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Analysis of sedimentation of canals

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Abstract

The dredged canals in the Niger Delta coastal flood plain are being threatened by siltation. This study is limited to those canals in Rivers State of Nigeria, which are under the influence of tidal waves. A total of eight canals were considered with four each from Ekulama and Cawthorne Channel. Different approaches were used to carry out this study, which includes field reconnaissance survey, hydrographic survey, soil sample analysis and collection of all available data and information. The typical bed materials size (D_{50}) is approximately 0.01mm; which gives a settling velocity of 0.09mm/sec using stroke's law. Hydrographic survey of the canals from 1992 to 1996 revealed an average siltation rate of 2.35m/yr. A regression equation was also derived which relates the cost of dredging to canal area, rate of siltation and average aggregation. A plot of canal centre profile; entrance, middle and end cross sections showing sediment distribution along the canal profile, shows that majority of the particles that form the sediment enter the canal from the rivers. The sedimentation is caused by the reduction in water current, which has average value of 0.0145m/sec. The bathyorographical check on the canals revealed that the sum of the two exterior angles of the canal with the river at the point of connection has to lie within $180^0 \pm 5^0$ for an effective flow that will minimize settlement of particles. In addition, the canals should be constructed to start and terminate on a moving water body, to avoid dead ends. A regression equation was determined which relates the cost of dredging to canal area, rate of siltation and average aggradations.

Keywords: Sedimentation, Canals, Analysis, Regression, Siltation, Bathymetry

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1. Introduction

Canals are natural or man-made waterways, which give access to the main navigable waterways. There are two types of canal, tidal and non-tidal. The tidal canals are those in coastal area, located directly adjacent to the ocean, or connecting the sea to a water body where facilities are located. Non-tidal canals are those with ends connecting natural river channels and most often connecting river channels with oil related field facilities or small port facilities and jetties.

Canals are frequently silted at an alarming rate; as a result of poor maintenance or lack of it. Canal maintenance is capital intensive and very necessary in order to make the facilities and ports, which they are linked with, accessible. Huge sums of money are spent annually in dredging these canals by the government and industries, which result to loss of aquatic lives due to excessive biological oxygen demand of the biodegradable portion of the sediments, which results to loss of dissolved oxygen in the receiving water bodies where the spoils from dredging are discharged.

This therefore necessitates the need for an understanding of the various factors that influences sedimentation, analyzing them critically so as to come up with some measures of checking the excessive sedimentation or as much as possible, bringing the rate of sedimentation to a minimum.

Due to the fact that most canals are artificially dredged connections, they do suffer from continuous and often severe siltation. The causes of the siltation may in principle be two fold. First reason is that the canals are dredged in a geotechnically very unstable area; the banks of the canals are unstable in themselves. This gives rise to a gradual flattening of the canals cross-sections thereby decreasing the navigable depth.

The second reason may be the intake of sediment from the river or ocean into the canal under the influence of the water flows entering the canals and tidal waves; a phenomenon, which is connected to the natural process of formation and preservation of the delta as a whole.

Sediments are described generally as solid particles, which are being moved or have been moved by a fluid. Sediment is in general classified according to size, specific weight, shape, mineralogical composition, colour and other aspects. With respect to its movement by the water, the grain size is the most important factor since it causes widest range of mobility. For the purposes of aquatic monitoring, sediment can be classified as deposited or suspended (Ongley, 1996). In practice, virtually all sediment transport occurs either as bed load or suspended load. The following discussion will be limited to particles moved by water.

In the past, researches have been conducted on sediment transport and the sedimentation problems associated with canals; solutions proffered. Studies have been conducted on open channel flow with suspended sediments (Itakura and Kishi, 1980), flow resistance and bed form geometry in a wide alluvial channel (Yang et al., 2005), criterion for deposition of sediment transported in rigid boundary channels (Arora et al., 1984), non-equilibrium bed load transport by steady flow (Bell and Sutherland, 1983), effect of turbulence on sedimentation (Dobbins, 1944), mechanics of sediment transport and alluvial stream problems (Garde and Ranga Raju, 1985), fraction-wise calculation of bed load transport (Patel and Ranga Raju, 1996). Galappatti and Vreugdenhil, (1985) derived a model for suspended sediment transport in unsteady and non-uniform flow. Basic equations for a mathematical model of sediment-laden flow in a nonorthogonal curvilinear coordinate system were derived using tensor analysis of two-phase flow and incorporate a natural variable-density turbulence model with non-equilibrium sediment transport (Fang and Wang, 2000).

The study on the sedimentation of dredged canals especially as it affects the navigability of the canals is very important due to the numerous economic benefits, both to the industries that use the canals to access their facilities and also indigenous populace, who depend on the canals for water borne transportation. It will enhance the appreciation of the various factors contributing to increased siltation rate, and will proffer measures to mitigate the siltation problems.

The research is centered not only on the study of the geotechnical behaviours of sub-soil in the zone; but includes the study of the engineering design and solutions of the bathymetric shape of the canals to influence the flow regime. These solutions will cause less sediment to build up at the entrance of the canal from the main water body, thus prevent the cutting off, of the canal from the entire river.

To this end, the specific aims and objectives of this research are summarized as follows:

a. To determine the rate of sedimentation of various canals and to compare them;
b. To determine the reasons for comparative higher rate of siltation in different canals;
c. To determine the settling velocity of sediments at low-low water level.
d. Determination of a regression equation that relates the cost of dredging to canal area, rate of siltation and average aggradations.
e. The overall causes of the sedimentation; and
f. To proffer solutions or recommendations to the sedimentation problems.

Recommendations reached in this report are based on the data obtained from soil borings and tests performed. Also information gathered from previous dredging, physical examination of the soil within the study depth, geotechnical and topographical situation of the study area. Information on tidal waves and the position of the study area in the Niger Delta coastal flood plain were also put into consideration.

1.1. Scope of study

This research study on sedimentation of dredged canals is centered not only on the study of the geotechnical behaviors of sub-soil in the zone; but includes the study of the engineering design and solutions of the bathymetric shape of the canals to influence the flow regime. These solutions will cause less sediment to build up at the entrance of the canal from the main water body, thus prevent the cutting off, of the canal from the entire river.

2. Materials and method

2.1. Study Area/Geology

The study areas lies in the Niger Delta coastal formation which consists of a chain of barrier islands interspersed by river estuaries, giving the delta, the typical shape like birds foot. The area is characterized by vast amount of sediment being washed down the rivers Niger and Benue for many thousand years ago. The canals serve as connecting links between the main navigable waterways and industrial field facilities, port facilities, landing jetties and fishing ports. This makes it necessary that a study, which will aim at finding measures of checking excessive siltation, should be carried out.

This sediment accumulates in rivers estuarine region, creating a vast flood plain. The selected study areas are: cawthorne channel and ekulama

2.2. Cawthorne channel

Cawthrone channel is located in the coastal salt-water mangrove swamp and backwash of the new Calabar River, Krakama Creek and Cawthrone Channel River. There is no known town, which exist in this area except some fishing villages. Many facilities belonging to Shell Petroleum Development Company are seen scattered all over the place. Most of the entire area is dry, especially during the dry season, except some area close to the adjoining rivers, which are found water logged at high tide.

Halophytic red mangroves and other salt-water trees are the main native plants of the area. The thickness of the undergrowth vegetation varies from medium to very dense but distinctly much lighter where the natural vegetation has been severely disturbed by previous human activities.

2.3. Ekulama

Ekulama falls within the mangroves swamp environment which is underlain by recent deltaic sediments and covered by medium dense to dense halophytic mangrove vegetation. The area is bathed by San Bartholomew River and Sego creek, with majority of the landscape mostly under water. Sediments entering the mangrove swamp environment are essentially polycentric. Suspended fines enter the system both from the sea and the rivers. The soils in these environments are in system both from peat, organic clays, salty clays and sand.

2.4. Soil stratigraphy

Evaluation of the soil stratigraphy at the areas to a depth of 3.5m was based on the soil sampling, cone penetration test and laboratory tests on the retrieved samples. The investigation revealed the domination of peaty (chikoko) soil, with high compressibility and color ranging from dark brownish to dark grayish, and from soft to firm texture.

