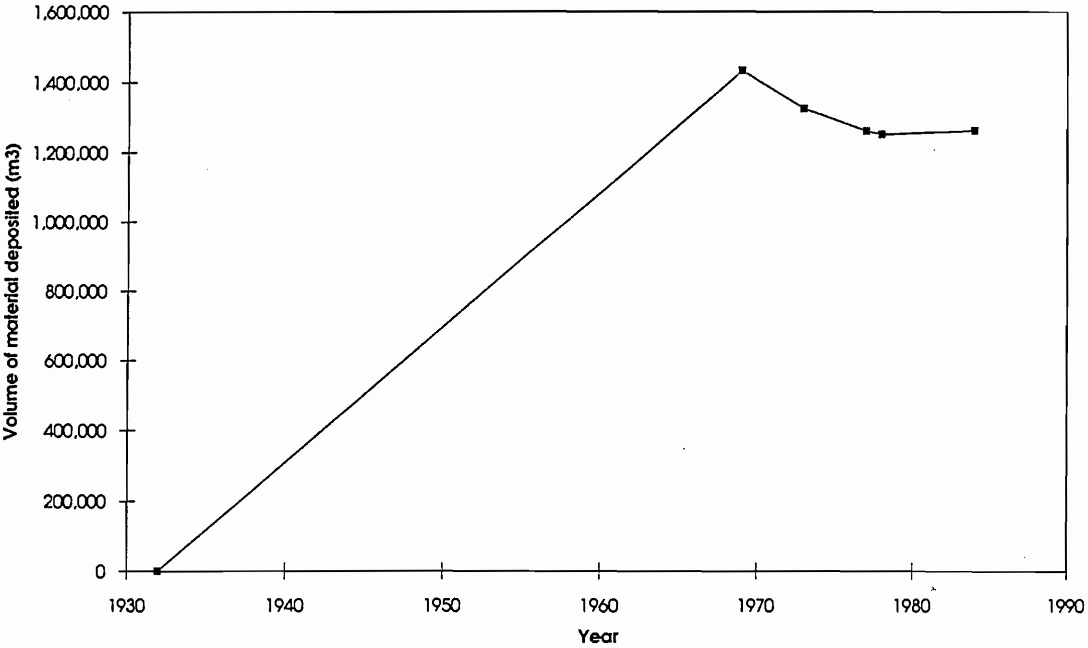

Figure 3.4 Brooklands Lagoon volume changes between 1932 and 1984, as determined by cross-section changes.

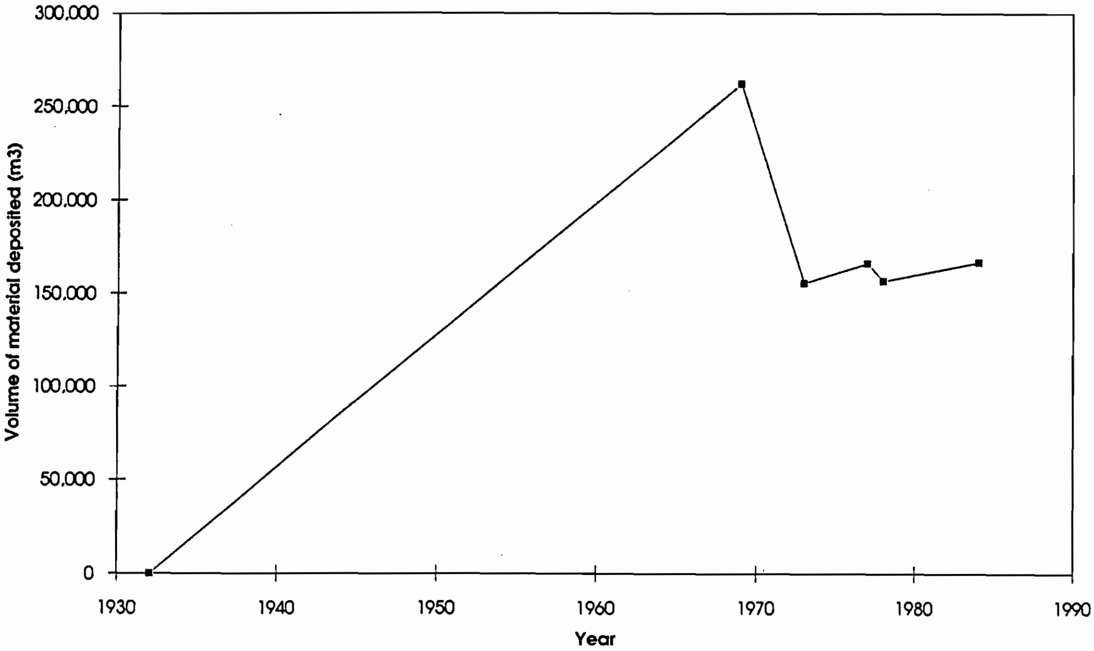

Figure 3.5 Volume changes in Brooklands Lagoon between sections J and H (near the Styx River mouth and the Waimakariri River - see Figure 3.2).

most of this deposition occurred soon after the change in the position of the Waimakariri River mouth in 1940.

Since the 1969 survey, changes have been relatively minor, indeed, with some increases in mean depths and lagoon volume in places (Figs. 3.3 and 3.4). The mouth area appears to have been the most active, with local erosion and deposition occurring in association with tidal channel migration, bar growth, and bank erosion. A loss of some 100,000 m^3 of material from the lagoon as a whole after the 1969 survey can be traced largely to changes at sections H and J near the mouth (Fig. 3.5). The most recent surveys of these two sections showed a net rise in the mean bed level of the lagoon at section H and a net fall of 15 mm at section J between 1977 and 1984 (Boyle, 1984).

Contrary to the evidence of these surveys, the anecdotal evidence is that the lagoon is continuing to fill appreciably. Sediment laden water certainly does fill the lagoon during Waimakariri floods, and drapes of mud a few mm thick cover the bed of the lagoon following these events. This sediment is, however, easily resuspended by wave action, and much may be removed from the lagoon with outgoing tides.

Thus our conclusion is that the rate of infilling of the lagoon is reducing asymptopically, with the present and future average rates liable to be no more than a few mm per year. The main net deposition can be expected to build north as the shallow flats at the Spencerville end are gradually transformed to marsh.

The chances of injection of coastal sand from wind-blows and/or storm wash-over should lessen progressively as the spit grows in width and height and is stabilised by vegetation. The likelihood of another major migration of the Waimakariri mouth should also diminish for the same reasons. The chances of a large input of sediment from the Styx catchment are small, given the present low yield (300-3900 m^3/yr) and given that the bulk of the Styx's sediment load appears to be trapped in the near-flat reach upstream of the tidal gates (see sections 4-6).

In the above, we have assumed that there has been little change since the last partial survey of the lagoon in 1984, while the last full survey was 16 years ago in 1977. We recommended that a full survey be carried out to confirm this assumption. Aerial photographs, taken every 5-10 years, would establish the erosion rate of the lagoon shoreline and the shifts in the banks of the Styx where it enters the lagoon.

4 River Channel Sedimentation and Dredging

4.1 Background

4.1.1 Information Needs

Sedimentation in the Styx River channel creates a number of problems, ranging from recreational (e.g., impaired navigation of small craft) to engineering (e.g., reducing flood-carrying capacity and drainage capability). Addressing these problems, the Styx River has been dredged on a semi-regular basis for the past 30 years. This dredging is a costly exercise, but to date has not generally been planned and conducted on a scientific basis. Information on channel sedimentation derives from two sources: repeat surveys of cross-sections and dredging volume records.

4.1.2 Cross-sections

Cross-section networks have been established on both the Styx River and Kaputone Creek. The Styx cross-sections begin at Brooklands Lagoon and extend some 23 km upstream to beyond Woolridge Road. The Kaputone Creek sections extend from the Styx River confluence upstream to near Johns Road. Surveys have been repeated from time to time, for assorted purposes, on some of the cross-sections in these networks.

Fig. 4.1 shows the space-time coverage of the Styx cross-sections. Only the 1984 survey (72 sections) covers the whole Styx River. The only other survey with similar coverage was in 1969 (41 sections) from Cunliffe Road to the tidal gates. A five section survey from the Oruhia Loop to Spencers Drain just downstream from Earlham Road was done in 1967. A similar survey from just upstream at Dunlops Road (five sections) was carried out in 1989.

The 1984 survey also included some tributary drains such as Horners Drain, but as there are no other surveys to compare them with they were not studied. In 1980 five sections were surveyed on Kaputone Creek, followed by a 17 section survey in 1986. As no sections were coincident, as little dredging had taken place (two chain in 1959), and as sediment movement appeared to be low, these sections were not studied.

4.1.3 Dredging

A compilation of dredging records for the Styx, Avon and Heathcote Rivers is given by Lovell-Smith (1992). The Styx River dredging record extends from 1952 to 1989 but has some gaps up to 1963. After 1959, annual estimates of dredged volumes are provided. These are based on counts of truckloads of spoil, assuming an in-situ volume of 2.5-3 m^3 per truckload. Before 1959, the information is limited to either the locations and chainages of channel worked by the dredges or simply the locations. In recent decades, the dredging has been mainly conducted by dragline (Lightfoot, 1990). The spoil has generally been removed to land-fill sites by truck, although it has sometimes been left on river banks. Low bunds of spoil are still evident on the banks from Earlham to Spencerville Roads. Their

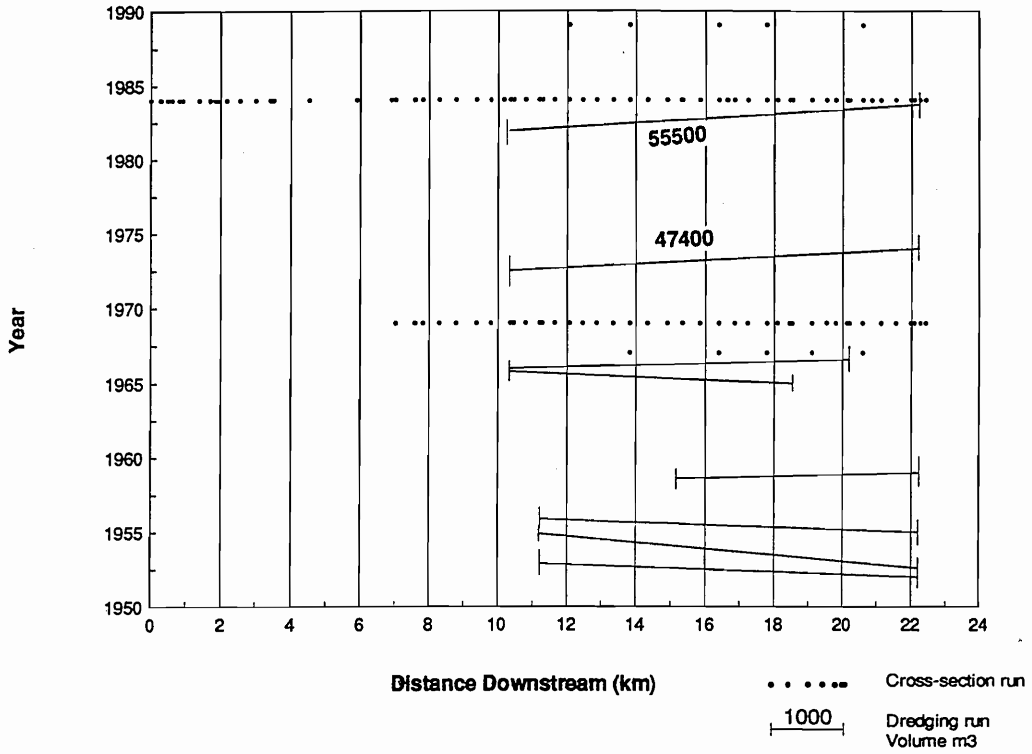

Figure 4.1 Time-distance plot showing cross-section surveys and dredging runs on the Styx River.

volume is estimated at 10,000 m^3. There is no record or knowledge of dredging of the Styx River before 1952.

