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River and Suspended Sediment Discharge into Byam Channel, Queen Elizabeth Islands, Northwest Territories, Canada

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ABSTRACT. During 1974, a stream from a small drainage basin (117 km^2) on the east coast of Melville Island discharged approximately 1.63×10^7 m^3 water containing 7.08×10^7 kg suspended sediment. Because nearby basins show hydrological similarity, these data can be extrapolated to provide an indication of the total suspended sediment discharge into the adjacent channels. The results suggest that much of this sediment is not deposited in the channels; rather it is incorporated into the active delta fronts or possibly transported out of Byam Channel above a pycnocline.

The values agree well with a hydrological study on nearby Bathurst Island where predicted discharge values for both runoff and suspended sediment are within an order of magnitude of those measured. Recent attention has focussed on the Mecham River which flows into Bridport Inlet, the site of a proposed LNG terminal which is to be situated on an active delta front. Values extrapolated from this study indicate that design criteria must consider typical runoffs of 1.2×20^8 m^3 with peak mean daily discharges in excess of 9.0×10^6 m^3/day and suspended sediment loads of 5.0×10^8 kg/year.

INTRODUCTION

During 1973 and 1974, the Geological Survey of Canada undertook coastal studies of eastern Melville and western Byam Martin islands (McLaren, 1981 and Fig. 1). This region was chosen because the intervening channel (Byam Channel) was the first of many proposed pipeline crossings to bring arctic gas to southern markets. Part of the program included studies of river and suspended sediment discharge into Byam Channel. Because of new interest in transporting gas via LNG tankers and the possibility of establishing a terminal in Bridport Inlet on the south coast of Melville Island (Arctic Pilot Project, 1979) it is appropriate to present the results of these studies from a nearby area.

PHYSICAL SETTING

The coasts of eastern Melville and western Byam Martin islands lie within the Parry Plateau, a division of the Innuitian Region (Bostock, 1970). The terrain is generally below 150 m and is characterized by broad, flat-topped, east-trending ridges which are separated by wide, flat-floored valleys. The average relative relief is about 90 m. Tozer and Thorsteinsson (1964) classify the region as ridges and plateaux developed on folded Paleozoic rocks.

Within the drainage basins that empty into Byam Channel the ridges are subdued and in spite of the dominant structure the drainage is dendritic (Fig. 1). This is due in part to the similarity of the geological formations which consist predominantly of sandstone and siltstone, and in part to variable lithification within formations. For example, the Hecla Bay sandstone (Hecla Bay Subgroup, Devonian: Embry & Klovan, 1976) may form ridges in one location and a valley floor in another. Surfical deposits are dominated by local bedrock lithologies and are composed mostly of sands, angular pebbles and felsenmeer. Below 100 m elevation, much of the coast has been submerged during Holocene time (McLaren and Barnett, 1978) resulting in an admixture of marine silts with whatever surficial materials occur (Barnett *et al.*, 1975).

There are 32 drainage basins on the two coasts (Fig. 1) of which seven enter Viscount Melville Sound, three flow northwards into Byam Martin Channel and the remaining 22 empty into Byam Channel. They range in size from 11 km^2 (basin 2, Fig. 1) to 1136 km^2 (basin 12, Fig. 1) with an average size of 116 km^2. Each basin discharges onto a delta that begins at the point where the river is no longer confined within valley walls and is characterized by a braided stream pattern (Shearer, 1974). This alluvial plain continues with a gentle slope to about the 3 m isobath, where a