2.5. Soil survey along the canal banks

Physical investigation was carried out on the soil along the canal banks which showed evidence of erosion in some of the canal banks that empties into the canal in areas of sparse vegetation. Bank slopes of 1:3, 1:2 and 1:1; and vertical slopes were seen to dominate the stretches of the banks of the canal visited.

Apart from man's influence on denudation process, investigation along the bank shows that some aquatic fishes like mod fish and crab are daily contributing to denudation process. These shell fished and crabs bore several holes daily along the canal banks, thus weakening the soil and making them more erodible with subsequent deposition of eroded materials into the canals as sediment through trapping by tidal waves and runoff. They also weaken the banks slope, which reduces the stability of the slope, giving rise to gradual flattening of the canal's cross-section with subsequent reduction in the canal's drought.

2.6. Tidal influence

The water in the areas under investigation is under influence of tidal waves due to proximity to the Atlantic Ocean. The tidal cycle has 8 hour return period. The average water current from the test conducted using floatation method shows a value of 0.0145m/sec, the velocity varies according to the hour within each return period and also according to the direction of the current. There are high and low tides, which controls the depth of the water, with the current appearing steady at the end of each return period or tidal cycle. In some cases, two different currents moving in opposing directions were observed, one on the surface of the water and the other 30cm to 100cm below the surface of the water. This may be attributed to waters flowing into the seas, which are under the gravitational influences, and with low salinity level capered to the one that exists on the top surface level, which are under tidal influence. At greater depth, a steady current may exist whenever this situation occurs.

The water level used in various survey conducted are based on the tide at its lowest water levels. This is known as "Low-Low water level", taken from the known levels on the benchmarks, which are indicated on the various Shell Petroleum Development Company's wellhead platform and other facilities for reference purposes.

2.7. Methodology

The program for the investigation consisted of Auger boring, Dutch cone penetration (CPT) tests, soil sampling, laboratory testing and hydrologic survey. Also preliminary information about the geological formation, the properties of the soil on the site and the ground water levels where obtained from in situ tests conducted and from geological maps of the study areas.

Water samples were collected before and after dredging, this was analyzed in the laboratory to determine the pH levels, total dissolved solids and sulphate content. Test on BOD_5 and dissolve oxygen content were not carried out because of the time lapse between when the water was collected and the time the laboratory tests were conducted.

2.8. Sampling methods

Disturbed and undisturbed soil samples were collected from the bank and bed of the various canals of the study areas. This was to enable measurements of classification and engineering characteristic to be made. Disturbed samples were taken from the bank through boring at a depth 0.5m interval while undisturbed samples were taken as when necessary. The total depth excavated was between 3m to 4m and the samples were collected using auger boring. The samples were fixed on to an adapter, which screwed either on to the handle or onto extension rod of the auger.

2.9. Handling of samples

The large undisturbed samples were adequately protected against change of moisture content and damage in transit. The samples were placed in tins, tightly packed with sand dust to prevent damage, with the lid of the tins sealed with adhesive tape. Careful records of all the samples taken were kept. Indicated on the lids were location position, depth and other relevant date. The appropriate and corresponding labels were pasted inside each tin. The tins were then placed in a cool, humid atmosphere until ready for testing, which was carried out with minimum delay.

2.10. Laboratory tests

Detailed laboratory investigations were carried out on representative disturbed samples obtained from the open borehole for the classification tests and other tests. The samples form the boreholes were described visually with respect to color and texture the laboratory tests being carried out includes: particle size analysis by sedimentation method, atterberg Limits, pH and Sulphate content, organic content tests, unconfined compression test, specific gravity test, quick and undrained triaxial compression test.

All the tests were carried out in accordance with BS1377 (1990) methods of test for soil for civil engineering purposes. Brief comments on the various tests results are given result discussion.

3. Results and discussion

The results of the soil tests are shown in Tables 1 to 3 while the data on cost, rate of siltation and duration of dredging are shown in Table 4. Table 5 gives the P^H level and sulphate content.

3.1. Soil Tests

Results of soil sample analysis from the bed and bank of the canals indicates that the soil samples are mostly peaty clay (Table 1) of high plasticity with typical bed material (D_{50}) of approximately 0.01mm, from which the settling velocity was computed as 0.09mm/s using stokes law:

$$S = \frac{d^2 g (p_s - p)}{18U}$$

$$= \frac{d^2 g ('Y_s - 1)}{18Y}$$

where: $'Y_s$ = Specific gravity

$'Y$ = Kinematics viscosity

P and p_s = Density of water and particles

d = Particle diameter

('Y and p_s is assumed to be 8.98 x10^{-1}mm^2/s and 2.40, respectively).

The materials were relatively unstable, with a very low angle of internal friction and cohesive strength (average $\Phi = 4.25^0$, average C= 23kn/m^2, Table 2).

Majority of the area studied is overlain by soft peat and peaty silty-clay mixture, up to the shallowest depth of 1.5m and can go as deep as 4.75m. This material which is locally referred to as "Chikoko" is dark brown to blown to black in color and fibrous with abundant plant remains. The formation is known for its undrained behavior and instability phenomena, such as liquefaction which contributes to its geotechnical hazards like flow-slides and extensive surface erosion.

From the laboratory consolidation tests carried out on relatively undisturbed samples, the bank materials samples are of high compressibility and exhibits appreciable swelling potentials and low bearing capacity value (Table 2 and 3). There was also a change in P^H level and sulphate content but not so significant as shown in Table 5.

3.2. Hydrographic surveys

Result of pre and post dredged survey of the canals from 1992 to 1996 were also obtained from SPDC dredging department, from which rate of siltation, frequency of dredging and cost of dredging each canal were calculated see Tables 4. Also plotted were canal center profiles and distribution of sediment across the channels as shown in Figures 1 to 4.

The above plotting were carried out in order to determine the source of the sediments, the effects of the catchments area on the sedimentation and also to know how the sediments were distributed along the canals and its cause. Average aggradations between 1992 to 1996 across each canal entrance cross-section were matched with the bathymetric shape of the canal at the entrance with the river that will discourage excessive siltation at the canal entrance; see Figures 5 to 6. The average flow velocity, frequency of dredging, fall velocity, inlet exterior angles and canal wave height for each of the canals are as shown in Figures 7 and 8.

The velocity of the canal currents during high and low tides were measured from which an average velocity 0.0145m/s was obtained. The current is higher for those canals that are constructed from the open river and lower for canals that have their roots from creeks.

The charts in Figures 1 to 4 shows a fairly uniform distribution of the sediments along the profiles, which implies that the sediments are not being washed into the canal from the river bank. If this were case a semi-concave shape of deposition pattern would have resulted such that more materials are deposited close to the bank than at the centre. Hence, the accumulated sediments result from river as either suspended into the canal, with only a minimal quantity coming from the river bank through either run off, or as a result of gradual flattening of canal cross section. From various centre profile and cross-sectional profile plotted, the deposition tends to be heavier towards the end of the canals as a result of the dead ends, which does not allow for a continuous flow. This results in lowering of the water current to approximately that, which would encourage siltation.

A check on the bathymetric shape of the canal especially at the canal entrance as it effects deposition of materials reveals that the canal has to start from the river with a particular alignment angle in order to discourage deposition at the entrance which may lead to cutting off, of the entire canal from the river body. From Figures 7 and 8, analysis of the various off take angles reveals that the exterior angles of the canal with the river have to sum up to $180^0 \pm 5^0$ for an effective water flow that will minimize settlement of particles. Also a thorough examination of the plots indicates that the best angular ratio is 60^0: 120^0 while 90^0: 90^0 will encourage deposition towards the edges of the canal, which may reduce the width of the canal (Figures 7 and 8). Angle summation that is far below or above 180^0 will result in deposition of material more at the middle of the entrance cross section or more at one of the ends of the canal cross sectional width. It should be noted that the above measures are only applicable to canals under tidal influence, and not for canals with its water flowing in only one direction. The choice of alignment and ratio of angle depends also on the curvature of the river at the point of the canal entrance.

From the result of the pre and post dredge survey of the canals from 1992 to 1996 average siltation rate of 2.35 m/yr. was estimated. The estimated cost, frequency of dredging, average flow velocity, fall velocity and canal wavelength of each canal including their average siltation rate are indicated in Tables 4 and 6 respectively.

The dredging cost is high ranging from N236,925 to N9,881,196.

