PROBLEM OF SILTATION IN UPPER GANGA CANAL

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CERTIFICATE

Certified that dissertation entitled "Problem of Siltation in Upper Ganga Canal" which is being submitted by Shri Lileshwar Prasad Srivastava in partial fulfilment of the requirements for the award of the Degree of Master of Engineering in Water Resources Development of the University of Roorkee is a record of the student's own work carried out by him under my guidance and supervision. The matter embodied in this dissertation has not been submitted for any other degree or diploma.

Certified further that Shri Srivastava has worked for a period exceeding nine months ending 15th September 1974 in connection with the preparation of this dissertation.

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L. P. Srivastava

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SYNOPSIS

For the first time, in more than a century, the upper Ganga Canal experienced heavy silting in the last week of July and early August 1970. This was due to hill slides in Alakhnanda Valley. The canal was unable to take its discharge and heavy silt clearance had to be carried out. The problem of silt deposition is still continuing.

The hydraulics of sediment transport is still imperfectly known. The phenomenon of silt deposition, scouring and movement of silt in Ganga Canal was found to be highly complex. However, guide lines for canal operation have been framed taking case of the health of the canal and minimising the closure period. Closure of canal means loss of irrigation water and power-generation. While studying the problem some interesting results have been obtained.

It has been observed that coefficient of rugosity (Manning's N) increases significantly in clear-water flow, specially in the middle reach of the canal-length under study. The transporting capacity of the canal for total bed material load is significantly affected by the level maintained at Pathri Power House. It is, therefore, important that during the monsoon months and for some time thereafter, the safe level (915.50) should be maintained at Pathri Intake. Even so, the carrying capacity of the canal is found to be limited varying from 1600 ppm to 250 ppm bed material load (about twice those of fines including wash load) from head reach to Pathri intake.

This means that certain amount of deposition during the monsoon months has to be accepted in this reach. A limit of 300 Lakh cft has been suggested keeping in view the requirements of maximum operating period as well as likelihood of erosion before the next monsoons. This will impose a certain amount of restriction on canal running. A permanent effective remedy would be to provide a sediment excluder on the Ganga Canal.

Chapter 1

INTRODUCTION

1.1. History of the Canal

1.1.1. The Upper Ganga Canal takes off from the river Ganga at Mayapur, Hardwar (U.P.). At present the canal has a capacity to carry a maximum discharge of 11,000 cusecs. The layout of the headworks are shown in Fig. 1.1

1.1.2. The Ganga Canal was conceived by Col. Sir Proby T. Cautley in the early 19th Century. The scheme was sanctioned after the very severe famine of 1837-38 which struck the western Uttar Pradesh, and cost the Government a crore of rupees by remission and for relief measures. The canal was first opened in 1850 and after modifications in 1866 it irrigated 5.5 lakh acres.

1.1.3. Since then, from time to time, alterations and improvements in the headworks and the canal structures were done. Specially, after the flood of 1924 which is the highest recorded flood of Ganga till now and was of the magnitude of 6.75 lakh cusecs, the canal structures and the headworks were badly damaged during the flood and heavy repair work was done.

1.1.4. Possibility of power generation was visualised during the present century and exploited gradually. At present, there are eight power houses on the canal with a total installed capacity of 45.2 MW. The irrigation on the canal has kept on increasing and now it irrigates annually about 18 lakh acres of land. The canal has been mostly a non-monsoon canal till 1920