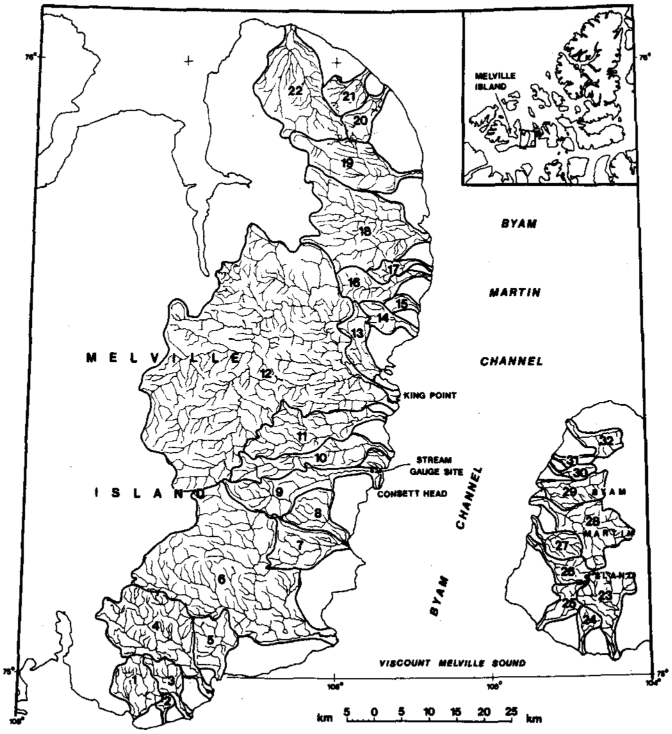

FIG. 1. Location of study area showing principal drainage basins entering Byam and Byam Martin Channels.

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sharp break in slope occurs marking the edge of steeply dipping (10°) foreset beds composed predominantly of sand (McLaren, 1975). The subaerial size of the deltas ranges from 0.06 km^2 to 58 km^2, the largest being at King Point (Fig. 1).

Continuous ice cover persists in Byam Channel for at least nine months of the year. Temperatures rise above freezing in late May or early June and river flow begins before the occurrence of ice breakup in the channel. Consequently river sediments are frequently deposited on nearshore ice, resulting in a decreased albedo and a more rapid melting at the delta fronts. The channel ice usually breaks up in July and does not freeze over again until October. River flow, however, generally stops altogether after mean daily temperatures drop below freezing in late August.

STREAM DISCHARGE

The stream at Consett Head (basin 9, Fig. 1) was chosen for study because its basin was close to the mean size of the drainage areas (117 km^2) and was a manageable size for field measurements. Flow and suspended sediment discharge were measured 15 times between 30 June and 1 August 1974 (Table 1) using standard techniques described by Church and Kellerhals (1970). Velocity measurements were taken with a Price Gurley 622AA current meter and continuous stage recording was obtained from 4 July to 21 July with a simple pressure head attached to a Foxboro tide gauge recorder.

Stream flow at the gauging site began on 29 June 1974, initially over at least one metre of snow. On 1 July discontinuous sand was being deposited on an ice stream bottom and by 3 July the stream had cut down to the channel bottom but was still contained within snow banks. Peak discharge occurred on 10 July, twelve days after initial flow, and by 16 July no snowbanks remained and the stream flowed in an essentially unchanging channel until the end of the season. After 1 August, flow was too slight to continue discharge measurements. It is unknown at what date flow stopped altogether. The mean monthly temperature dropped below 0°C in September and flow probably ceased prior to the end of August.

TABLE 1. Stream and sediment discharge data for Consett Head River

Date	Time	Discharge Q(m^3/sec)	Sediment Discharge Qs (Kg/sec)	Concentration Qs/Q(kg/m^3)	Stage cm
June 30	1115	.57	.13	.23	—
July 1(a)	0945	.28	.11	.39	—
1(b)	1800	.44	.41	.93	—
2	0910	.40	—	—	—
3	2200	1.28	1.29	1.00	—
4	1000	.90	—	—	6
6	1730	2.87	9.64	3.36	13
7	0900	5.00	—	—	21
16	1230	6.24	2.74	.44	24
19	0900	4.03	.51	.13	18
21	1000	2.41	.20	.08	11
22	14.30	1.69	.09	.05	—
25	1100	.88	.04	.05	—
28	1000	1.49	.11	.07	—
Aug. 1	1030	1.00	.07	.07	—