Table 1. Characteristics and Nature of Samples at Various Depths

STATION	DEPTH (M)	COLOUR	NATURE	STRENGTH	COMPRESS-IBILITY
EKULUMA	0.0-1.0	Dark Grey	Organic Clay	Soft	High
	1.0-2.5	Dark Grey	Peaty Clay	Soft	Very High
	2.5-3.5	Brownish Grey	Silty Sand	Loose/Fibrous	Very high
CATHORNE CHANNEL	0.0-1.5m	Brownish	Peaty/Chikoko	Soft/Fibrous	Very High
	1.5-2.0	Grayish	Clay	Firm	High
	2.0-2.5	Grayish	Grayish	Silty Sand	Loose/Fibrous High

Table 2. Undrained Triaxial Compression Tests

STATION	DEPTH (M)	Natural moisture content (%)	Bulk unit weight γ (KN/M³)	Dry weight γd (KN/M³)	Undrained Cohesion Cu (KN/MM2)	Friction cohesion ϕ	Description of Sample
EKULUMA	1.0	90.0	13.5	7.1	20	5	Soft brownish gray fibrous peaty clay
	3.5	88.5	13.1	6.9	23	3	Soft to firm dark gray peaty clay
CAWTHORNE CHANNEL	1.5	90.5	13.7	7.2	22	4	Soft to firm dark gray peaty clay
	3.5	90.0	13.1	7.0	20	5	Soft to firm dark gray peaty clay

Table 3. Classification Test (Atterberg Limited)

STATION	DEPTH (M)	Natural moisture content (%)	Liquid Limited (%)	Plastic Limit (%)	Plasticity Index (%)	Liquid Index	Casangrande Classification
EKULUMA	1.0	90.0	96.0	43.3	52.7	0.89	CH
	2.5	90.3	9601	43.3	52.8	0.89	CH
	3.5	88.5	94.2	43.0	51.2	0.89	CH
CAWTHORNE	1.5	90.5	96.3	43.4	52.9	0.89	CH
	2.0	89.7	95	43.1	52.3	0.89	CH
	3.5	90.0	95.8	43.2	42. 6	0.89	CH

Table 4. Rate of siltation and cost of dredging

STATION	Date of Dredging	Duration from date last dredged	Average Siltation (m)	Canal area (m^2)	Rate of Siltation (m/d)	Quantity of material dredged (m^3)	Cost per m^3 (Assumed)	Total cost of dredging	Siltation rate (m/yr)
EKULAMA CANAL 2	29-8-92	-	3.038	8,906.25	-	27,057.19	N150.00	N4,058,578.00	-
	16-3-93	7 months	3.072	9,365.00	0.00144	28,769.28	-Do-	N4,315,392.00	5.27

EKULAMA CANAL 9	19-9-94	13months	2.745	6.172.00	0.0069	16,942.14	-Do-	N2,541,321.00	2.53
	16-8-93	5months	1,529	6,581.25	0.0100	10.064.50	-Do-	N1,509,675.00	3.66
	20-3-93	14months	1.615	6,227.50	0.0038	10.057.41	-Do-	N1,508,611.50	1.39
	23-1-92	-	2.532	5,601.25	-	14,182.37	N150.00	N2,127,355.50	-
	04-9-96	17months	2.913	9,347.50	0.0056	27,229.27	-Do-	N4,084,390.50	2.05
	22-4-95	10 months	2.557	8.846.25	0.0084	22.619.86	-Do-	N3,392,979.00	3.07
	0-7-6-94	7 months	2.797	8,906.25	0.013	24.910.78	-Do-	N3,736,617.00	4,758
	11-11-93	8 months	2.949	7,801.25	0.012	23,005.89	-Do-	N3,450,883.50	4.39

EKULAMA CANAL 28							
03-12-96	13-8-96	24-8-94	15-10-93	11-05-93	01-03-92	23-1-97	06-5-95
4months	24months	10months	5months	13months	-	8months	8months
1.307	3.403	1.703	2.063	1.328	2.375	2.812	1.997
11.567.00	11,937.50	15,290.00	11,617.00	13,441.50	11,617.50	6,125.00	6.403.75
0.0107	0.0047	0.0056	0.01360	0.00323	-	0.0115	0.0082
15.118.07	40.945.63	26,038.87	23,966.90	17,852.30	27.592.16	17.223.50	12.788.29
-Do-	-Do-	-Do-	-Do-	-Do-	N150.00	-Do-	-Do-
N2,267,710.35	N6,141,844.00	N3,905,830.00	N3,595,035.00	N2,677,845.00	N4,138,035.00	N2,583,525.00	N1,918,243.00
3.92	1.72	2.05	4.97	1.18	-	4.21	3.00

CAWTHORNE CHANNEL CANAL 1			EKULAMA CANAL 18				
12-5-94	03-5-93	13-4-92	16-10-96	07-5-95	23-5-93	11-9-92	06-3-92
12months	13months	-	17months	24months	8months	6months	-
3.562	3.008	3.238	2.650	2.659	1.809	1.218	2.520
3.162.50	3,250.00	3,360	4,400.75	4,481.25	4,207.50	4,481.25	4.582.00
0.0098	0.0076	-	0.00512	0.00364	0.0074	0.0067	-
11,265.34	9,776.00	10,879.68	11,661.99	11,915.64	7,611.37	5.458.16	11.547.90
-Do-	-Do-	N150.00	N150.00	-Do-	-Do-	-Do-	N150.00
N1,689,801.00	N1,466,400.00	N1,631,952.00	N1,749,298.00	N1,787,346.00	N1,141,705.50	N818,724.00	N1,732,185.00
3.58	2.78	-	1.87	1.33	2.71	2.45	-

	07-2-95	9months	2.387	3,818.75	0.0087	9,115.36	N150.00	N1,367,304.00	3.18
CAWTHORNE CHANNEL FLOW STATION 2	07-6-92	-	2.612	25.220.00	-	65,874.36	N150.00	N9,881,196.00	-
	06-9-93	14months	2.424	21.190.00	0.0057	51,364.58	-Do-	N7,704,684.00	1.09
	04-9-95	24months	2.111	25.004.00	0.0029	52,783.44	-Do-	N7,917,516.00	1.06
CAWTHORNE CHANNEL CANAL 17	06-5-92	-	1.891	12.887.5	-	24,370.26	N150.00	N3,655,537.00	-
	01-5-93	12months	1.884	12,895.5	0.0037	24,280.10	-Do-	N3,642,007.00	1.35
	16-12-94	19months	1.3595	14,086.25	0.0024	17,650.17	-Do-	N2,641,525.00	0.878

CAWTHORNE CHANNEL CANAL 10	06-7-92	-	1.732	4,721.25	-	8,177.21	N150.00	N1,226,580.00	-
	26-9-93	14months	1.531	4.887.50	0.0036	7,482.76	-Do-	N1,222,414.00	1.32
	16-9-95	24months	2.021	5,326.25	0.0028	10.764.35	-Do-	N1,614,652.30	1.03
	29-12-95	3months	0.405		0.00443	1,579.50	-Do-	N236,925.00	1.62

Table 5. Water Test before and after Dredging

STATION	PARAMETER	SAMPLE BEFORE DREDGING	SAMPLE AFTER DREDGING	W.H.O STANDARD (Mg/l)
EKULUMA CHANNEL	pH	7.8	8.6	6.5-8.5
	SO_4^{2-} (mg/l)	144	260	400
	Total solid (mg/l)	600	14400	500
CAWTHORNE CHANNEL	pH	7.35	8.77	6.5-8.5
	SO_4^{2-} (mg/l)	200	295	400
	Total Solid (mg/l)	550	13550	500

Table 6. Average flow velocity, frequency of dredging, fall velocity and canal wave heights

STATION	Frequency of Dredging (1992-1997)	Average velocity of flow (m/s)	Rate of siltation (m/yr)	Average canal width (m)	Average side slope	Average canal depth (m)	Fall velocity (mm/s)	Wave heights (m)
Ekulama channel Canal 2	6	0.195	3.90	70	0.34	2.91	0.09	0.15
Ekulama channel Canal 9	6	0.165	2.96	60	0.33	2.66	0.09	0.12
Ekulama channel Canal 28	6	0.110	2.77	95	0.30	2.76	0.09	0.09
Ekulama channel Canal 18	5	0.162	2.09	60	0.29	2.85	0.09	0.11
Cawthorne channel Canal 1	4	0.193	3.17	70	0.34	2.83	0.09	0.15
Cawthorne channel Canal 2 F/S	3	0.165	1.57	130	0.28	2.86	0.09	0.12
Cawthorne channel Canal 17	3	0.188	1.01	55	0.25	2.92	0.09	0.14
Cawthorne channel Canal 10	4	0.103	1.32	65	0.26	3.00	0.09	0.07