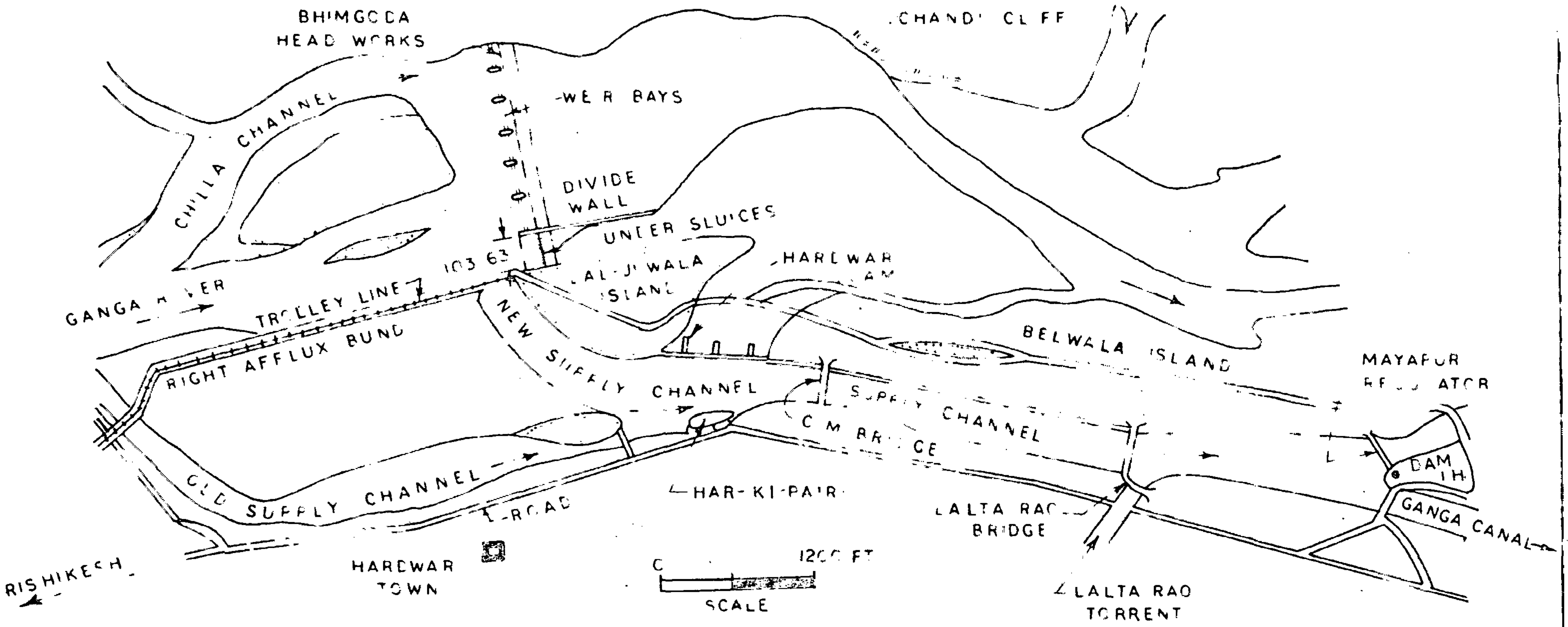


FIG.1·1_ LAYOUT OF GANGA CANAL HEADWORKS.

or 1924 when the first hydel Bahadrabad power house was commissioned.

1.2. The Headworks Complex

1.2.1. Old Supply Channel :

At the site of the headworks near Hardwar, the river is a braided stream. One of the streams flowed along Hardwar and it carried low supplies during winter. It was thought proper to take off the canal from this stream. Now, this stream is called the old supply channel. During the monsoon season, it attracts a large discharge depending on the set and the level of the river. At the end of the monsoons, its head stops functioning.

1.2.2. The Supply Channel :

Originally, Col. Cautley made a 300 ft wide, 14750 ft long, supply channel flowing along Hardwar to Mayapur, where the canal head regulator was located. All the cold weather supply was diverted by constructing temporary bunds across the other braided streams of the river downstream of the head of the supply channel.

1.2.3. The Hardwar Dam :

In the year 1879 the Hardwar dam was constructed opposite Hari-ki-Pauri to escape the surplus discharge back to Ganga. It has a masonry floor with wooden drop shutters of 6-ft height which are lifted by two movable cranes. The falling shutters of the Hardwar dam are not allowed to be overtopped. When these shutters are dropped, a significant portion of the flood arriving at the confluence of the old and new supply channels is passed back into the river.

1.2.4. The Bhimgoda Weir:

The arrangement for diverting winter flow of Ganga into the supply channel was made by constructing Bhimgoda Weir in 1920. The head works consist of a weir divided into 6 bays each of 300-ft width plus 6 undersluices on the right flank, each of 50-ft span fitted with stoney gates of 12.0-ft height and a head regulator on the right flank and nearly at right-angles to the axis of the weir. The crest levels of Bhimgoda Weir bays have been changed from time to time to train the flows on the upstream in order to ensure proper feeding of the new supply channel. Thus, today out of the six weir-bays at Bhimgoda, five are provided with wooden drop shutters of varying height which are lifted by travelling cranes. The last bay at the right end does not have any shutters because its crest was raised 0.5 ft higher than the top of all the falling shutters.