A scheme for improvement of the Styx River originated with the Waimari District Council in 1950. It provided for a 9.3 m wide dredged channel from the tidegates up to the Marshland Road Bridge and a cleared and deepened channel at the proposed outlet to the diversion of Horners Drain. The dredging, carried out by dragline, was completed during 1952. As early as 1954 the deepening and widening continued a further kilometre upstream to Radcliffe Road. Further dredgings continued to 1955. Maintenance dredging was then carried out at about 10 yearly intervals in 1965-66, 1972-73, 1981-82, and 1993. The early dredging was a major exercise with one or two dredges working full-time for years at a time. The 1993 dredging, by hydraulic excavator, was a lot more controlled, taking out less material, to form a design trapezoidal cross-section. This dredging occurred from the Oruhia Loop upstream to Radcliffe Road and lowered the mean bed level by about 0.3 m.

4.1.4 Purpose of this section

This section sets out to analyse systematically the information contained in the Styx cross-section database and to incorporate the results with records on dredging in order to establish a history of total and net (i.e., after dredging) sedimentation along the river channels. We also describe some channel changes observed after the 1993 dredging run.

4.2 Methods for Analysis of Cross-Sections and Dredging

4.2.1 Calculating cross-section areas and mean bed levels

The ideal approach for comparing area changes between two repeat surveys of cross-sections is to calculate the area change between fixed points on either bank. This requires that the repeat surveys reoccupy exactly the same line. Unfortunately, we could not be sure of this condition for many of the Styx sections, for example, sometimes repeat sections started from a different end-point or appeared to be located a few metres upstream or downstream. Because of these problems, an alternative approach was employed. This involved determining the change in channel area below a datum surface which sloped downstream at the average bed slope (Fig. 4.2). In practice, this surface was defined by a step function which was tuned by trial-and-error to ensure that the datum at any cross-section was lower than bank level yet covered the bed[1]. By this method, the mean bed level at a section, z_b, was calculated as:

$$z_b = z_o - A/w$$

where z_o is the datum surface level, A is the channel area below the datum, and w is the channel width at the datum surface.

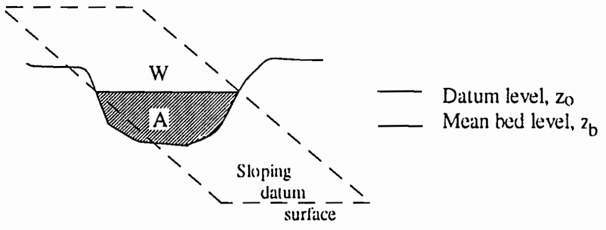

Figure 4.2 Definition diagram for determining mean bed level under a cross-section. z_o is datum level, z_b is mean bed level, A is channel area below datum, W is channel width at datum.

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[1] The step function used for the Styx channel is:

$z_o = 30.8 - 1.92x$ for $x < 7$

$z_o = 30.2 - 2.232x$ for $7 < x < 7.7$

$z_o = 20.0 - 0.9375x$ for $7.7 < x > 10$

$z_o = 12.5 - 0.19x$ for $10 < x < 12.5$

$z_o = 11.85 - 0.1333x$ for $12.5 < x < 25$

where z_o is the datum level (m) and x is an arbitrary distance downstream (km), with the tidal gates at 22.438 km.

4.2.2 Calculating reach volume changes

The river lengths were sub-divided into reaches on the basis that channel form and slope remained relatively uniform along a given reach. Generally, the reach boundaries were adjusted to coincide with the runs of cross-section surveys and/or dredging (Fig. 4.1). The sediment volume within a reach at any survey time was found by the end-area technique, i.e., by multiplying the average area at two adjacent cross-sections (below the datum surface) by the length of channel between, and summing along segments of the reach[2]. The width of the datum surface at each cross-section, integrated with distance along the reach, provided the surface area of the reach. Dividing the reach volume by the reach surface area provided the average net sediment depth along the reach. Average reach sedimentation rates were found by dividing reach sedimentation volumes and average depths by the time period between surveys.

The cross-section surveys show the net changes in sediment storage, either a net loss due to dredging exceeding sedimentation, or net deposition with sedimentation exceeding dredging. Thus the actual sedimentation equals the sum of the dredging and the net change in bed storage indicated by the cross-section surveys.

4.3 Results

4.3.1 Bed Levels

Mean bed level (MBL) and thalweg changes along the Styx River are shown on Fig 4.3. The following interpretations are made with some caution, owing to the uncertainties in cross-section relocation discussed previously and the few cross-sections surveyed on several occassions.

There is very little difference in MBL between the 1967 and 1969 surveys, which span a period without dredging. The latter appears to give a slightly lower MBL upstream from Spencerville Road and a slightly higher MBL below it. The 1969 thalweg is generally higher than the 1967 thalweg, reflecting deposition.

Between the 1969 and 1984 surveys, there was only a minor increase in MBL above Radcliffe Road (Fig. 4.3a), and the thalweg profile (Fig. 4.3b) indicates a stable bed upstream from the Horners Drain confluence. Downstream from Radcliffe Road, the MBL profile indicates a general lowering of the bed between 1969 and 1984, with 'holes' being evident below Trelevan's Drain and below Spencerville Road. The general reduction in bed level over this period is consistent with the two dredging runs which took place in 1972-73 and 1982-83. The variation in thalweg levels downstream from

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[2] A spreadsheet-type calculation approach for determining sedimentation/erosion depths and volumes was used in this study. The cross-section survey data were supplied by Christchurch City Council in MIKE II format. This was translated into an intermediate text format for input to a specialist program that calculated areas and widths below the datum surface. Output from this was imported to an EXCEL spreadsheet for integration of reach volumes and averages.

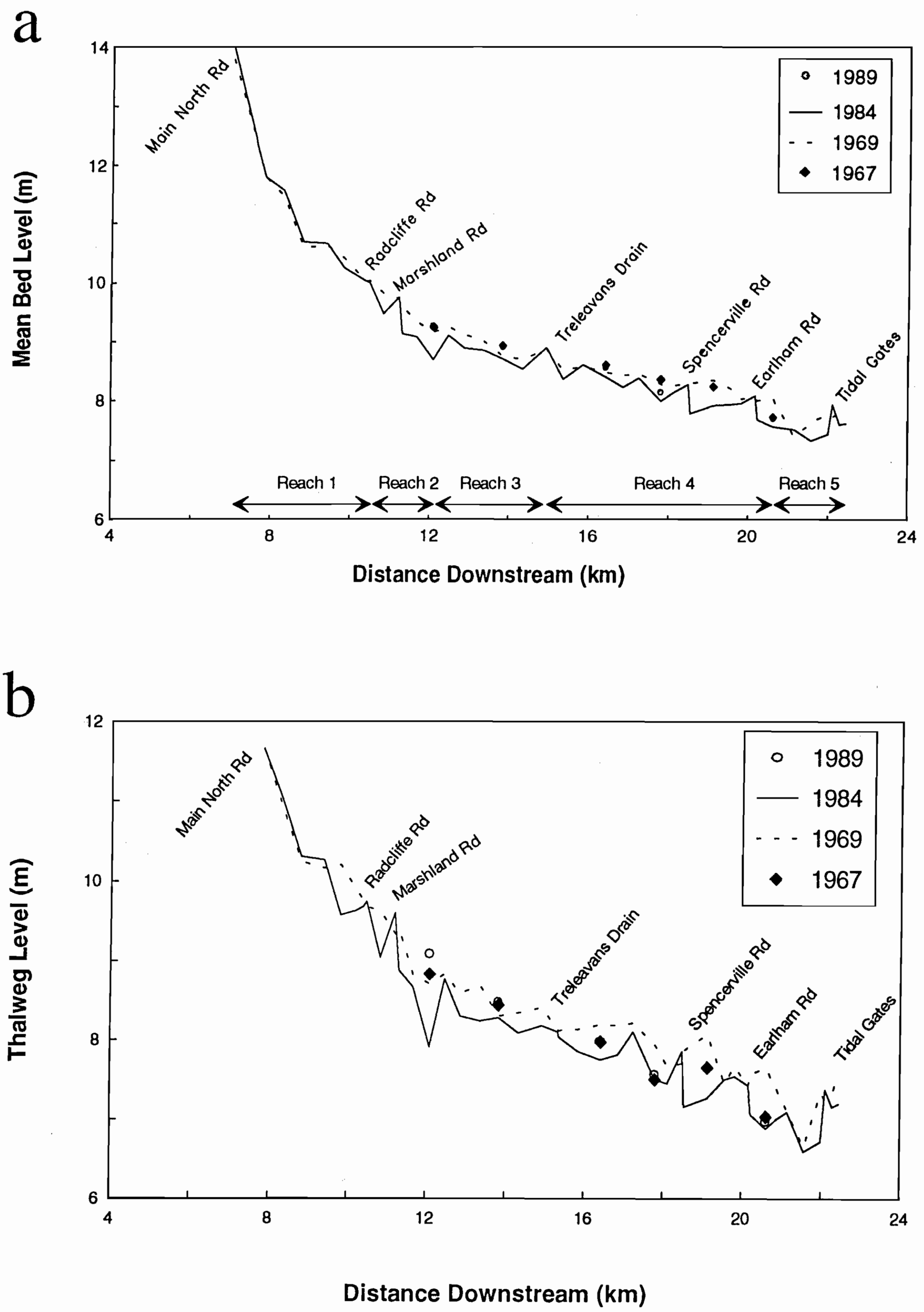

Figure 4.3 Bed level profiles of the Styx River, 1967 to 1989: **a** Mean bed levels, **b** thalweg levels.

Radcliffe Road indicates that the dredging locally dropped levels by up to 0.7 m.

The few cross-sections surveyed in 1989 indicate that at least upstream from Spencerville Road the bed had aggraded to near its former (1967-69) levels, with the 'hole' downstream of Trelevan's Drain having been filled.

Thus overall along the lower Styx, between the first survey in 1967 and the most recent in 1989, there was very little net change in mean bed level, except for a minor drop of 0.22 m just above Spencerville Road. Because the lower Styx was dredged in 1972-73 and 1982-83, the lack of net change indicates ongoing sedimentation.

Changes at 10 cross-sections down the 1.4 km reach between the tidal gates and Brooklands Lagoon from 1979 to 1983 were analysed by Boyle (1984). His analysis showed an irregular pattern of mean bed level change, ranging from + 0.21 m to - 0.28 m.

4.3.2 Volume changes

There are two sections of the river that can be examined for volume changes.