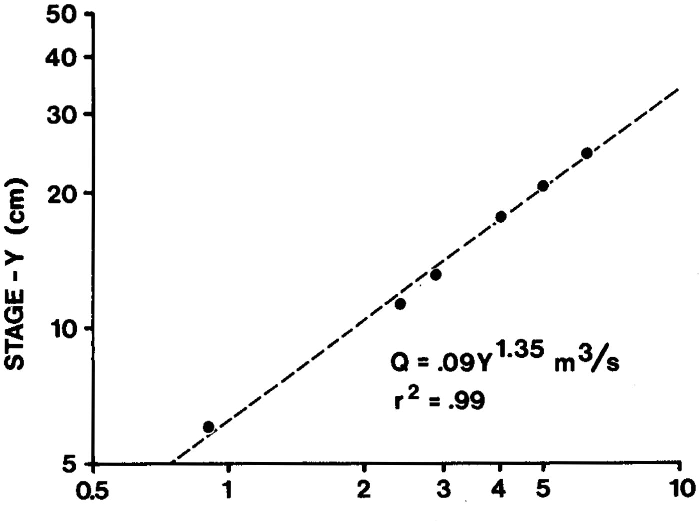

FIG. 2. Rating curve (based on data shown in Table 1) for Consett Head River during 1974.

During the measurement period mean daily discharge, as determined from the stage-discharge relationship (Fig. 2), rose to three separate peaks. The first occurred on 9 July and continued to 10 July, although mean daily temperature peaked on 9 July and fell on 10 July (Fig. 3). The second, on 13 July, followed a temperature peak on 12 July. This suggests that discharge, which is dependent on snow melt and therefore on temperature, appears to have a 24-hour response time to mean daily temperature changes. The third peak on 17 July coincided with a

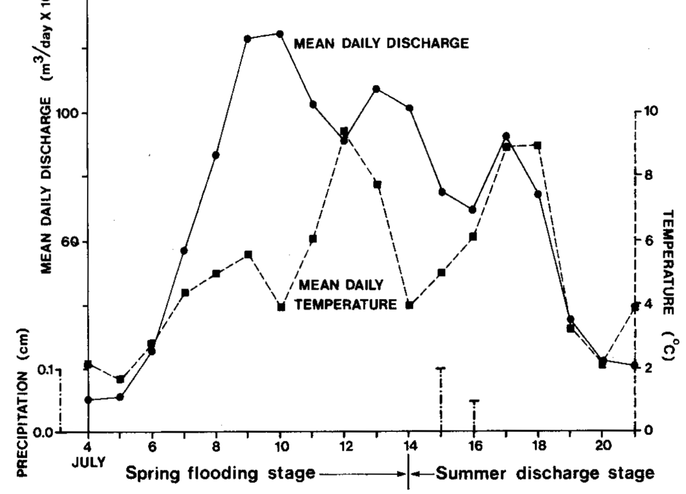

FIG. 3. Mean daily discharge, temperature and precipitation at Consett Head River.

temperature peak and, in spite of a high temperature on 18 July, discharge dropped rapidly. Between 13 July and 17 July, discharge thus changed from being dependent on snow melt to a dependence on other factors such as precipitation and drainage from the active layer. July 14 is arbitrarily selected as the date separating the two types of discharge.

A similar, though more complex, situation was observed for the breakup of the Colville River in Alaska (Arnborg *et al.*, 1967). The authors were able to recognize four distinct phases in the river discharge. The terminology for these phases is not applicable to the much smaller Consett Head River; however, based on their concepts, discharges occurring before and after 14 July are referred to as the spring flooding stage and the summer discharge stage respectively (Fig. 3).

Although there are few stage data prior to 4 July and none after 21 July (Table 1), an estimate can be made of the total discharge from the Consett Head drainage basin. From 4 July to 21 July inclusive, mean daily discharge values are derived conventionally from the water level records by means of the rating curve (Fig. 2, Table 2). From 30 June to 3 July, based on five spot discharge measurements (Table 1), there is an average discharge of 0.59 m^3/sec or 20 × 10^4 m^3 for the four-day period. Similarly, there is an average discharge of 1.35 m^3/sec or a total of 117 × 10^4 m^3 from 22 to 31 July. On 1 August a discharge of 1.00 m^3/sec (Table 1) was measured, and although stream flow probably became less, this value is extrapolated as an average discharge for the whole month. The discharge during August is likely to be overestimated, but the value is sufficiently small that the total is not greatly affected. The total discharge for the summer is estimated at 1.63 × 10^7 m^3 (Table 2).

SUSPENDED SEDIMENT DISCHARGE

From 30 June to 6 July, suspended sediment concentration increased steadily with increasing discharge (Fig. 4). In spite of a large increase in discharge on 16 July, however, suspended sediment concentration dropped to 0.44 kg/m^3 from the previous 3.36 kg/m^3 (Table 1). Two power curves fitted to these data are interpreted as being representative of the spring flooding stage and the summer discharge stage respectively (Fig. 5). The two equations for these correlations provide an estimate of total suspended sediment discharge of 7.08 × 10^7 kg (Table 2).