1.2.5. The New Supply Channel:

A new supply channel was excavated to join the old supply channel from the Bhimgoda Weir. It meets the old supply channel just upstream of Hari-ki-Pauri.

1.2.6. The New Supply Channel Head Regulator:

This head regulator consists of 10 spans of 20 ft each. In accordance with an agreement with the Ganga Sabha, Hardwar, initially gates were not provided in this regulator. However, in the year 1952, the Ganga Sabha permitted use of two steel shutters, one of 6.0-ft height and the other of 3.0-ft height (so that the operative sill can be 3 feet, 6 feet or 9 feet higher in times of floods) in all spans except one. These shutters are worked by one common travelling winch, and it takes a long time to operate the same. Thus, head regulator of the new supply channel cannot very much regulate the discharge entering the canal and during flood season lot of sediment enters through this regulator. Moreover, because of the absence of the breast wall above the top of gates, this regulator cannot be completely closed.

1.2.7. The Mayapur Dam:

At the downstream end of the supply channel at Mayapur, a small weir consisting of 15 bays of 10.0-ft span each was built to act as an escape but it was remodelled in the year 1895 to its present form, with seven undersluicebays and an overflow weir with falling shutters. The undersluicebays are fitted with vertical lift gates operable with mechanical winches.

1.2.8. The Canal Regulator at Mayapur:

The canal head regulator at Mayapur consists of 10 bays of 20-ft span each. It was remodelled in the year 1895 (after the flood of 1894 due to well-known Gohna hill slide) and fitted with steel shutters of 20.67 x 6.0 ft and 20.67 x 6.5 ft in two tiers, which are operated through wire ropes from a moving crane. These shutters can either be fully lowered or fully lifted, and are not meant for regulation by partial gate openings.

Headworks complex spreads over a distance of 2 miles along the right bank of the river. It will be noted that the Headworks complex is not at all suited for sediment control. The new supply channel has itself an uncontrolled opening, and can-

-not be shut off completely. The oldsupply channel which brings considerable discharge during monsoon is uncontrolled. Further, a small torrent, Lalta Rao, joins the combined supply channel above Mayapur Headworks and brings in further sediment.

The regulation devices comprise outmoded and inflexible arrangements of falling shutters and gates of non-regulating type; all cumbersome and time-consuming in operation. It seems that at some time in the past, a submerged wall was constructed partially across the mouth of the approach channel to head regulator for diverting the bed load towards Mayapur sluices. But, there is no arrangement for exclusion of silt in any of the weir either at Bhimgoda or at Mayapur. At Mayapur itself the configuration is not favourable to sediment selection. The canal head regulator is somewhat on the inside of a curve while the escape weir is on the outside - the reverse of what is needed. The adverse effects of these are seen by shoal deposition during monsoon near the upstream end of Mayapur regulator. In fact, actual silt measurement in 1972 showed that when Mayapur escape is opened alongwith the canal, the former takes less silt-laden water than the latter. No silt ejector has been provided in the canal. In fact, in the whole of Headworks complex there exists little control of discharges and no control of sediment entry.

1.2.9. The Canal:

The last remodelling of the canal was done in the year 1951 when the existing power house at Pathri came up replacing the old Bahadrabad Power House. With this remodelling the canal is having a design discharge of 11,000 cusecs. In the head reach, the theoretical bed-width of the canal is 200 feet (the actual bed-width varies much along the length of the canal). The water depth of the canal is 10 feet. The canal runs in deep cutting upto 12 miles but the problem of silt deposition is upto Pathri Power House which is situated at 7-3-0 mile. In the reach of the problem considered, i.e. upto Pathri Power House, the canal crosses the Ranipur torrent at 5th mile. This torrent was made to pass over the canal in masonry trough and the canal is in syphon.

The Ganga Canal in upper reach has a varying slope upto Pathri Power House. In its first mile, the slope is about 3.6 ft/mile (i.e. 6.82×10^{-4}). From Mile 1, to Mile 3, it has a bed slope of 2 ft/mile (i.e. 4.17×10^{-4}), while the bed slope in the remaining reach upto M. 7-3-0 is about 1.2 ft/mile (i.e. 2.28×10^{-4}).