Firstly, we can compare the combined effects of the dredgings in 1972-73 and 1982-83 with the bed material volumes measured by the extensive surveys in 1969 and 1984. These are examined on a reach basis, with five reaches being defined between Main North Road and the tidal gates on the basis of changes in slope, whether dredged or not dredged, and cross-section location (Fig. 4.3). The results of this analysis are summarised in Table 4.1. The volumes per unit channel length plotted in Fig. 4.4 clearly indicate where deposition and dredging were most active.

Points to note are:

- In the steeper Reach 1, upstream from Radcliffe Road where there was no dredging, there was little change in volume recorded by the surveys and the average deposition rate was 2 mm/year.
- Dredging and deposition rates were greatest in Reach 2 (from Radcliffe Road to the upstream end of the Oruhia Loop near Dunlops Road). There, the average sedimentation depth was 0.72 m at a rate of 48 mm/year (12400 m^3 deposition over a bed area of 17200 m^2 in 15 years)
- In Reaches 3 to 5, from the Oruhia Loop downstream to the tidal gates, the dredging and deposition volumes per unit channel length were about two-thirds those in Reach 2, while the average depostion rates decreased to 26 mm/yr in Reach 3 and 19 mm/yr in Reaches 4 and 5.
- Along the four dredged reaches (i.e. Reaches 2-5) between 1969 and 1984 approximately 92000 m^3 were dredged, there was a net enlargement of the channel by 33000 m^3, thus some 59000 m^3 were deposited.
- The pattern of dredging mirrors the pattern of deposition (Fig. 4.4b), indicating that the dredging has generally been 'in tune' with the deposition.

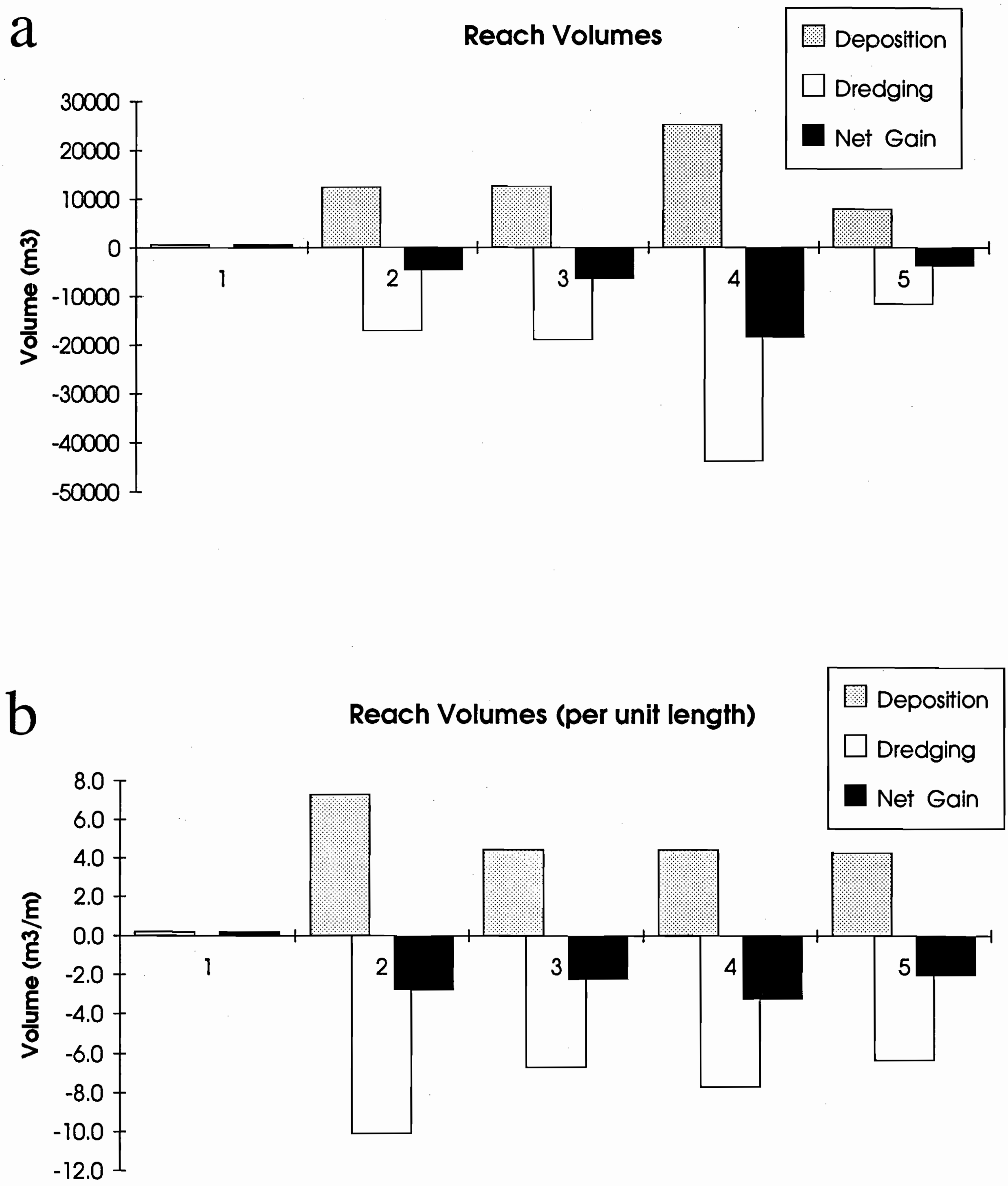

Figure 4.4 Net-change, deposition, and dredging volumes down Styx channel, 1969 to 1984: **a** volumes per reach, **b** volumes per metre length of reach.

Reach No.	Sectns	Dist D/S (km)	Reach Length (km)	Reach Surf. Area (m2)	Ave Surf Width (m)	1969 Vol (m3)	1984 Vol (m3)	1969-84: Volumes (m3) Deposition	Dredging	Net Gain	1969-84: Unit Volumes (m3/m) Deposition	Dredging	Net Gain	1969-84: Depths (m) Deposition	Dredging	Net Gain	Deposition Rate (mm/yr)
1	SR350-430	10.385	3.355	21557	6.43	13763	13096	667	0	667	0.2	0.0	0.2	0.03	0.00	0.03	2.1
2	SR290-350	12.085	1.7	17168	10.10	12280	17066	12393	-17179	-4786	7.3	-10.1	-2.8	0.72	-1.00	-0.28	48.1
3	SR230-290	14.924	2.839	31996	11.27	33910	40340	12618	-19048	-6430	4.4	-6.7	-2.3	0.39	-0.60	-0.20	26.3
4	SR080-230	20.609	5.685	90849	15.98	84410	103035	25267	-43892	-18625	4.4	-7.7	-3.3	0.28	-0.48	-0.21	18.5
5	SR020-080	22.438	1.829	26632	14.56	33517	37320	7829	-11632	-3803	4.3	-6.4	-2.1	0.29	-0.44	-0.14	19.6
Totals			15.408	188202		177880	210857	58774	-91751	-32977							20.8

Table 4.1 Results from analysis of cross-section surveys and dredging of Styx channel for period 1969 to 1984.

Period	Surface Area (m2)	Net Change (m3)	Dredging (m3)	Deposition (m3)	Deposition rate mm/yr	m3/yr	m3/m/yr
1967-69	98083	5398	0	5398	27.5	2699	0.32
1969-84	98083	-17735	62940	45205	30.7	3014	0.35
1984-89	98083	14474	0	14474	29.5	2895	0.34
1967-89	98083	2137	62940	65077	30.2	2958	0.35

Table 4.2 Results of analysis of cross-section change and dredging for Reaches 3 and 4 over the period 1967 to 1989.

Secondly, the additional 1967 and 1989 surveys in Reaches 3 and 4 allow an examination of volume changes over a longer time period than discussed above. Although overlapping at only 5 cross-sections, the four surveys, when combined with dredging volumes, indicate a steady deposition rate of around 3000 m^3/yr, equivalent to a spatially-averaged deposition rate of around 30 mm/yr (Table 4.2)[3]. They also show that the increased channel volume between 1969 and 1984 due to the dredging runs in 1972-77 and 1982-83 was almost eliminated by deposition between 1984 and 1989.

In summary, there has been little change in the undredged upper reach above Radcliffe Road, while downstream, deposition has more-or-less matched dredging.

4.3.3 Comments

The general observation can be made that deposition is related to bed slope, with deposition rates being greatest immediately downstream of the main reduction in slope, then with lesser but uniform deposition along the long gently-sloping reach down to the tidal gates. The tidal gates themselves likely influence the deposition (see section 5).

Excessive local dredging, such as below Spencerville Road during 1973/73 and 1982/83, creates a 'hole' which the river immediately attempts to fill.

To minimise the amount of future dredging, and to encourage sediment to pass down the river, future dredging should be carried out to a designed hypsometric profile and cross-section shape. The fact that sedimentation follows dredging indicates that the past dredged profiles have not been equilibrium profiles.

Future monitoring should include cross-section surveys at about 1 kilometre intervals from 1 km above Radcliffe Road to the tidal gates, based on the current cross-sections, to be carried out at 5 yearly intervals. The cross-sections should be tied in with one another, have a permanent bench mark at one end and a permanent location for the other end of the cross-section. The cross-sections further upstream should only need to be resurveyed prior to any major urban expansion. Some attention should be given now, though, to ensuring that the locations of the endpoints and benchmarks for these sections are well documented.

Records should be kept of any dredging. These should include the location, duration, machine size and type, bucket capacity and estimates of volume, whether carried away or left on the banks. The machine work rate and duration of job should reconcile with the volumes of material dredged. Surveys should be carried out before dredging in order to target the dredging.

We suggest a one-off investigation to clarify how dredging 'holes' propagates upstream, and to establish how quickly they refill. This

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[3] The accuracy of these results calculated from only five widely-spaced cross-sections can be assessed by comparing the 3013 m^3/yr deposition so-calculated in the period 1969-1984 (Table 4.2) with the 2525 m^3/yr deposition calculated from all 22 sections along reaches 3 and 4 (Table 4.1). This comparison suggests that the 22-year average deposition rate for these reaches is about 2500 m^3/yr (equivalent to 25 mm/yr).

would involve resurveying selected cross-sections now (i.e., immediately after the 1993 dredging run), then annually for the next 3-5 years. At the end of the experiment, measurements should be made of the bulk density of the new deposits. There is yet considerable uncertainty as to the density of the deposits that accumulate in conjunction with weed banks.

4.4 Observations of Channel Response to 1993 Dredging

The authors inspected the Styx channel on 8 October 1993, a few weeks after the 1993 dredging run was completed. In the reach between Radcliffe and Marshlands Roads, the dredging had lowered the channel by about 0.3 m, as indicated by the exposed low-flow line along the banks and the shift in water levels at the staff gauges. We also observed marked degradation of the tributaries and drains that enter the Styx along this reach - a response to the change in base level. Kaputone Creek had scoured some 0.3 m, changing its pre-dredging sandy bed to a gravel bed. We estimate that 500 m^3 of the quick fine sandy bed material that had previously accumulated in the Kaputone channel had been sluiced into the Styx by only the normal flows following the dredging. A sandy delta several m^3 in volume had built from the right bank drain at Marshlands Road. At Radcliffe Road, the normal flow velocities were much faster, the bed was cobbly gravel, and it was clear that the dredged hole was spreading upstream by headward scour.