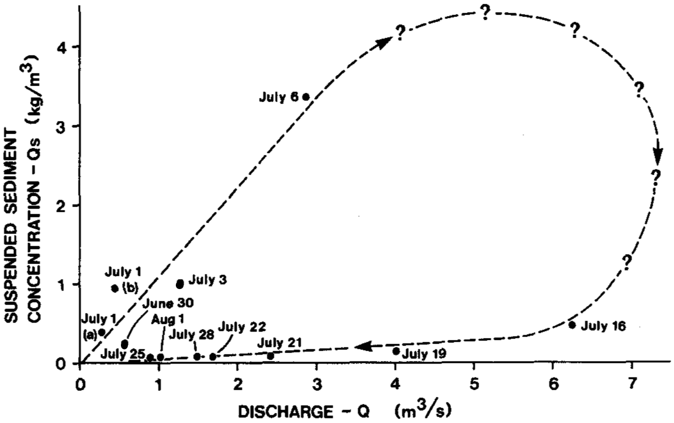

FIG. 4. Suspended sediment concentration versus stream discharge plotted sequentially through time.

The sudden drop in the suspended sediment discharge on 15 July, owing to change from the spring flood to the summer discharge regression line, probably is unrealistic (Table 2). If more data had been obtained between 6 and 16 July, the points, if plotted on Figure 4, probably would

TABLE 2. Estimates of total discharge and total suspended sediment out of Consett Head River during the summer of 1974

Date	Mean daily stage (cm)	Mean discharge (Q) m^3/sec (from equation, Figure 2)	Mean daily discharge m^3/day x 10^4	Mean daily suspended sediment discharge (kg/day x 10^4 (from equations, Figure 5)
June 30 to July 3	—	0.59	20 (4 day total)	13 (4 day total)
4	7	1.18	10	12
5	8	1.42	12	16
6	14	3.01	26	68
7	25	6.58	57	296
8	34	9.97	86	647
9	44	14.11	122	1244
10	44	14.11	122	1244
11	38	11.58	100	858
12	35	10.36	90	695
13	40	12.41	107	977
14	38	11.58	100	858
15	31	8.80	76	28
16	29	8.04	69	24
17	36	10.76	93	42
18	30	8.42	73	26
19	18	4.23	37	7
20	13	2.73	24	3
21	12	2.45	21	2
22-31	—	1.35 (average)	117 (10 day total)	7 (10 day total)
August 1-31	—	1.00 (average)	268 (31 day total)	13 (31 day total)
			1.63 x 10^7 m^3 water	7.08 x 10^7 kg suspended sediment

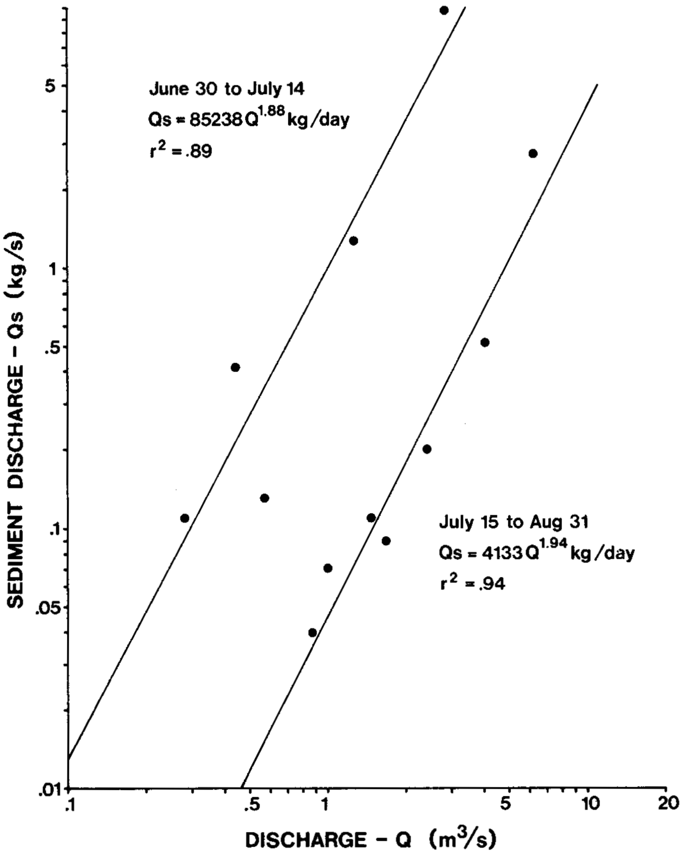

FIG. 5. Regression lines used to calculate total suspended sediment discharge.