1.2.10. The Pathri Power House

The Pathri Power House was constructed in 1954 to replace the old Bahadrabad Power House which was utilising a much smaller head and discharge. The Pathri Power House is utilising a discharge of 8,750 cusecs and a head of 32 feet which is made available by combining the falls at Ranipur, Bahadrabad and Pathri. A byepass has been provided on the left flank of the Power House. This byepass has been fitted with fish belly gates hinged at the concrete crest. The byepass is designed to take up the full discharge of the canal in case of power-house closure. The gates are operated by a float mechanism to ensure a pre-

-determined level upstream of power house. The water level corresponding to maximum head and minimum head for power generation is 918.50 and 915.00, respectively.

1.2.11. For the first time in its life of one-and-a-quarter century, the canal was very heavily silted up in the head reaches during the last week of July and early August 1970. This was due to land slides in Alakhnanda Valley, resulting in very heavy sediment concentrations, presumably of the order of 30,000 ppm.

1.3. History of the Problem

1.3.1. Sliding of steep hill slopes is not an uncommon phenomenon in Alakhnanda Valley. The well-known Gohna slide (1893) is one of the examples in which Birahi-Ganga (a tributary to Alakhnanda) was blocked near Village Gohna by a 900-ft natural dam created by hill slides. This dam was overtopped in the next monsoon of 1894 and was eroded from 900 ft, to 450 ft. From the year 1894 to the year 1924, the Gohna lake got gradually silted up, reducing its capacity. There is no record of heavy spillage till the year 1924. Due to very heavy rain in 1924 it was again heavily overtopped giving the highest recorded flood of Ganga (6.75 lakh cusecs). The blockade was eroded to about 200-to-300 feet.

1.3.2. It has been estimated by the Alakhnanda Enquiry Committee, that a cloud burst of about 20 cm took place in the later afternoon and early evening of 20th July 1970 all along the Kunwarikhal ridge in the area of about 30 sq. miles. Kunwarikhal is reported to have been made up of highly-weathered dolomites and magnesites subjected to severe temperature variation both diurnally and seasonally. The valley of Alakhnanda is also reported to have been subjected to frequent seismic disturbances in the past which helped in loosening and breaking up the rock formation. Twotremors were recorded on 19th July 1970 at Dehradun with their epicentre about 60 miles north of Dehradun.

1.3.3. As the Central Himalayan Thrust runs through Kunwarikhal, one should expect, in the given tectonics, a very highly crushed shear zone of substantial width along the same. In general, the Himalayan slopes are well-known to be unstable and steep, with rocks highly fractured, faulted and folded. The planes of cleavages in the rock masses are of such precarious stability that huge land slides take place when disturbed. These can be caused either by a rain storm or a seismic disturbance or by both.

1.3.4. The cloud burst of 20th July 1970 might have resulted in heavy land-slides all along the ridge. Consequently, the floods arising from the Kunwarikhal ridge brought down unusually large quantities of detritus. The tributaries of Alakhnanda, such as Helong, Patalganga and Garurganga (Fig.1.2), coming from Kunwarikhal join Alakhnanda on its left bank. These tributaries have steeper slopes and in high flood with excessive detritus, swiftly block the Alakhnanda to varying heights from 50 ft to 100 ft from the river bed. The highest blockade was created at the junction of Patalganga with Alakhnanda.

The heavily silt-laden flood from Rishiganga arrived at the river block, filled up the valley quickly and overflowed. the block, carrying alongwith it a part of the contents of the river blockade as well as emptying the impounded waters in a sort of flood bore.