Thus our impression was that dredging in the main lower Styx channel initiates a flush of bed material from the tributary streams and drains whose base level is controlled by the Styx (including the upper Styx). On the one hand this is beneficial, but it also leads to rapid redeposition in the Styx channel. We predict that as the Styx bed aggrades again through sedimentation, the tributary beds will also aggrade.

We observed that the dredged material was largely peaty silt, but there were significant patches of sand and gravelly sand. We interpret the coarser sediment as having been dredged from the centre of the bed, with the peaty silt originating from deposits within weed along the channel margins.

5 Effects of the Tidal gates and Weed

The tidal or flood gates near Harbour Road are designed to pass Styx flood flows downstream but to prevent high tides and flood waters from the Waimakariri River from passing upstream. They open when the upstream/downstream stage difference exceeds 100 mm, and close when the reverse is true (T. Oliver, Christchurch City Council, pers. comm.). By ponding water along an extended reach for roughly half of every day, these gates must certainly be inducing sedimentation - as is evident from the cross-section surveys. It is unclear, though, how much additional sedimentation occurs due to the tidal gates. Without the gates, the lower Styx would still be a sediment trap due to tidal backwater effects, sediment flocculation due to upstream penetration of saline waters, and periodic backflows by sediment-laden Waimakariri flood waters.

On the day of our inspection, the healthy raupo and grass vegetating the banks upstream from the gates attested to little saline penetration, while the Waimakariri-muddied waters downstream of the gates were far more turbid than the Styx waters upstream.

We suspect that for small to moderate sized floods, probably much of the Styx sediment load is trapped in the low gradient reach between Radcliffe Road and the tidal gates. The trap efficiency of this reach should be less with larger events.

Weed must also be a significant factor in trapping sediment in this reach, first by lowering velocities and secondly by binding the sediment to prevent resuspension. Typically, the weed grows up to within about 0.5 - 1 m of the water surface. Sediment will be trapped after falling from suspension into the slower, less turbulent flow through the weed layer.

Perhaps surprisingly, little is known about this process. Given the effort expended in weedcutting and dredging in the Styx[4], Avon and Heathcote catchments, we suggest that further research be conducted into the effects of weed on flow hydraulics and sedimentation.

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[4] In recent years, aquatic weed in the Styx channel has been cut twice per year in order to maintain channel conveyance (K. Couling, Christchurch City Council, pers. comm.)

6 River Sediment Loads

6.1 Introduction

Information on sediment loads is useful to clarify the need for dredging and to locate the sediment source areas in terms of sub-catchment and landuse. The latter pin-points where erosion control work may be required and allows estimate of changes in the sediment load arising from changes in catchment landuse.

Prior to this study, there was no useful information on sediment loads in storm runoff in the Styx catchment. The only existing information is of spot concentrations collected on a quasi-regular basis at several sites for the Christchurch City Council's Water Quality Monitoring Programme, and these were generally collected during low flows when the streams were clear (J. Robb., Christchurch City Council, pers. comm.)

The approach followed in this study was to measure sediment loads in storm runoff on the main tributaries that join near Marshlands Road. This location is at the upstream end of the low-gradient reach where the bulk of the channel bed sedimentation and consequent dredging occurs, and is upstream of tidal influence.

6.2 Data Collection

6.2.1 Sites

Five sites were monitored (Fig. 6.1). The Styx main stem at Radcliffe Road and Kaputone Creek at Riverlea were monitored continuously with instrumentation. Horners, Rhodes and Quaids Drains, all of which join and enter the Styx some 400 m upstream from the Radcliffe Road site, were monitored manually during two storm events. Table 6.1 shows catchment landuse and areas for these sites.

6.2.2 Instrumentation and Methods

The Styx and Kaputone sites had Kainga pressure transducers logging continuously to Campbell CR10 data-loggers, with Manning auto-samplers collecting water samples during storm flows. Their sampling was initiated when the water level exceeded a critical value, then continued at 30 minute intervals through events. Both sites were opened on 1 January 1993. Kaputone Creek was closed on 1 July; Styx at Radcliffe Road continues at the time of this report.

Flow gaugings were conducted during two stormflow events in order to derive stage-discharge ratings for these sites. During the same storms, manual suspended sediment gaugings were undertaken to obtain relationships between cross-section mean sediment concentration and the point concentration at the auto-sampler intakes. For these manual gaugings, depth-integrating samplers were used with the 'equal-transit-rate' method over five equally-spaced verticals. Some manual samples were duplicated to obtain samples for particle size analysis. These were analysed, after adding dispersant, by the 'pipette' method. Bedload sampling was

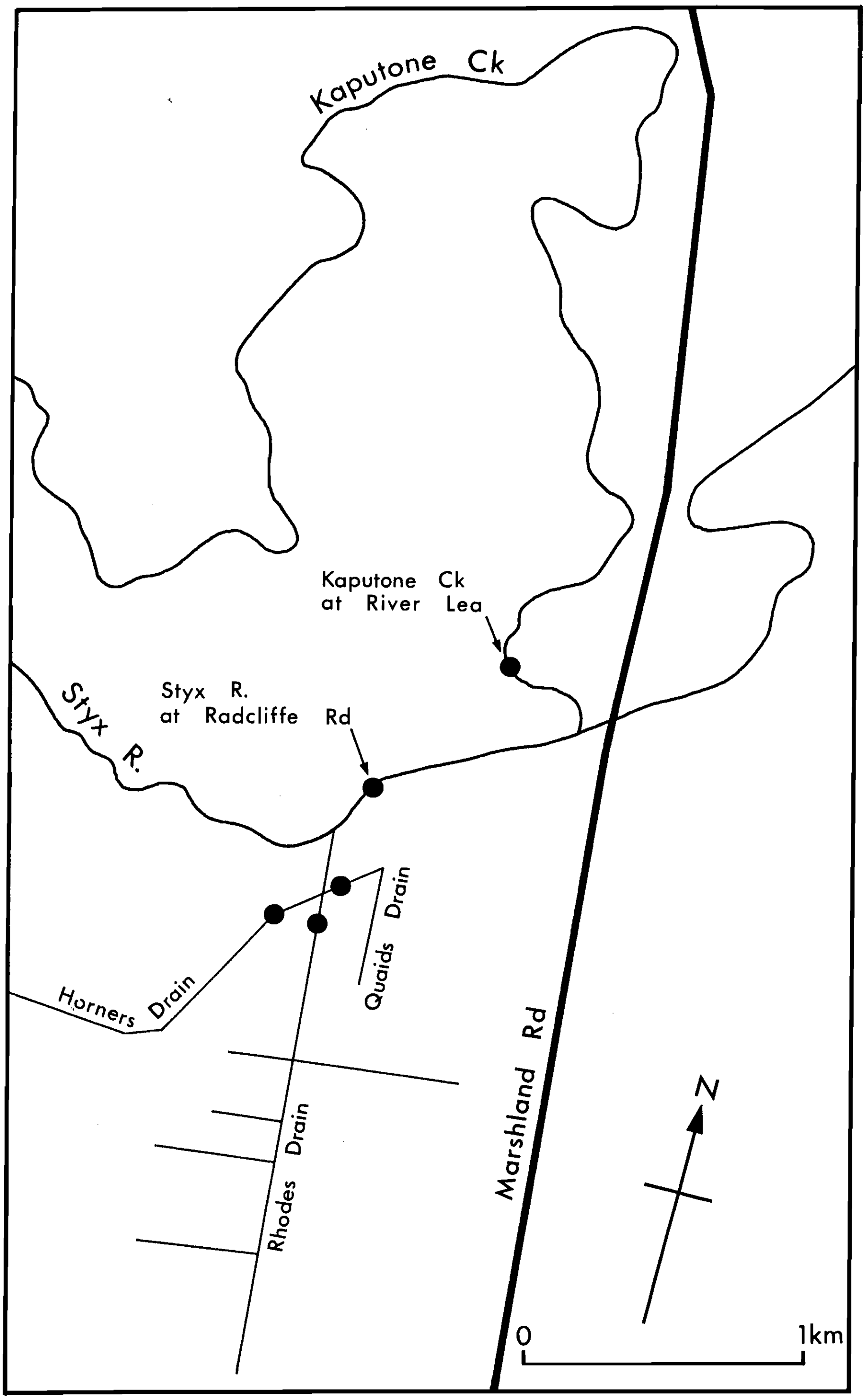

Figure 6.1 Locations of sites for storm sediment load measurements.

Landuse	Styx u/s Radcliffe Road	Styx u/s Horners Drain	Horners Drain	Rhodes Drain	Quaids Drain	Kaputone Creek	Styx d/s Marshlands Road	Total Styx
Industrial	1.2%	0.7%	3.0%			1.6%	2.6%	1.9%
Commercial	3.8%	4.1%	4.2%					1.6%
Residential	29.3%	21.9%	57.1%			11.1%	0.2%	14.0%
Rural	63.7%	73.0%	29.3%	100%	100%	86.6%	59.7%	64.4%
Schools	1.9%	0.4%	6.3%			0.5%		0.9%
Bush/ plantation/ dunes							37.5%	17.1%
Area (ha)	2157	1405	569	137	21	547	2278	4982

Table 6.1 Landuse and areas of Styx sub-catchments monitored for storm sediment loads.

attempted at both sites using a 75 mm orifice rod-mounted Helley-Smith sampler with a 0.25 mm mesh sample bag.

The three drain sites were monitored manually during the storm event of 17-18 May 1993. This involved observing the stage and collecting depth-integrated multi-vertical samples at intervals of several hours. Stage-discharge ratings were prepared for each drain based on measurements of channel width, depth and surface velocity. Once-only samples were collected from Horners and Rhodes Drains during an event on 11 February.

Suspended sediment concentrations were analysed by the filtration technique at the Christchurch City Council laboratory at Pages Road. A subset of samples were also analysed for organic (volatile) content. NIWA Oceanographic conducted the particle-size analyses.

6.3 Results

6.3.1 Auto-sampler calibrations

The relationships between cross-section mean suspended sediment concentration (Cm) and point concentration sampled by the autosamplers (Cp) are shown in Fig. 6.2. The regression relationships are:

Styx at Radcliffe Road: $Cm = 1.08\ Cp + 8.5$ ($r = 0.96$)

Kaputone Creek: $Cm = 0.93\ Cp + 3.6$ ($r = 0.99$)

Since the latter was not significantly different from a 1:1 relationship, no correction was applied to the Kaputone Creek autosampled concentrations.