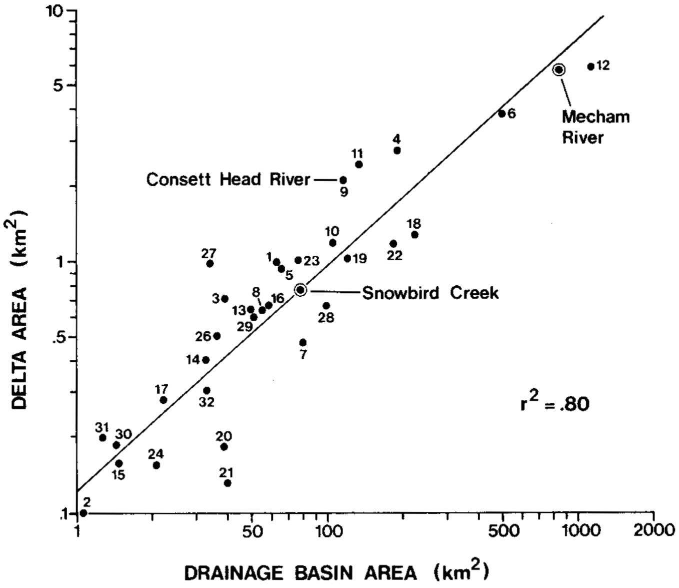

FIG. 6. Relationship between delta area and corresponding drainage basin area (numbers identify the basins shown in Fig. 1).

have continued to rise after 6 July to some maximum before falling steadily down to the point plotted for 16 July. Because more days are being extrapolated on the spring flooding curve (6-14 July) than on the summer discharge curve (15-16 July), the amount of total suspended sediment is probably overestimated rather than underestimated.

DISCUSSION

Sedimentation in Byam Channel

Discharge values derived from the Consett Head River basin may be extrapolated to adjacent basins by virtue of their hydrological similarity (Church and Kellerhals, 1970). This similarity is illustrated by the relationship of sub-aerial delta areas with the corresponding drainage basin area (Fig. 6). Other good morphometric correlations between the former and stream frequency ($r = 0.90$) and with the total length of channel per basin ($r = 0.88$) also suggest hydrological similarity among the basins (McLaren, 1977).

Discharge may be scaled proportionately to the drainage area by the following relationship:

$$Q = bA^k$$

where A = basin area and b and k are derived empirically (Church and Kellerhals, 1970). In this environment permafrost causes runoff to be dominated by overland flow and k will probably approach 1.0, in which case the total area of all the basins (3.79×10^3 km^2) shown in Figure 1 could have produced 52.49×10^7 m^3 water containing 7.30×10^7 kg sediment. The value of k, if not equal to 1.0, will be less and therefore these estimates are again high rather than low.

Although no specific limits can be set for an area of sedimentation in Byam Channel and adjacent waters, data from Polar Gas (pers. comm.) suggest that a silty-clay facies occurs in bathymetric lows below 100 m and is thought to be the result of present deposition. Seismic interpretation indicates an average thickness of 1.8 m representing an average sedimentation rate of 0.18 mm/yr since deglaciation approximately 10 000 years ago. However, assuming a bulk density of 1.77 gm/cc, a value calculated from 18 bottom samples in the silty-clay facies, and a hypothetical area of 5800 m^2, the estimated total amount of suspended sediment could have formed a layer of sediment 0.23 mm thick in the 1974 runoff season. The hypothetical area includes the whole of Byam Channel and the water adjacent to the remaining basins flowing into Byam Martin Channel and Viscount Melville Sound. Because this area is much larger than the aerial extent of the bathymetric lows (present bathymetric charts have insufficient coverage for an accurate determination), it appears evident that much of the suspended sediment is not being deposited in the channels.