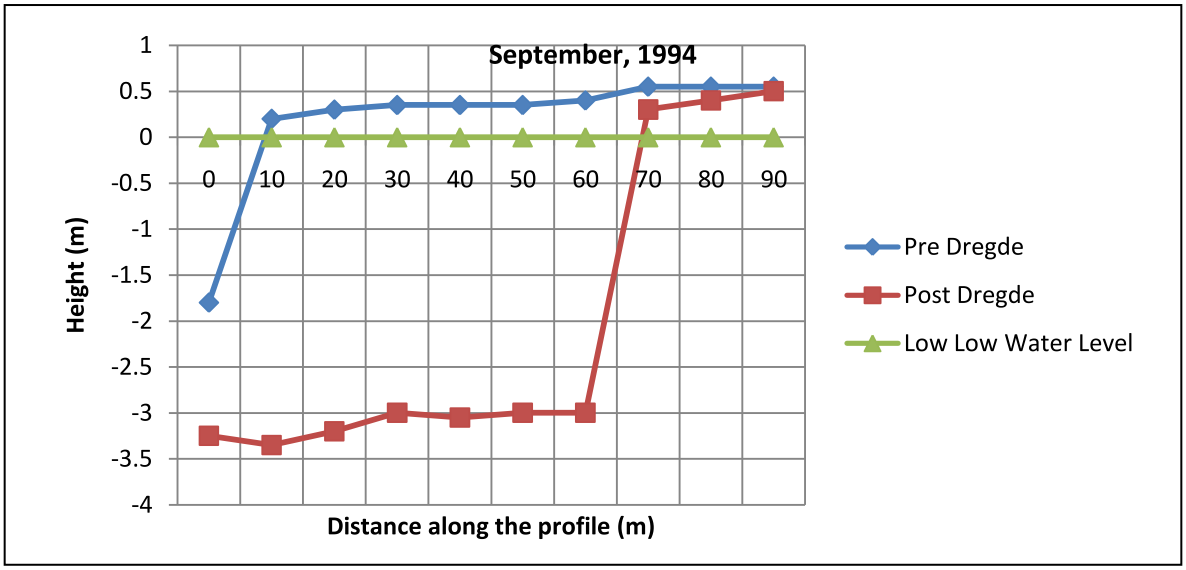

Figure 1a. Center profile of Ekulama channel 9

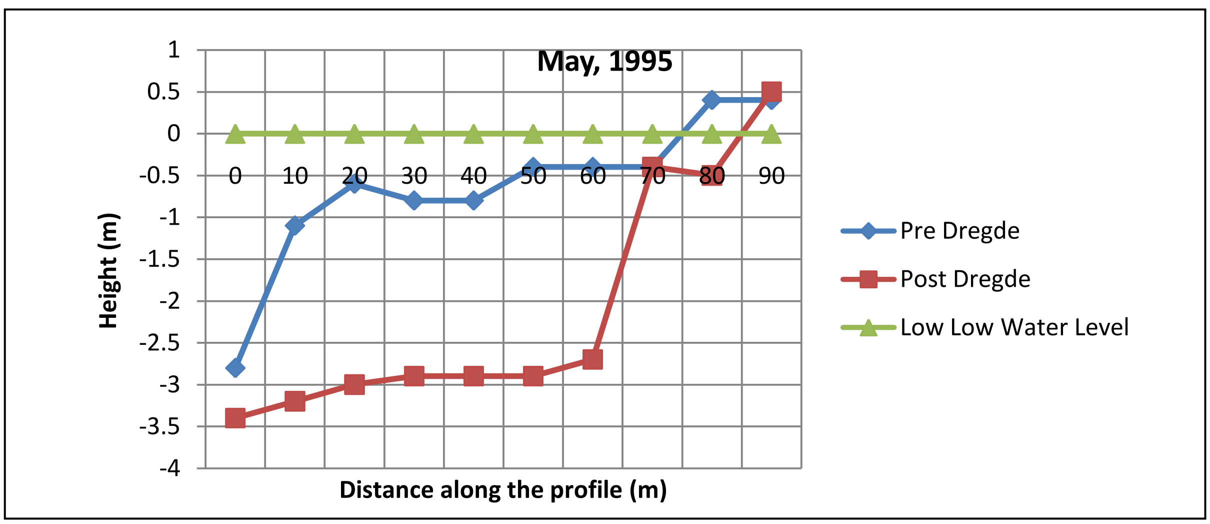

Figure 1b. Center profile of Ekulama channel 9

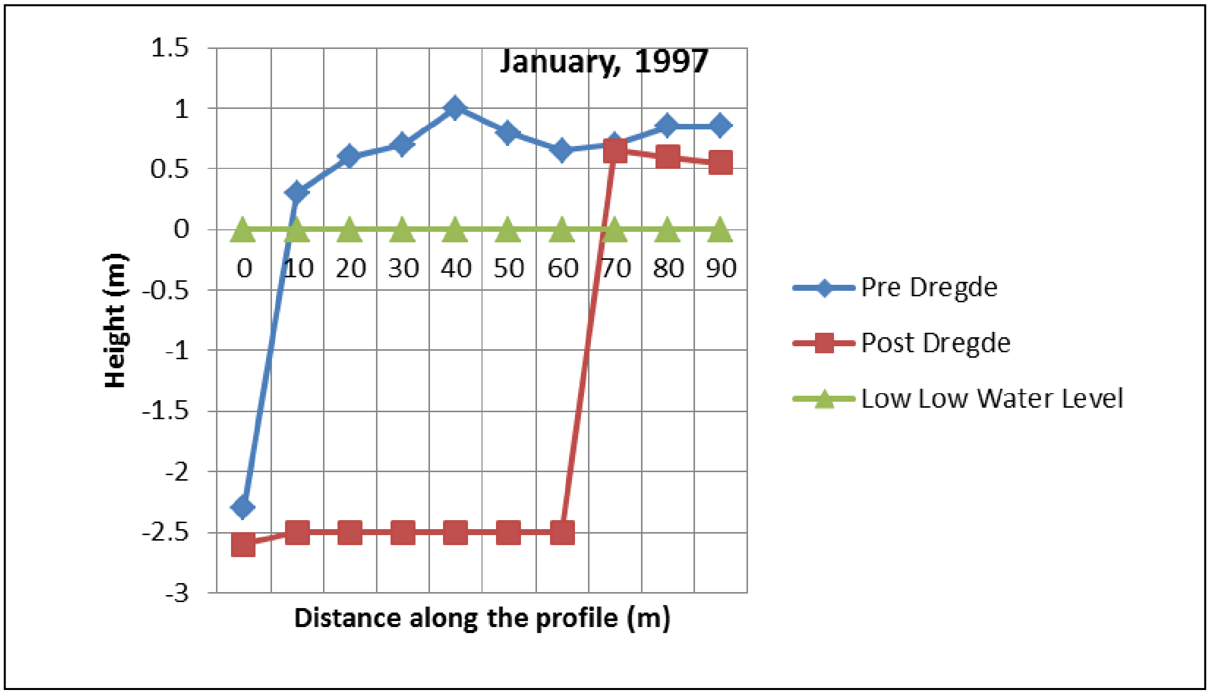

Figure 1c. Center profile of Ekulama channel 9

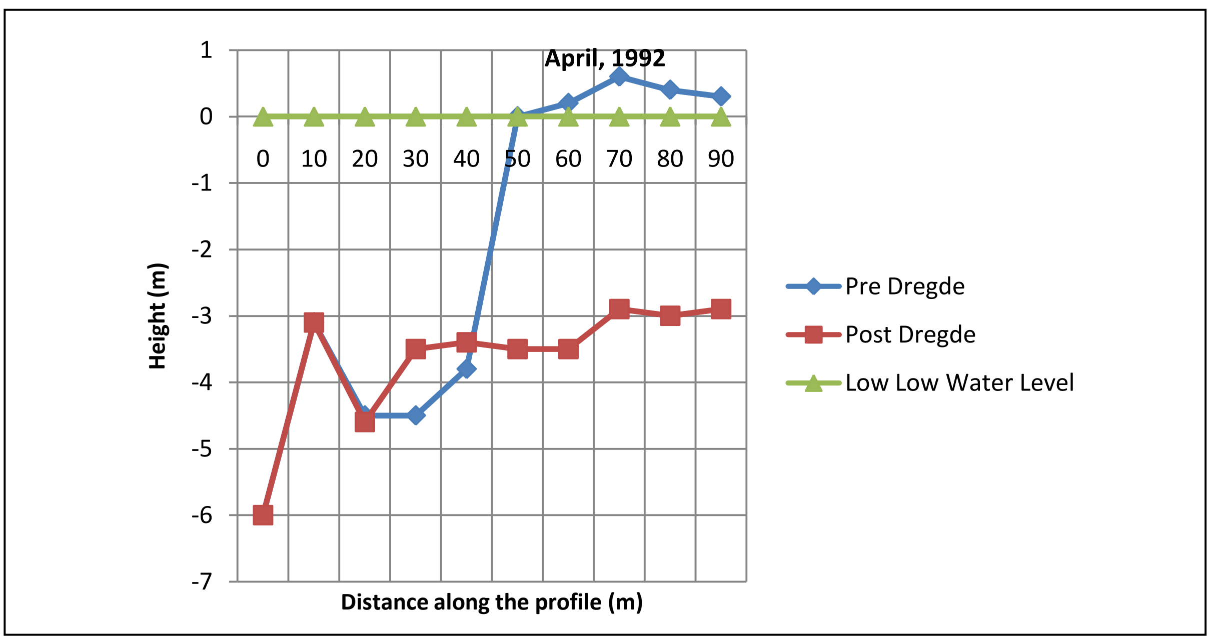

Figure 2a. Center profile of Cawthorne channel 1

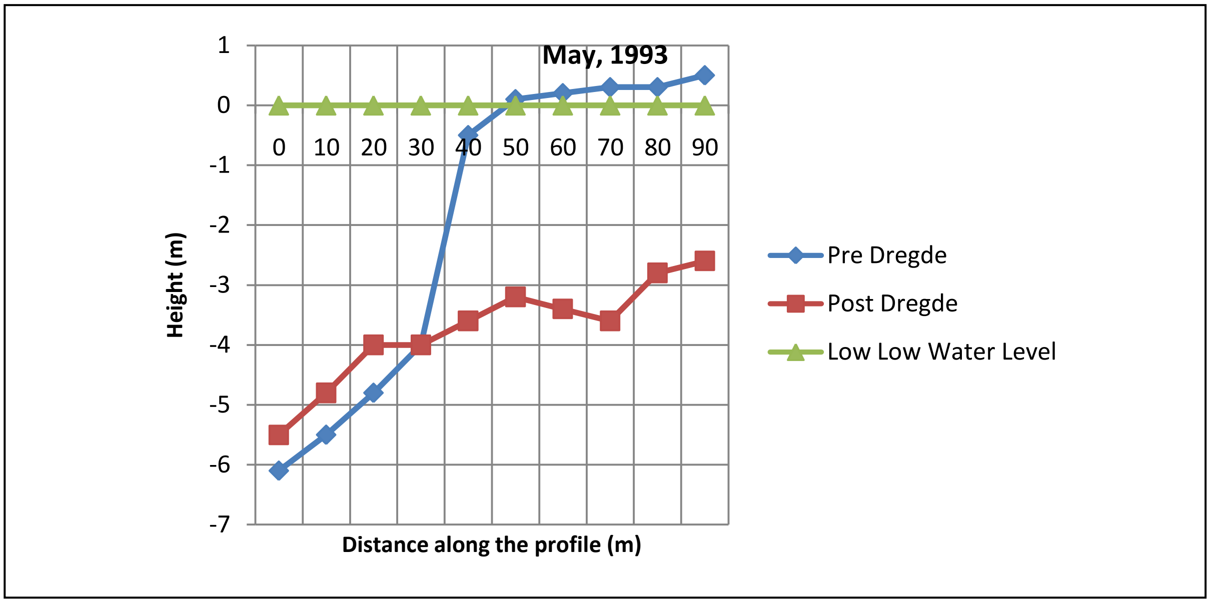

Figure 2b. Center profile of Cawthorne channel 1

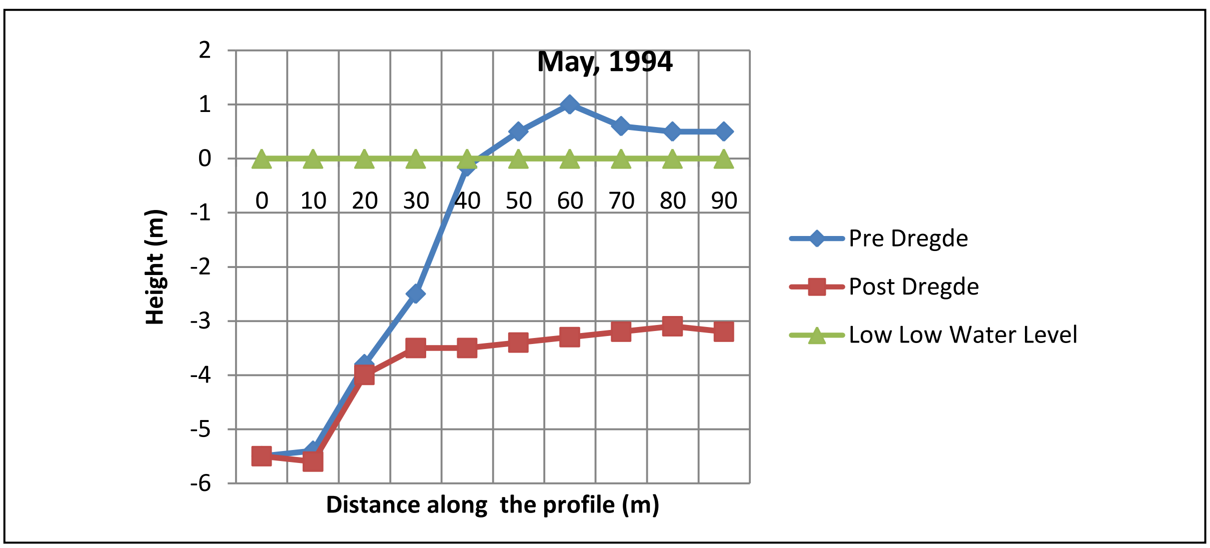

Figure 2C. Center profile of Cawthorne channel 1

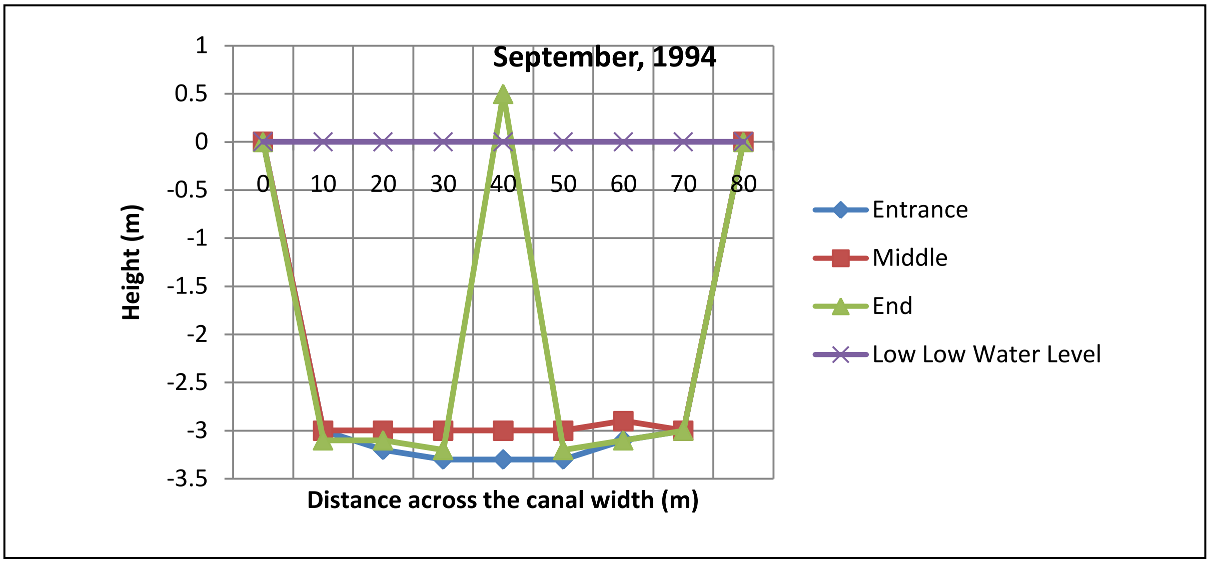

Figure 3a. Distribution of sediment across Ekulama channel 9

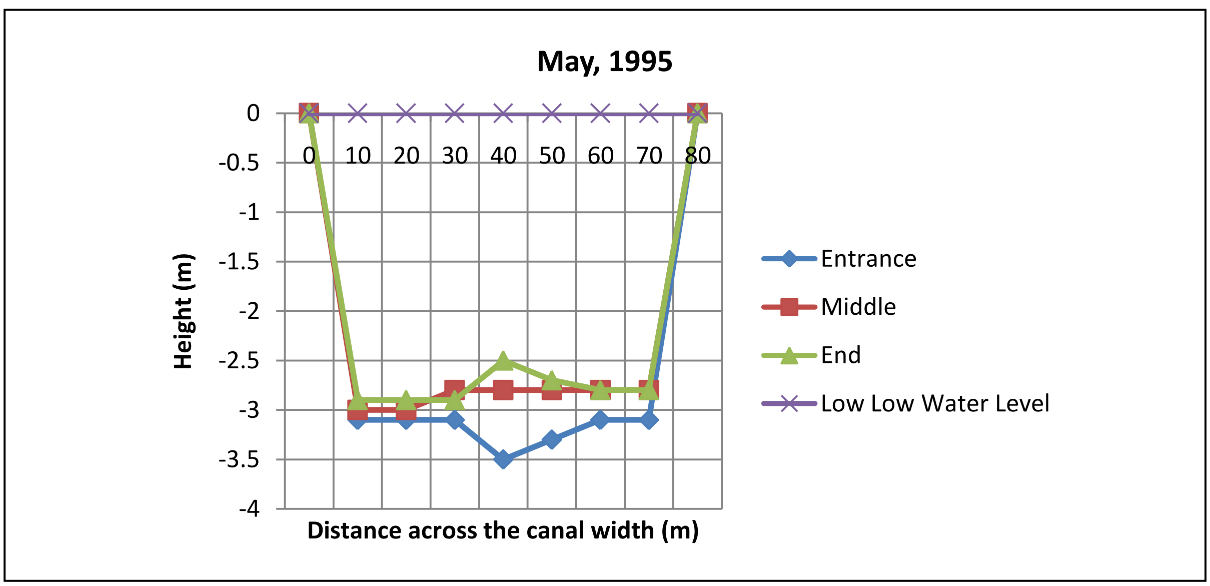

Figure 3b. Distribution of sediment across Ekulama channel 9

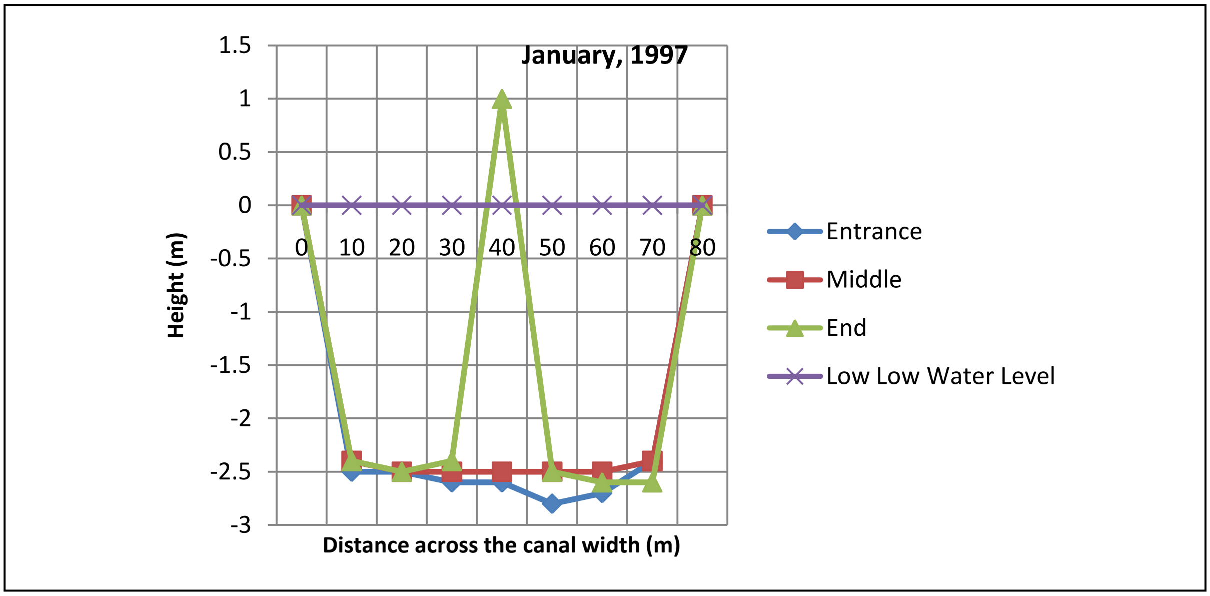

Figure 3c. Distribution of sediment across Ekulama channel 9

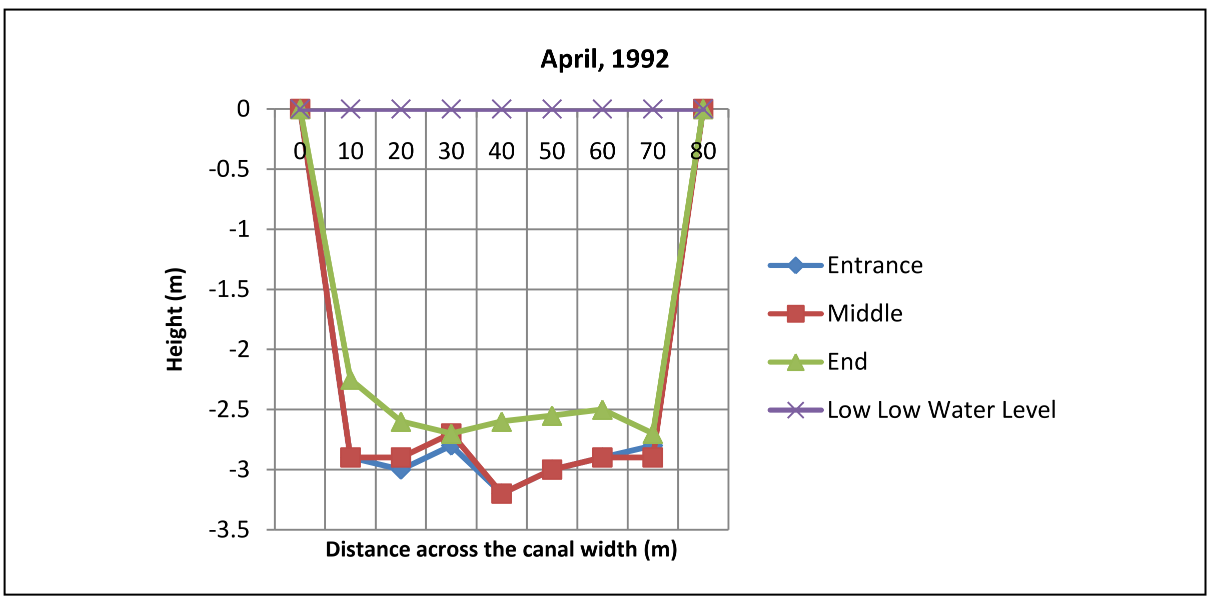

Figure 4a. Distribution of sediment across Cawthorne channel 1

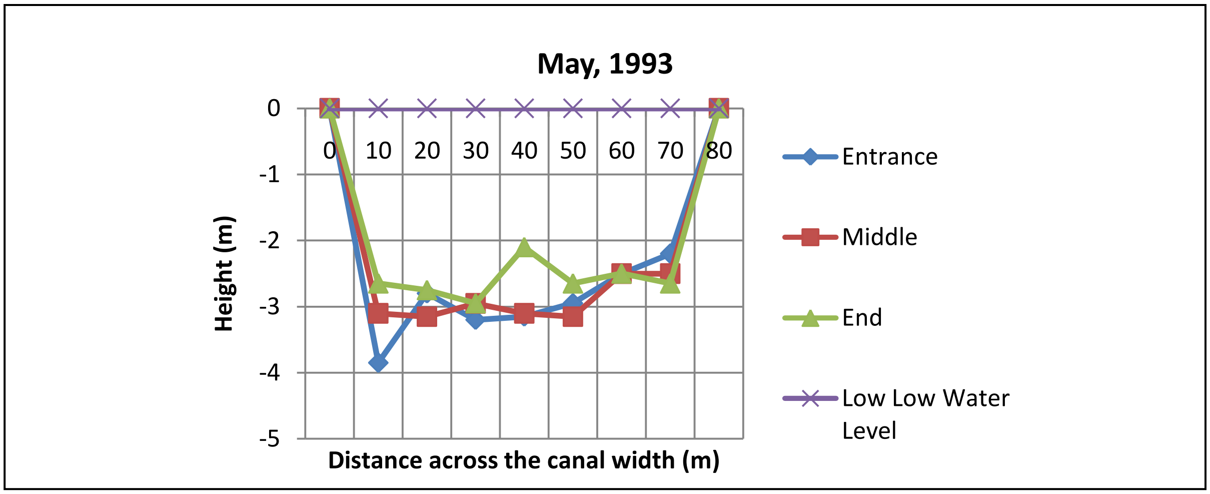