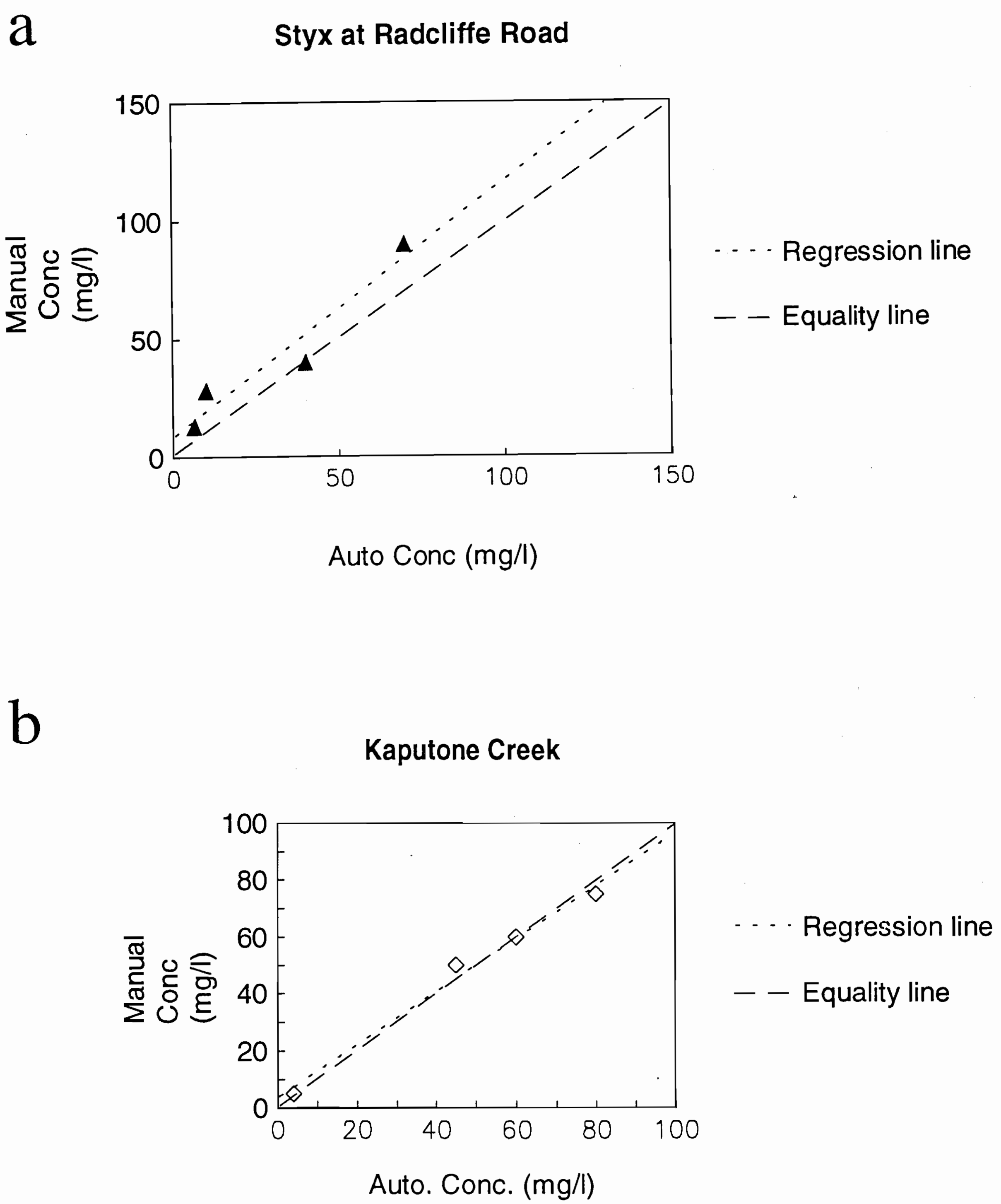

Figure 6.2 Calibration relationships between auto-sampled suspended sediment concentration and manually sampled cross-section mean concentration: **a** Styx at Radcliffe Road, **b** Kaputone at Riverlea.

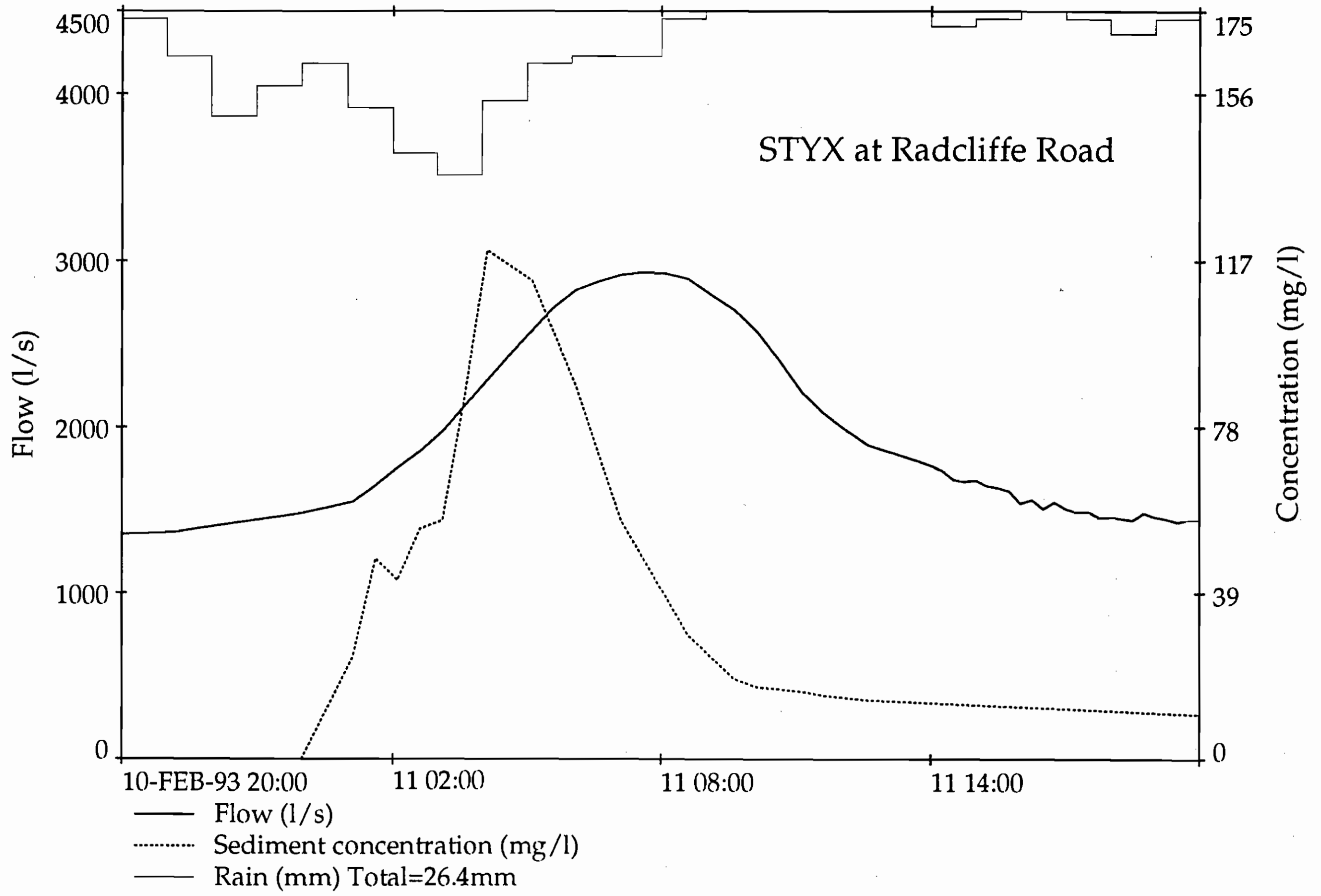

Figure 6.3 Flow, suspended sediment concentration, and rainfall for Styx at Radcliffe Road, storm of 10-11 February 1993.

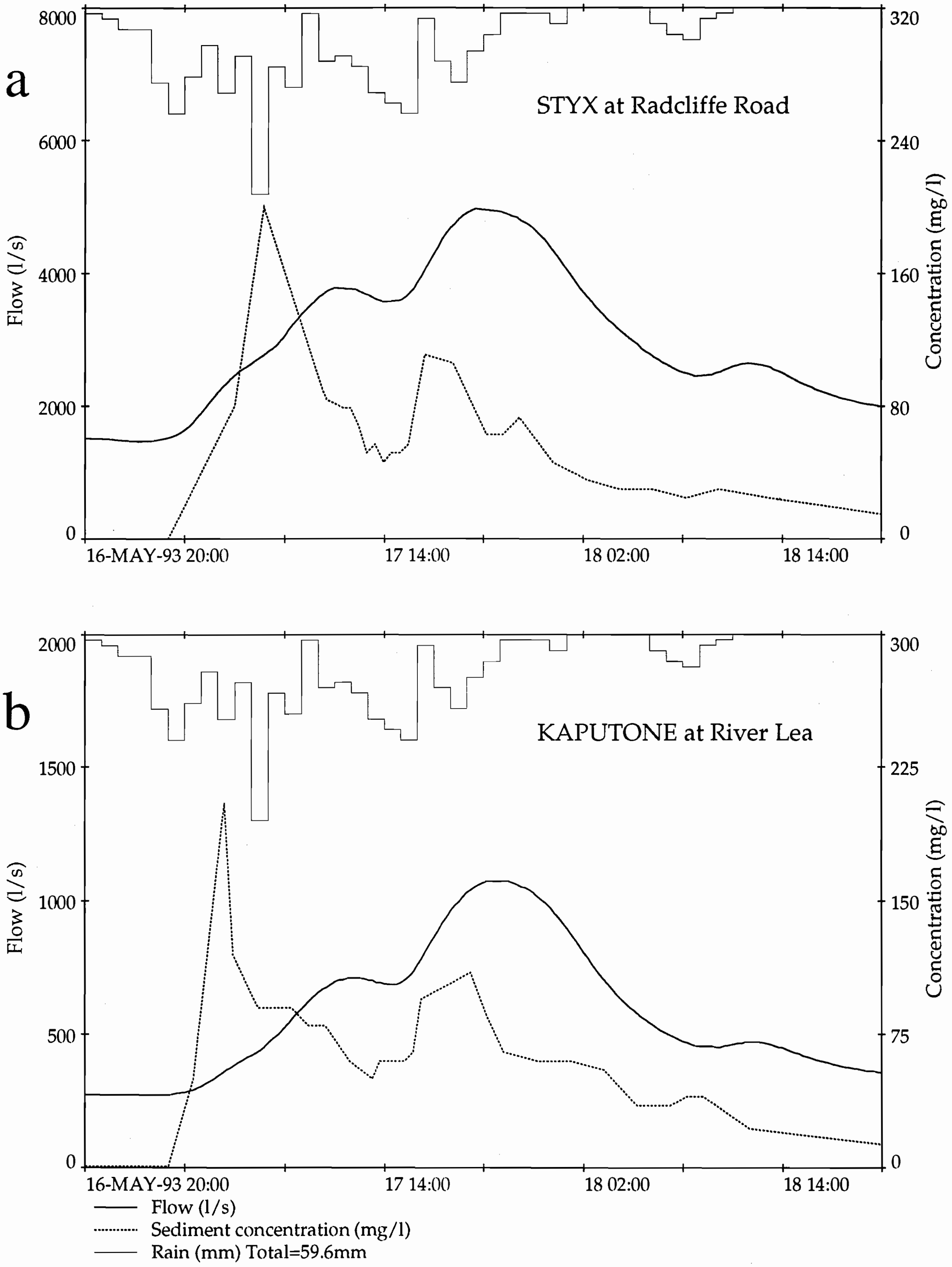

Figure 6.4 Flow, suspended sediment concentration, and rainfall for storm of 17-18 May 1993: **a** Styx at Radcliffe Road, **b** Kaputone at Riverlea.