Since peak sediment discharge invariably occurs into ice-covered waters, much of the suspended sediment load probably is deposited as part of the delta fronts. Shearer (1974) has described the sedimentology of raised delta foreset and prodelta beds on the east coast of Melville

Island. Both include well-sorted sand units separated by thinner laminae of silt or clay. Fining upward sequences were observed in individual sand beds. Cores taken by divers on a delta front (McLaren, 1981) also show silt and clay beds. Shearer demonstrated that the presence of ripple-drift cross lamination and graded sequences indicates that density underflows are an important mechanism for deposition on the delta front. Thus it is probable that delta growth is responsible for removing much of the suspended sediment that during open water conditions would otherwise have been deposited in the channels.

Other mechanisms to remove suspended sediment from the channels include transport in surface fresh water above a pycnocline and transport in bottom currents. Diving observations (McLaren, 1977) indicate that fresh water, commonly 1-2 m deep and in which visibility is nil, lies above clear saline water. The interface with the saline water appears as a narrow zone of mixing less than 50 cm thick. It is suggested that the fresh water above the pycnocline is sufficiently stable to maintain its suspended load for long periods of time during the summer months.

A current meter in Byam Channel at a depth of 107 m recorded a mean maximum velocity during April 1973 of 28 cm/sec (Polar Gas, pers. comm.). Currents ranged from 5-40 cm/sec indicating that sufficient current energy is available to maintain material in suspension, if not to cause erosion (Hollister and Heezen, 1972). For these reasons it appears that much of the sediment potentially available for deposition in the adjacent channels is being lost, lending support to the conclusion, based on diving observations, that little or no sedimentation is occurring in Byam Channel (McLaren, 1977).

Extrapolation of Data to Nearby Basins

The nearest hydrological study to Consett Head took place in the Snowbird Creek basin, Bathurst Island in 1976 (Wedel *et al.*, 1977). Situated about 130 km east-northeast of Consett Head, Snowbird Creek drains a terrain geologically identical to the east coast of Melville Island. Its position on the regression line shown in Figure 6 suggests a hydrological similarity with the Melville and Byam Martin Island basins.

Using Consett Head data, the predicted annual runoff for Snowbird Creek draining the area above the stream gauge site (61.1 km^2) is 8.49×10^6 m^3. The actual runoff calculated by Wedel *et al.* (1977) was 9.53×10^6 m^3, a value only 12% higher than predicted.

Similarly, the predicted value for the total suspended sediment discharge for Snowbird Creek is 3.69×10^7 kg sediment which, when compared to the actual value of 1.98×10^6 kg sediment, is slightly less than one order of magnitude higher. Considering differences between the two years in which each data set was taken, variations in snowmelt runoff intensity, grain size differences, availability of sediment and the probable overestimation of the total suspended sediment for Consett Head river, the similarity among the values is reasonable.

Of interest at the present time is the Mecham River Basin entering Bridport Inlet on the south coast of Melville Island, the proposed site for an LNG terminal (Arctic Pilot Project, 1979). The proposal calls for plant storage barges placed in berths at the edge of the Mecham River delta. A causeway and the barges will make a semicircular dam crossing about 75% of the mouth of the Mecham River.

Located 88 km southwest of Consett Head, the basin (844 km^2) drains a geologically similar terrain and its position near the regression line on Figure 6 suggests hydrological similarity with the more eastern basins. Extrapolating the data derived from Consett Head, design of the terminal must take into account a summer runoff which is typically 1.17×10^8 m^3 with peak mean daily discharges in excess of 9.0×10^6 m^3/day. Estimated suspended sediment loads that may incur entrapment behind the terminal are expected to be about 5.0×10^8 kg/yr., an amount equivalent to a 5-cm thickness over the entire delta area of 5.72 km^2. Furthermore, sheet pilings and barges surrounded by rock berms are to be placed at the break in slope between delta topset and steeply dipping foreset beds. These deltas grow by the migration of megaripples over an actively aggrading tidal flat which accumulate at the break in slope, followed by sudden movement in the form of density underflows down the delta front. The potentially unstable site will need protection by the diverting of river flow in an unchanging channel through the part of the delta flat not contained by the terminal system.

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