Figure 4b. Distribution of sediment across Cawthorne channel 1

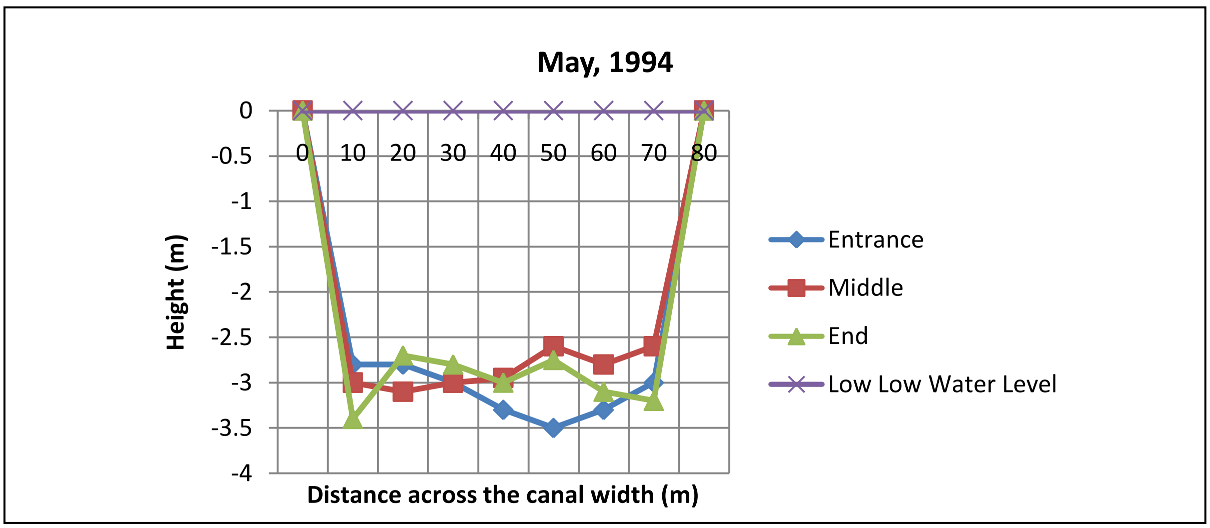

Figure 4c. Distribution of sediment across Cawthorne channel 1

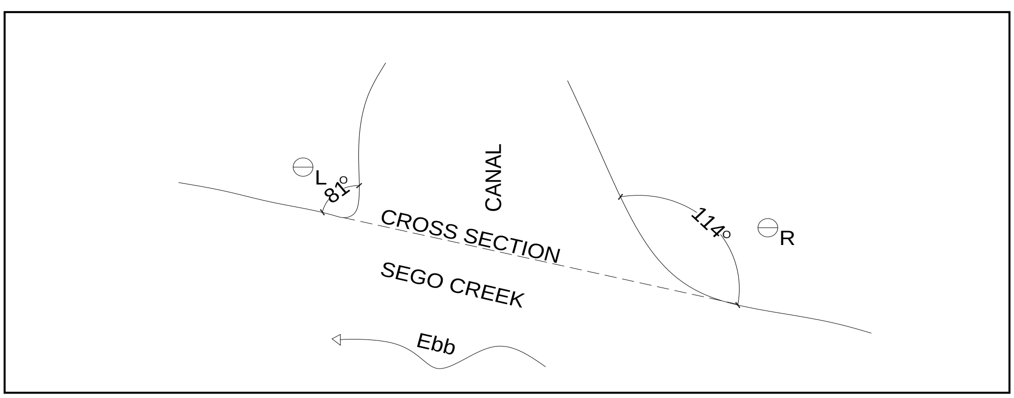

Figure 5. Entrance cross-section of Ekulama channel

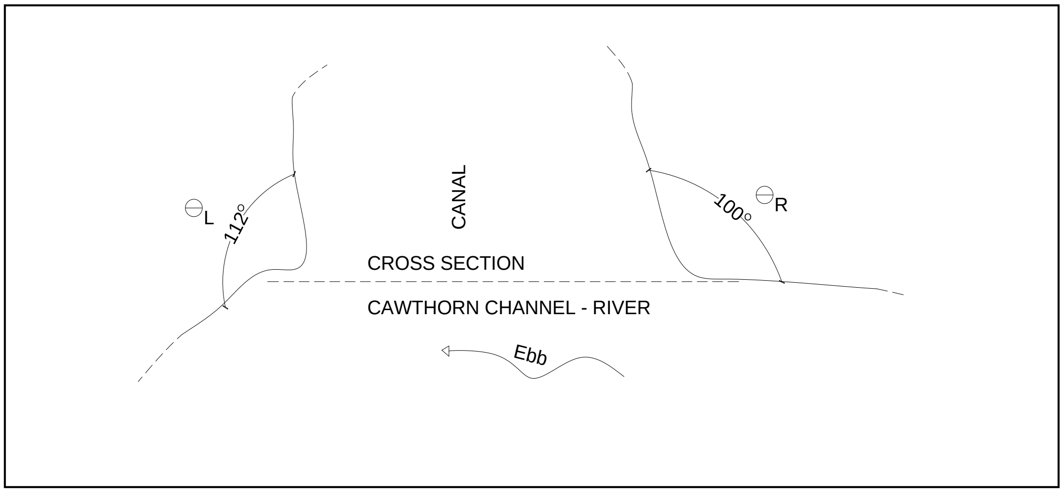

Figure 6. Entrance cross-section of Cawthorn channel

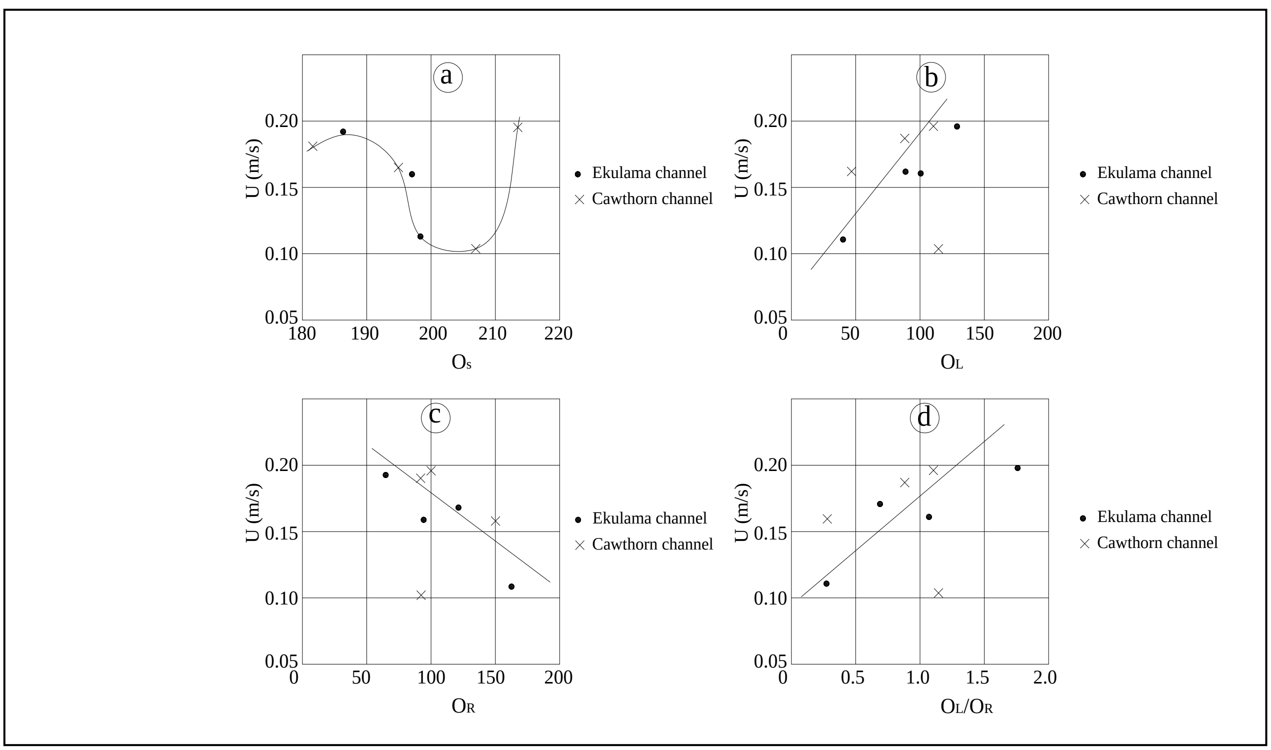

Figure 7. Variation of velocity with different angle parameters (a) θs, sum of the channel inlet exterior angles (b) θ_L, left inlet exterior angle (c) θ_R, right inlet exterior angle (d) θ_L/ θ_R, ratio of left to right inlet exterior angle

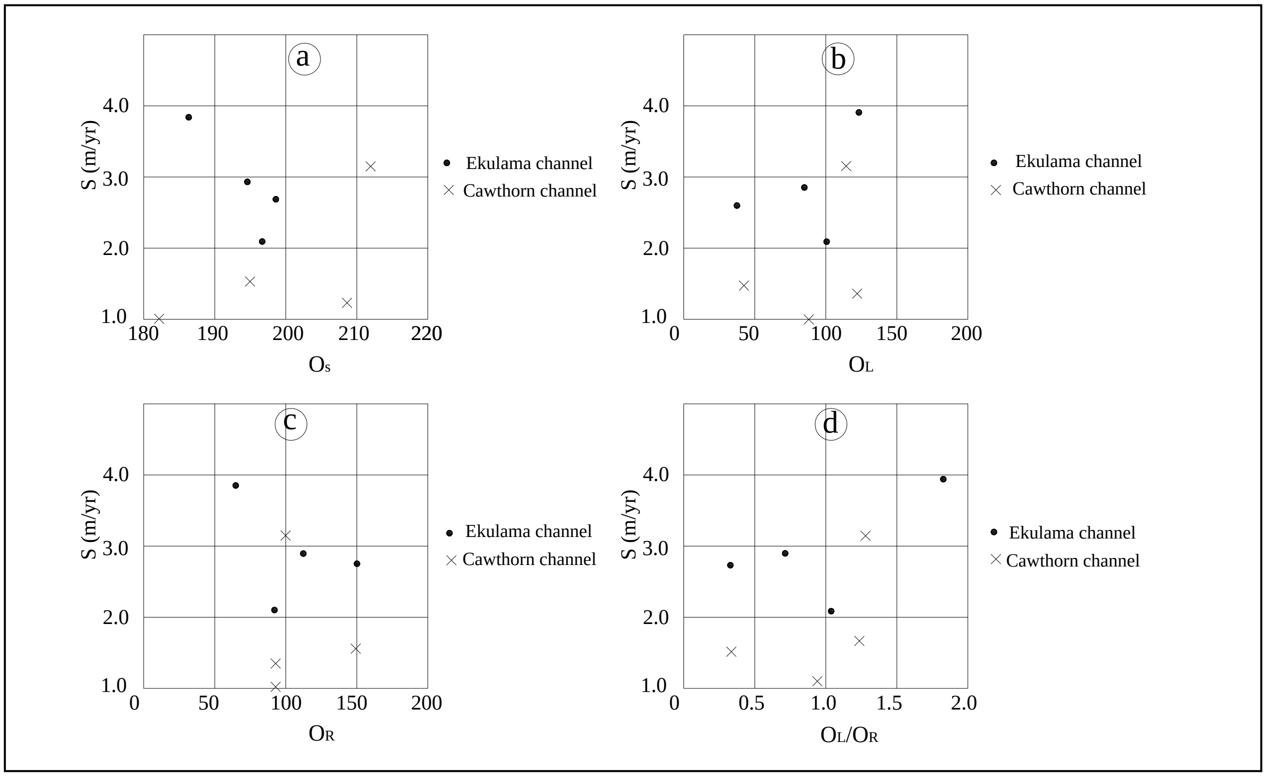

Figure 8. Variation of average sedimentation rate with various angle parameters (a) θs, sum of the channel inlet exterior angles (b) $θ_L$, left inlet exterior angle (c) $θ_R$, right inlet exterior angle (d) $θ_L$/ $θ_R$, ratio of left to right inlet exterior angle

3.3. Regression analysis