6.3.2 Suspended sediment concentrations and storm yields

Sediment load data were collected during two storms. The storm time-series of discharge, concentration, and rainfall at Kaputone Creek and Styx at Radcliffe Road are shown in Figs. 6.3 and 6.4. Synthetic low concentration values were added at the start and end of the runoff events.

Summary results of sediment concentrations and yields are listed in Table 6.2.

Site	Peak Flow (l/s)	Maximum Sampled Concentration (mg/l)	Minimum Sampled Concentration (mg/l)	Measured Yield (kg)	Measured Specific Yield (t/km2)	Yield Estimated by Rating (kg)
Event of 10-11 February (930210 @ 2100 to 930211 @ 1900) Rainfall = 26 mm						
Styx	2930	102	5	6040	0.28	6170
Event of 17-18 May (930517 @ 0100 to 930518 @ 2100) Rainfall = 60 mm						
Styx	4970	95	15	30880	1.43	30300
Kaputone	1072	205	35	6030	1.10	7270
Horners Drain	748	270	60	9510	1.67	
Rhodes Drain	590	185	60	4890	3.57	
Quaids Drain	162	440	200	3410	16.2	

Table 6.2 Sediment yields measured at study sites during storms of 10-11 February and 17-18 May 1993. Yields also estimated using sediment ratings for Styx and Kaputone sites.

For the storm on 11 February 1993, when some 25 mm of rain fell overnight, hourly auto-samples were collected at the Styx site. Unfortunately, the Kaputone sampler failed to trigger, and so only manual samples were collected there during the event recession. Once-only manual samples were collected from Horners and Rhodes Drain at 0930 hours, about the time of the peak Styx flow. Quaids Drain remained dry. The Horners Drain water was turbid (concentration = 106 mg/l, 14% organics); Rhodes Drain water was less turbid and a darker brown colour, indicating a greater organic content of its suspended material (concentration = 17 mg/l, 45% organics). Kaputone Creek was similarly less turbid and darker brown in colour (concentration = 4-6 mg/l, 31-44% organics) than the Styx water. The Styx concentrations are shown in Fig. 6.3. For this event, the Styx sediment yield at Radcliffe Road was 6.0 tonnes, with the bulk of this appearing to originate from Horners Drain.

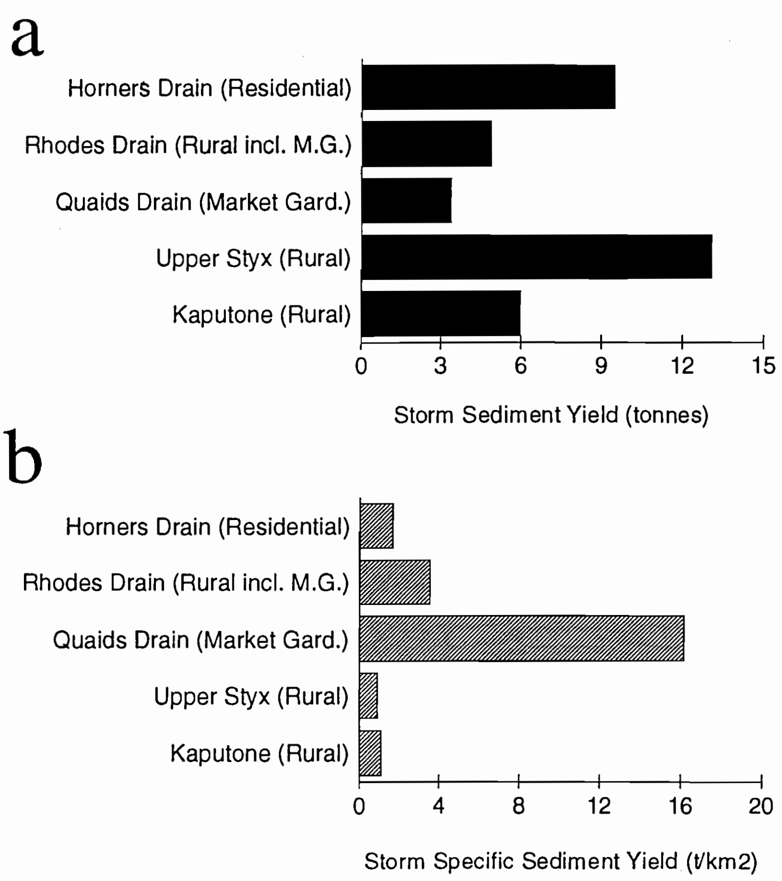

Figure 6.5 Yields of suspended sediment from Styx sub-catchments for 17-18 May 1993 storm: **a** total yields, **b** specific yields.

For the 17-18 May 1993 storm, when some 60 mm of rain fell, data were obtained at all five sites. This is summarised in Table 6.2. A sediment yield budget (Fig. 6.5a) shows that of the total yield of 37 tonnes at Marshlands Road, 48% came from the Horners Drain network, 36% from the upper Styx, and 16% from Kaputone Creek. The specific yields of Kaputone Creek and the upper Styx were both about 1 t/km^2; the drain specific yields were significantly higher due to the high input from Rhodes Drain and particularly Quaids Drain.

This pattern reflects catchment landuse, with the highest specific yield coming from the drain with a largely market gardening catchment and the lowest from the dominantly rural pasture catchments (i.e. upper Styx and Kaputone). The intermediate yield from Horners Drain reflects a mixture of landuses (Table 6.1).

All sites experienced double peaks in concentration in response to two main phases of storm rainfall. A ‘flushing effect’ was notable at the Styx and Kaputone sites, with concentration peaking while the water level was still rising and the concentration peak being lower for the second rainfall event (Fig. 6.4). This pattern is typical of sediment exhaustion. Concentrations remained relatively high in the drains during the second rainfall event, suggesting more extensive sediment supplies to the drains.

During the May event, the waters in Quaids and Rhodes Drains were very turbid and red-brown in colour, while the Horners Drain water was grey-brown and less turbid. It was apparent that, with the higher rainfall of this event compared to the February event, the runoff and sediment yields from these smaller drains were proportionally larger. We expect that with even heavier rainfalls, the relative yields from the market-gardening areas would be higher still.

6.3.3 Organic content of suspended load

The organic content of the Styx suspended sediment samples varied from 20 to 50%. It tended to increase as total concentration decreased (Fig. 6.6), notably on storm recessions. In Kaputone Creek the organic component of the load varied from 8 to 43%, and showed a similar increase on storm recessions.

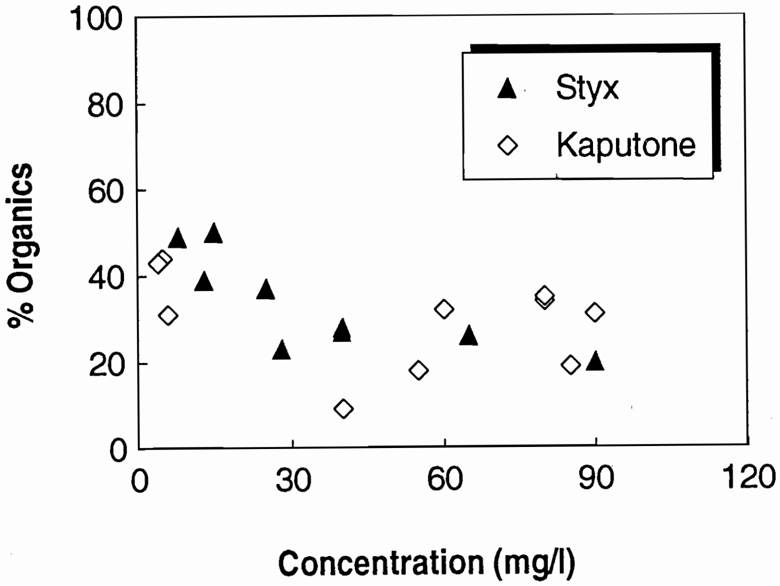

Figure 6.6 Relationship between suspended load organic content and total suspended solids concentration, Styx at Radcliffe Road and Kaputone at Riverlea.

6.3.4 Suspended load particle size

Particle-size of the suspended load was analysed on samples from Kaputone Creek[5], Styx at Radcliffe Road, and Horners Drain. The results are shown in Table 6.3 and Fig. 6.7. The Kaputone and Horners sediment was (after deflocculation) almost all silt-clay grade.

Half of the Horners Drain sample was clay finer than 2 microns. The Styx sample was 43% clay finer than 2 microns and 43% fine sand, which suggests two separate sediment sources. Many of the rural drains had sandy bed material. Residents of the area believe that sand is introduced with flow from springs.

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[5] There was sufficient mass in the Kaputone sample only to determine a sand/fines split.

Sample					Cumulative % finer than grain size						
Site	*Date*	*Time*	*Conc (mg/l)*	*Disch. (l/s)*	*Ø*	*4*	*5*	*6*	*7*	*8*	*9*
					µm	*62*	*31*	*15.6*	*7.8*	*3.9*	*2.0*
Styx	17/5/93	1030	90	3625		56.8	54.4	52.8	51.0	50.1	43.1
Kaputone	17/5/93	1200	60	712		91.7					
Horners Drain	17/5/93	1130	80	486		83.6	78.0	69.1	57.6	51.2	48.1

Table 6.3 Results of particle-size analyses of suspended sediment load sampled on 17 May 1993.

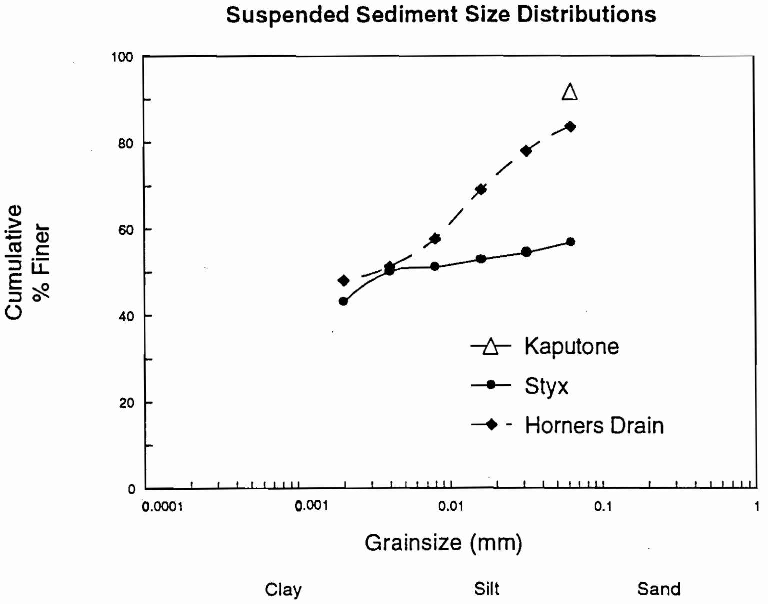

Figure 6.7 Size-gradings of suspended load sampled at Styx, Kaputone, and Horners Drain sites on 17 May 1993.