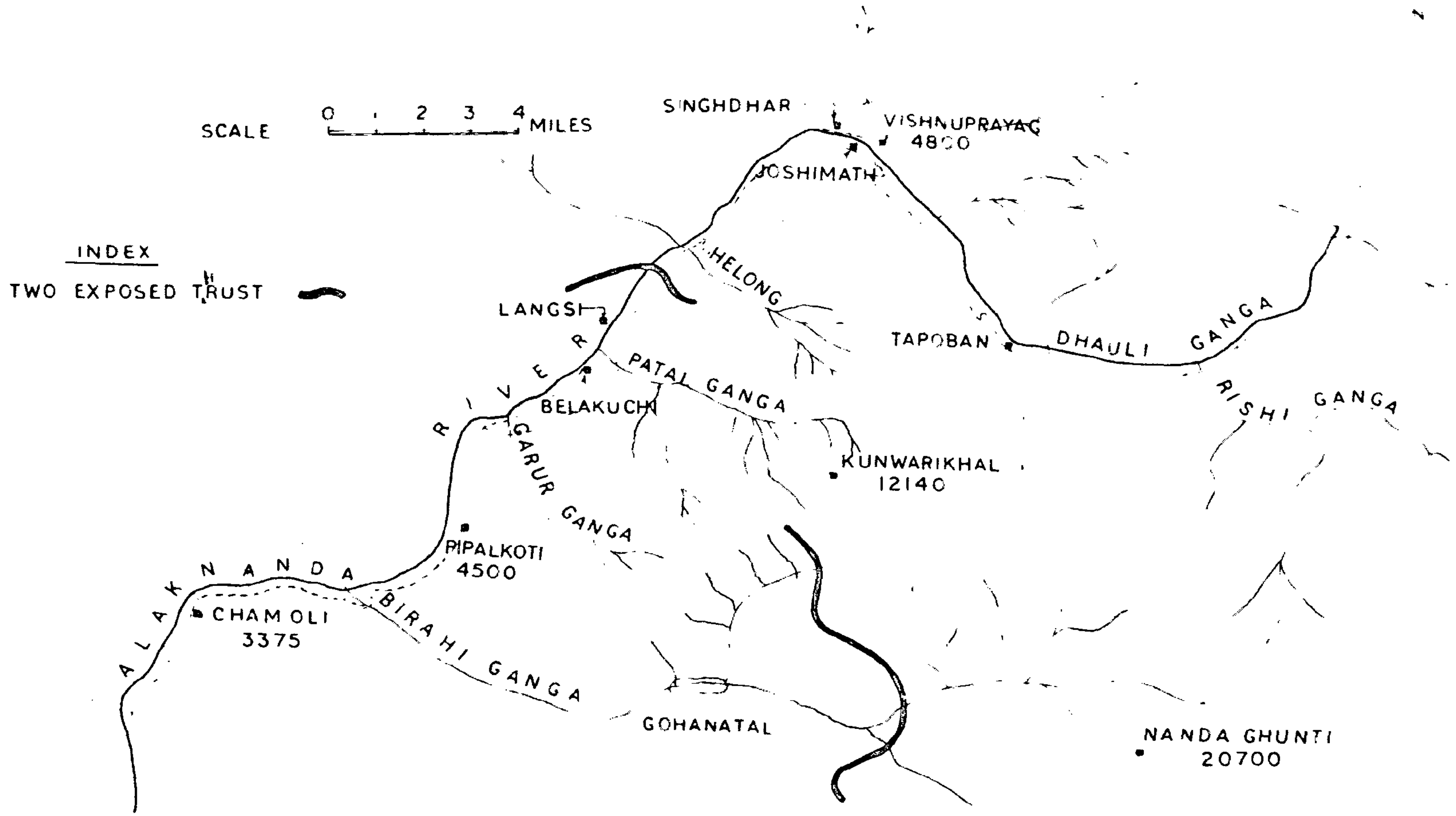


FIG. 1·2 _ INDEX PLAN OF ALAKNANDA VALLEY

Topan nala, Dhak nala (tributaries to Dhauliganga) also contributed to the flood crest in a similar manner. The silted-up lake of Gohna also completely disappeared in this flood.

1.3.5. The resulting peak flood discharge at Raiwala on 21st July 1970 was only 2.23 lakh cusecs, i.e. one-third of the recorded maximum flood of 6.75 lakh cusecs of 1924. Even so, the flood gauge at Rudraprayag (confluence of Mandakini and Alakhnanda) exceeded the 1924 mark. This may be explained by the flood of silt and water carried over a temporarily aggraded bed. The flood bore though moderated at Raiwala was still so much that the river rose and fell by 9.0 ft in 15 hours.

The silt concentration has been estimated to be of the order of 30,000 ppm.

1.3.6. The floods rose at Hardwar, in the early hours of 21st July 1970. Hardwar-dam gates were dropped and the gates at the head of New Supply Channel were lowered by the evening of 21st. The heavily silt-laden river water came into the supply channel through the uncontrolled head of old supply channel, and through the one uncontrolled span of the new supply channel and by overtopping the gates of the other spans of the same.

1.3.7. The Mayapur river sluices were closed in the crucial dates from 22nd July 1970 onwards, with the result that whatever silt came with the discharge, entered the canal.