A regression equation was determined with relates the cost of dredging to canal area, rate of siltation and average aggradations. The equation is as stated below.

C= 8249448 + 732.16A x 5721404H – 3480303R

C= cost of dredging

A= canal area

H = average aggradations

R= Rate of Siltation

ANOVA[b]

Model	Sum of squares	df	Mean square	F	Sig.
1 Regression Residual Total	3.43E+13 6.37E+12 4.07E+13	3 4 7	1.1440E+13 1.5936E+12	7.179	044[a]

a. Predictors: Constant, R,A,H

b. Dependent Variable: C

COEFFICIENT[s]

Model	Unstandardized Coefficients		Standardized Coeffients	t-value	Sig.
	B	Std. Error	Beta		
(Constant)	-6249448	2725990.5	.933	-2.293	*.084
A	732.159	179.901	1.238	4.070	*.015
H	5721404.0	1613248.7	-1.435	3.547	*.024
R	-3480303	899355.13		-3.870	*.018

*= significant at P <0.05

4. Conclusion

The result of this study show that for canals under tidal influence, sedimentation can only take place whenever there is reduction in water current due to constrictions and barriers to flow water in the canal. Being that most of the constrictions are natural occurrence due to the process of delta formation, the prevention of excessive sedimentation to approximately that which would occur under natural conditions, relies on eliminating all forms of barriers or impediment to water flow as much possible. This will invariably maintain the water current in such a way that it will keep the sediments afloat in order to facilitate its transportation to areas where navigation is not affected.

Based on the above fact and finding from test and physical examinations, the following recommendations are proffered which if adhered to, will lead to both short and long term measures of checking excessive siltation.

5. Recommendation

The following recommendations are presented based on the results of the study:

1. Canal should be constructed in a closed circuit form, with no dead ends. It should be constructed to start and terminate on a moving water body, be it a river or a creek.
2. All impediments, constructions and barriers to free flow of the sediments should be eliminated as much as possible.
3. The exterior angle of alignment of the canal with the river should sum up to $180^0 \pm 5^0$ with choice angle ratio depending on the curvature of the river, preferably 120^0: 60^0.
4. Excessive speeding of boats should be discouraged in canals access. This is to discourage waves generated by the boat from causing sliding of unstable canal banks. This recommendation is yet to be proved scientifically and therefore further research is needed.
5. Bund walls should be provided where spoils from dredging are to be deposited to avoid dredged materials flowing back into the canal during or after dredging.
6. Dredging should be done in such a way that the movement of the dredger should not be against the direction of the river current, so as to discourage the settling of suspended particles on the dredged area.

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