6.3.5 Bedload

The bedload sampling, attempted at the Kaputone and Styx sites at the peak of the May runoff event, caught nothing but organic debris. This indicates that if there was any bedload being transported, it was finer than the 0.25 mm mesh-size of the sampler bag. The suspended load particle-size results indicate that there certainly was some fine sand moving in the vicinity of the Styx bed, but the concentrations suggest that this fine bed load would have been very small - of the order of 2% of the total load.

6.3.6 Longer-term suspended sediment yields

The data collected at the Styx and Kaputone sites during the two storms were used to estimate the sediment yields over the 6 month period of flow record. Separate log-log regression relationships (i.e., sediment ratings) between sediment concentration and water discharge were derived for rising and falling stages. These ratings (Fig. 6.8) were:

Styx at Radcliffe Road:

Rising stage: $C = 5.2\,Q^{0.34}$ (r = 0.28)

Falling stage: $C = 2.9 \times 10^{-5}\,Q^{1.74}$ (r = 0.92)

Kaputone Creek:

Rising stage: $C = 94$ (r not sign. > 0)

Falling stage: $C = 4.0 \times 10^{-5}\,Q^{2.2}$ (r = 0.79)

where C is cross-section mean concentration in mg/l and Q is water discharge in l/s. The coefficients include a factor to correct for bias in log to linear detransformation (following Duan's, 1983, method). These ratings were combined with the flow records to estimate the 6-month sediment yields. Given that the base flows at both sites are clean but vary (often in response to inputs from irrigation), it was assumed that sediment concentrations were zero in flows less than 1600 l/s in the Styx and at flows less than 290 l/s in Kaputone Creek. These threshold flows were set after inspection of the hydrographs.

The 6-month sediment yields are shown in Table 6.4 along with the yield estimated for the Avon River over the same period using the Avon sediment rating given in Hicks (1993). The specific yields from both the Styx and Kaputone Creek are similar, and suggest a yield from the whole Styx catchment of 6.1 t/km^2/yr.

The accuracy of these yield estimates can be assessed by comparing the rating-estimated sediment yields for the February and May storms with the actual measured yields. As shown in Table 6.2, the two Styx storm yield estimates were both within ± 2% of the measured yields, while the Kaputone yield was overestimated by 20%.

	Area (km^2)	**Sediment Yield** (t/km^2/yr)
Kaputone Creek	5.47	4.76
Styx at Radcliffe Road	21.6	6.24
Styx at tidal gates	50	6.10
Avon at Gloucester Street	38	39.7

Table 6.4 Estimates of specific sediment yields for the period January-June for the Avon and Styx Rivers and for Kaputone Creek.

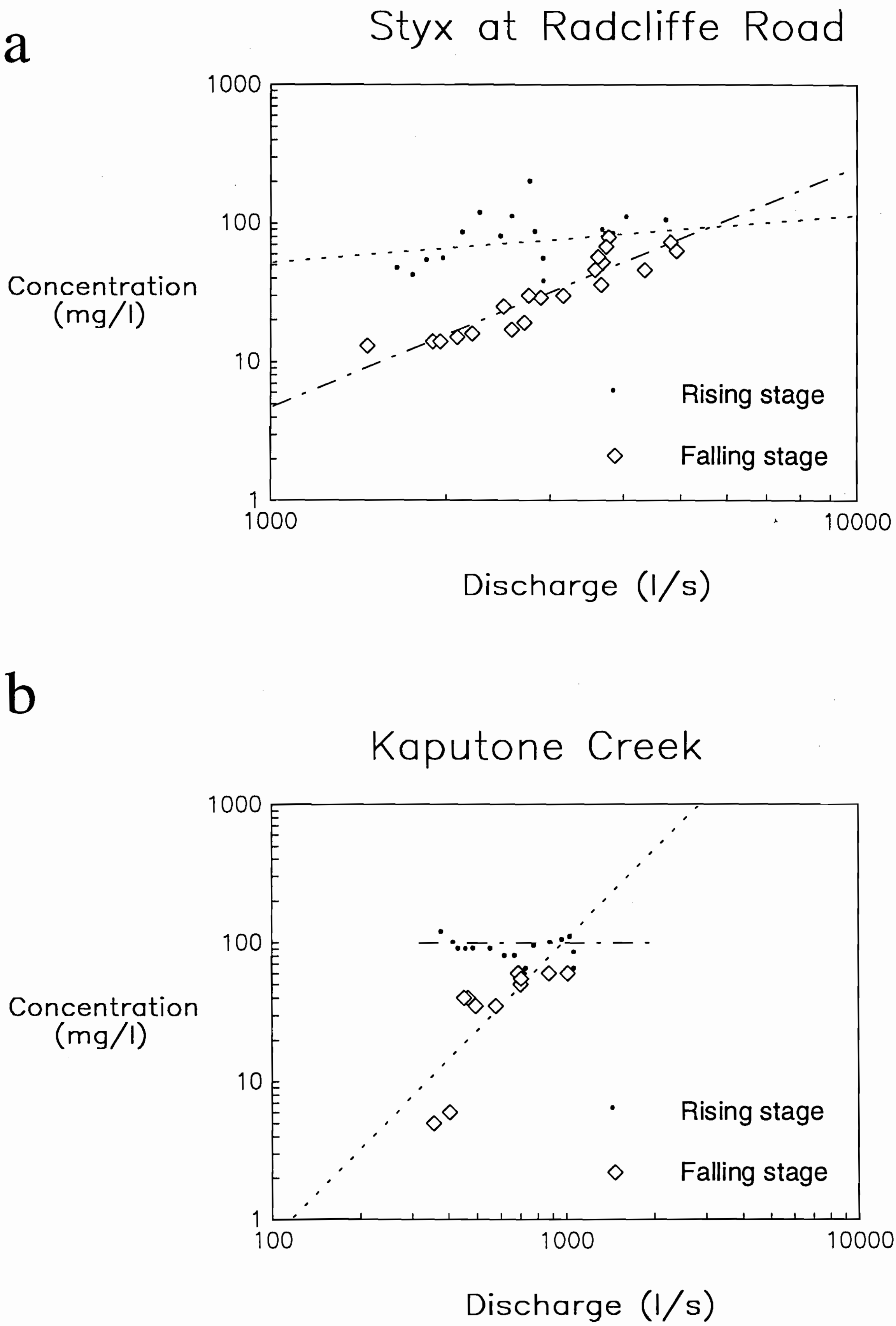

Figure 6.8 Suspended sediment rating plots, with separation of rising and falling stage data: **a** Styx at Radcliffe Road, **b** Kaputone at Riverlea.

6.4 Discussion

6.4.1 Long-term average yields

The annual specific yield of the Styx estimated above is surprisingly low, first compared with the Avon yield (39 $t/km^2/yr$), but more so compared with the average Styx sediment yield estimated from the analysis of cross-section and dredging data (78 $t/km^2/yr$, assuming a bulk density of 1 t/m^3).

One explanation is that the first six months of 1993 were unseasonably dry, but this is not supported by rainfall records: at the Belfast gauge, centrally located in the Styx catchment, the 1993 January-June rainfall was 257 mm, 12 mm more than the long-term average for the January-June period (D. Carver, Christchurch City Council, pers. comm).

An alternative explanation is that a heavier rainfall is required over the Styx before an erosion threshold is passed. Certainly, rainfall during the study period was never particularly heavy - the May storm totalled only 60 mm and had a peak intensity of only 7 mm/hour. Fig. 6.9, comparing storm specific sediment yield with storm rainfall for the Styx, Avon, and Heathcote catchments, suggests that the Avon and Heathcote catchments pass an erosion threshold after about 50 mm of storm rainfall. With heavy rain over the Styx, particularly after a prolonged period of wetting, we would expect greater runoff and soil erosion, particularly from market-gardening areas. A high erosion threshold is also likely given the low relief and gradient of the Styx.

Another possibility is that the sediment supplies to the Styx have varied during the past few decades in response to landuse change. The main phase of urban development in the Styx catchment was during the 1970's (M. Binnie, Christchurch City Council, pers. comm.). With this we would expect sediment yields to have been higher due to ground disturbance and clearing. Williamson (1993) suggests that yields from urbanising catchments can increase by at least a factor-of-ten from those when the catchment was in its pre-development rural state or after it has 'matured' under urban landuse. However, the dredging and cross-section data (Table 4.2) suggest only a slightly higher yield during the period 1969-84.

Likewise, it is unlikely that uncertainties in the dredging volumes contribute much to the discrepency since similar deposition rates (Table 4.2) were determined for the non-dredging periods (1967-69 and 1984-89) as for the dredged period (1969-84).

A final possibility lies with the organic content and assumed bulk density of the dredged bed material. If a significant component of the dredged material is weed and branches, etc, then the actual sediment loads carried into the river from its tributaries will be less than indicated by the dredging and cross-section information.

In synthesis, it is probable that the present average annual sediment yield of the Styx catchment is larger than our 6 $t/km^2/yr$ estimate from the short, 6-month measurement period which lacked any intense rainstorms. It is probably also somewhat less than the 78 $t/km^2/yr$ estimated from dredging and cross-section data through the 1960's-80's. Measuring sediment loads for a longer period and measuring the bulk density and weed content of the dredged material would reduce the uncertainty in this sediment yield figure.

6.4.2 Comparison with yields from other catchments

The specific sediment yields measured from the Styx and Kaputone catchments are compared with yields measured from other New Zealand urban and rural catchments in Table 6.5. Around the country, sediment yields vary considerably depending on landuse, climate, topography, geology, and the period of measurement. While the Styx and Kaputone yields lie at the lower end of the range of yields from pasture catchments, this is expected given their flat topography and coastal-floodplain geologic setting. The flat, dominantly pasture catchment of Milnes Drain near Hallswell has a similar yield at 8 t/km^2/yr.

6.4.3 Landuse effects

The effect of landuse is clear, with the May 17-18 specific yield from Quaids Drain from a dominantly market-gardening area being a factor-of-ten higher than the yields from the other rural catchments, while the yield from the dominantly residential Horners Drain catchment was 50% larger than those from the 'clean' rural catchments (Fig. 6.5b). We would expect these differences to increase relatively for a larger rainstorm.

From these patterns, we can at least qualitatively predict how the Styx yield might change as a result of future changes in landuse. If more pasture was converted to market-gardening, then we would expect higher sediment yields. With increasing urbanisation, temporarily higher yields should be expected during the construction phase. Figures provided by Williamson (1993) suggest that specific yields could increase by a factor of 10-100, depending on the proportion of the catchment under construction. Since the yields from 'mature' urban areas are much lower, urbanising market-gardening land should result in lower sediment yields in the long run.

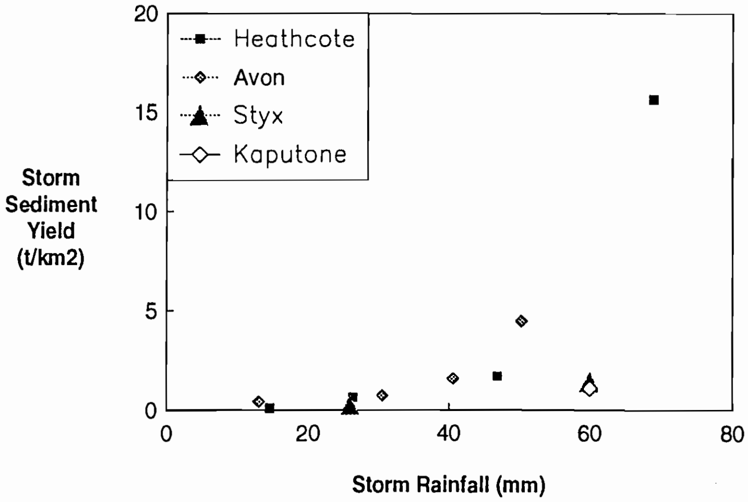

Figure 6.9 Relationship between sediment yield and rainfall for individual storms for Styx, Kaputone, Avon, and Heathcote sites.

Catchment	Area (km^2)	Dominant Landuse	Topography	Sediment Yield ($t/km^2/yr$)	Reference
Styx	21.6	Pasture	Flat	6.2	This study
Kaputone	5.5	Pasture	Flat	4.8	" "
Avon	38.0	Mixed urban	Flat	35	Hicks 1993a
Heathcote	65.3	Rural/urban mixed	Hill and flat	43	"
Milnes Drain	1.3	Pasture	Flat	8	"
Haytons Drain	7.1	Urban and industrial	Flat	10	"
Riccarton Drain	3.2	Urban	Flat	15	"
Kokopu, Northland	3.1	Pasture	Rolling	67	Hicks 1990
Scotsman, Waikato	0.2	Pasture	Hill	95	"
Purutaka, Rotorua	0.2	Pasture	Rolling	23	"
Moutere, Nelson	0.1	Pasture	Hill	79	"
Kintore, East Otago	2.9	Pasture	Hill	4.3	"
Wairua, Auckland	1.5	Mature urban	Rolling	109	Hicks 1993b
Manukau, Auckland	0.3	Pasture	Rolling	40	"
Alexandra, Auckland	2.2	Developing urban	Rolling	618	"
Mature urban catchments				5-100	Williamson 1993
Large catchments with small pockets of construction				200-800	"
Low hill-country pasture catchments				20-200	"

Table 6.5 Specific sediment yield data for urban and rural catchments around Christchurch and elsewhere in New Zealand.

6.5 Conclusions

We conclude that while the storm sampling provided a reasonable indication of relative sources of sediment into the Styx, the measured 6-month yield almost certainly underestimates the long-term average value. We recommend that automatic monitoring be continued at the Styx at Radcliffe Road site for several years, at least until several high intensity or prolonged rainfall events have been sampled. We suggest using a turbidity probe instead of an auto-sampler, so long as an adequate calibration is established.

We would expect significant increases in the sediment yield in the future with either a major intensification of market-gardening or rapid urbanisation. Slow progressive urbanisation, with only small pockets of construction at any one time, would be unlikely to cause appreciable change from the sediment supply of the past decade.

7 Synthesis and Summary

7.1 Sedimentation Issues

This section summarises the study results, distilling from them the current management issues for sedimentation in the Styx catchment and Brooklands Lagoon, recommending future monitoring practices, and identifying areas that would benefit from further investigation. The main sedimentation issues concern:

- sediment loads and source areas
- landuse effects on sediment production
- river channel sedimentation and dredging
- sedimentation in Brooklands Lagoon.

7.2 Sediment Loads, Yields and Sources

The present average specific sediment yield of the 50 km^2 Styx catchment is somewhere between 6 and 78 t/km^2/yr. The lower value derives from direct measurements of sediment load made over a relatively benign 6-month period in 1993, and is amongst the lowest yields measured in pasture catchments around New Zealand. The high value derives from data on deposition and dredging in the lower Styx channel from 1967 to 1989, a period that saw the main phase of urban development in the catchment. Although this higher value includes uncertanties to do with the volumes, bulk density, and weed content of the dredged material, we suspect that it is probably more indicative of the present average yield.

In both the Styx River and its largest tributary, Kaputone Creek, practically all of the sediment load is carried in suspension, at least up to moderately large storm discharges. The Styx suspended load comprises both clay and fine sand populations. A Kaputone Creek suspended load sample was dominantly silt-clay grade, but fine sand is probably also suspended there at higher flow rates. Horners Drain suspended sediment was dominantly silt-clay. In both the Styx River and Kaputone Creek, the organic component of the suspended load during storm runoff ranged from 10% to 50% and increased as the total suspended solids concentration decreased on storm recessions. The drains from the market-gardening areas appeared to carry very high amounts of suspended organic material.

Sub-catchment yields measured during one rainstorm showed that of the total sediment yield at Marshland Road, 48% came from Horners Drain, 36% was from the upper Styx, and 16% was from Kaputone Creek. On a unit area basis, the yield from Horners Drain was significantly higher.

Although erosion processes were not investigated, it appears that most of the sediment entering the stream channels and drains is associated with surface runoff, particularly from bare-earth rural areas. Sand also appears to be supplied from springs. Bank erosion does not appear to be a significant sediment source.

7.3 Landuse Controls on Sediment Production

Landuse appears to exert an important control on sub-catchment sediment yields. The unit area yield during storm runoff from a largely market-gardening catchment (Quaids Drain) was a factor-of-ten higher than the yields from the other rural sub-catchments, while the yield from the dominantly residential Horners Drain was 50% larger than those from the rural catchments dominantly in pasture. These landuse effects are expected to be greater with longer and more intense rainstorms.

With any future increase in the rate of urbanisation, the Styx sediment yield could be expected to increase temporarily for a number of years until the new development 'matured'. It would also increase with more market gardening. The actual yields would depend on the relative areas undergoing landuse change. The figures for the 1970's period, when the yield was of the order of 80 t/km^2/yr, might be a reasonable index of the yields that could occur with increased urbanisation.

7.3 River Channel Sedimentation and Dredging

Analysis of cross-section and dredging records for the period 1969-84 showed that in the low-gradient, tidally influenced reach between Radcliffe Road and the tidal gates some 92,000 m^3 of sediment were dredged, the channel was enlarged by 33,000 m^3, indicating that 59,000 m^3 of material was deposited. Deposition rates over this period averaged 48 mm/yr in the 2 km-long sub-reach downstream from Radcliffe Road, 26 mm/yr around the Oruhia Loop to Treleavens Drain, and 19 mm/yr along the 7.5 km long sub-reach down to the tidal gates. The Styx channel upstream from Radcliffe Road experienced little sedimentation (2 mm/yr) and has not been dredged apart from some local channel enlargement at the Horners Drain confluence. Four repeat surveys at five cross-sections indicated that deposition rates were steady over the period 1967 to 1989.

Considering all available records from dredging and cross-section surveys, it is apparent that the maintenance dredging programme of recent decades in the lower Styx has more-or-less matched sedimentation, with little net change in mean bed levels.

Dredging of the Styx channel causes a drop in base-level for the tributary streams and drains, including the upper Styx, that enter the dredged reach. In consequence, bed material from these tributaries is then flushed into the dredged Styx channel - even by normal flows. The tributary beds re-aggrade in phase with deposition in the Styx. Sedimentation appears to progress particularly rapidly in 'holes' that are dredged excessively.

Although no direct measurements have been made of the sediment trap efficiency of the long flat reach upstream of the tidal gates, it appears that relatively little sediment passes downstream of the gates. This is to be expected given the low slopes and the gates being closed on average for something like half of every day. Aquatic weed appears to encourage sedimentation in this reach by slowing flow velocities and 'hiding' sediment.

Only one repeat survey, covering the period 1979-83, has been conducted of the Styx channel downstream of the tidal gates. This showed an irregular pattern of bed-level change, with some sections aggrading, others degrading, and little net change overall.

7.4 Sedimentation in Brooklands Lagoon

Brooklands Lagoon, through which passed the main Waimakariri River channel earlier this century, has since the 1940's been a quiet tidal backwater, a trap for sediment suspended in Waimakariri floodwaters, sand blown and washed over the Brooklands spit from the coast, and to a lesser extent sediment from floodflows in the Styx River.

Sedimentation rates in the lagoon were high soon after the departure of the Waimakariri, but have waned in recent years. Some 1.4 million m^3 deposition was detected by surveys in 1932 and 1969, with average sedimentation rates of 30 mm/yr in the old river channel over this period. A subsequent survey in 1977 actually showed some flushing of sediment, mainly from the mouth area of the lagoon. Since then, gradual infilling has progressed from the top (south) end of the lagoon while towards the mouth, localised erosion and deposition has accompanied shifts of tidal channels, bars, and some erosion of the spit bank. Fine sediment is draped over the lagoon bed after Waimakariri freshes and floods, but much of this appears to be reworked and flushed by tidal flows, at least in the lower reaches of the lagoon. Overall, the recent net changes have been relatively minor. The present and future average sedimentation rates are inferred to be of the order of a few mm/yr.

The spit has experienced major change since the 1940's: then it was a low, largely unvegetated area of shifting sand, now it is well vegetated with marram grass and pine plantation and is broadening and increasing in elevation. Its lagoon shore, near the lagoon mouth, appears to have been gradually eroding over the past 20 years, partly as a consequence of the much-reduced supply of wind-blown sand across the spit and partly due to shifts in the lagoon channels. The stabilisation of the spit has lessened the likelihood of the Waimakariri channel reoccupying the lagoon and of wind-blows and storm-wave wash-over along its narrowest central portion.

The mouth of the Styx River has been shifting to and fro in recent decades. This instability can be related to some extent to the shallowing of the lagoon, although such lateral migrations are typical of river mouths generally.

7.5 Recommendations

- Monitoring of storm sediment loads should be continued at the Styx at Radcliffe Road site for a further year or two in order to sample a broader range of runoff events. Automatic instrumentation is suggested, ideally with a turbidity sensor. Over one storm event, we suggest that sediment samples be collected also from the Styx downstream of the tidal gates, in order to establish the efficiency of sediment entrapment in the flat reach upstream of the gates.
- A sub-set of the existing cross-section network along the Styx channel from Radcliffe Road downstream to the tidal gates should be monitored at 5-yearly intervals. The first survey should be within the next year, to fix the channel condition after the 1993 dredging run.
- The volume of spoil left on the banks from the 1993 dredging run should be surveyed as soon as possible and compared with the dredging records to indicate the reliability of the latter.
- The cross-section surveys should be used to target dredging. The dredging should be to a design bed profile.
- The cross-sections in the reach between the tidal gates and Brooklands Lagoon should be resurveyed within the next few years. This will confirm that the changes there over the past decade follow the same pattern as the changes observed from 1979 to 1983.
- All the cross-sections in Brooklands Lagoon should be resurveyed within the next year or two, since the last full survey was in 1977.
- Further research is recommended on three topics:

  First, we suggest establishing an experimental reach in the lower Styx channel. In this, resurveys of closely-spaced cross-sections at increasing time intervals over the next several years will establish the rate of resedimentation following the most recent phase of dredging, particularly in dredging 'holes'.

  Second, monitoring weed growth and changes in hydraulic roughness in the experimental reach over the same time would clarify the inter-relationships between sedimentation, weed, and hydraulic conveyance. It may be that sediment entrapment - and hence dredging - can be minimised by appropriately scheduled weed control works.

  Third, analysing the bulk density of the bed material deposited by the end of the experimental study would greatly diminish the present uncertainty in converting volume rates of deposition to mass rates, which would make for better comparison of dredging and cross-section data with measured loads.

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