It is estimated that a heavily silt-laden flood bore arrived at Hardwar soon after mid-night 20th/21st July 1970 and the sharp peak (rise and fall) lasted 15 hours from 400 to 1900 hours on 21st. The flood bore travelled from Belakuchi to Hardwar, a distance of 150 miles in 8 hours. During this flood peak time, the canal was running full till about 6.00 p.m. on 21st and it is estimated that at least 120 lakh cft of silt entered the canal and partly got deposited. This resulted in considerable reduction in conveyance capacity of the canal. On 22nd morning the canal headregulator downstream gauge recorded 8.6feet for 4200 cusecs against a normal gauge of about 6.0 ft corresponding to an unsilted bed.

1.3.8. The silt concentration was so high that it exceeded the canal capacity to carry silt even in its first mile which is having the steepest slope of 3.6 ft/mile. Coarser material was dropped in the first mile and less coarse material in the miles to follow upto Ranipur Superpassage or even upto Pathri Power House. The Pathri Power House gauge was maintained at about its high stage.

1.3.9. On the morning of 23rd, the upstream head regulator gauge went up by 1.2 ft and downstream gauge by 0.53 ft for the same canal discharge compared to the morning gauge of 22nd. This was the measure of the silt deposition on 22nd over and above what was caused on 21st. The Pathri pond was raised by 2.6 ft on 23rd morning.

1.3.10. On the 24th July 1970 after raising the Hardwar-dam gates, canal supplies could be restored to 8500 cusecs with a downstream regulator gauge of 11.4 ft against a normal gauge of 10.3 ft for the same discharge. That means that more deterioration took place on 23rd. The water surface slope on 24th from head regulator to Ranipur was steeper than the surface slope on 23rd.

23rd. This extra energy due to extra depth and steeper slope, caused a movement of the silt deposited in mile 1-0-0, towards mile 2-0-0 and 3-0-0. In this process of translation of sediment, a hump must have been formed at the point of change of energy slope till its height exceeded the limit when critical flow conditions could be induced. This critical velocity flow over the humped bed resulted in the formation of the very heavy waves in mile 2 and 3 which were observed on 25th and 26th. This wave phenomenon resembled somewhat to a submerged standing wave. Gradual silt accumulation in the canal downstream of wave phenomenon upto Pathri Power House, raised the canal bed continuously and as this was achieved, the wave disappeared. Thereafter, the discharging capacity of the canal steadily fell from 8,500 cusecs on 24th, to 2,600 cusecs on 30th July 1970. The siltation seems to have almost completed by about this time.

1.3.11. An attempt to scavenge the deposited silt by closing the power house and byepassing the discharge, was made between 5th and 9th August 1970. But this had an effectiveness for a short length upstream of Pathri power house only and the canal discharge did not increase. It was felt that nothing could be done except to close the canal and take up silt clearance work.

1.3.12. The silt clearance was carried out to a line a little higher than the theoretical bed-line approved in 1951. The canal was again opened on 14th October 1970 and was run with full gauge. Within a fortnight of its running, the canal bed attained the non-monsoon regime conditions and the bed got scoured to below theoretical levels. The canal ran satisfactorily till the next monsoon.

1.4. Behaviour of Canal during Monsoon 1971

1.4.1. During the monsoon 1971 the canal was run according to the criteria recommended by the Alakhnanda Enquiry Committee. These were to close the canal when the sediment concentration reached 12,000 ppm, while precautions were to be taken when it was above 7,000 ppm. The canal was to be run with as high discharge as possible. With these canal-regulation criteria, substantial silting was observed in the canal towards the end of August and thereafter, the canal was not run if the sediment concentration exceeded 5000 ppm for more than 48 hours. The canal was run with a discharge of 9000 cusecs practically throughout the monsoon and had to be kept closed for 33 days due to excessive silt charge.

1.4.2. The first flood of the 1971 monsoon came in the river on 11th June 1971 night and was of the order of 1,17,430 cusecs. It brought down excessive silt charge which rose to 25,203 ppm in the night. The canal was closed when the silt charge exceeded 12,000 ppm. The average silt contents in the water at the head of the canal remained of the order of 16,800 ppm during the third week of June when the canal was kept closed. Floods of the magnitude of 1,27,170 cusecs came in on 26th June 1971 and of 1,33,410 cusecs on 1st July 1971. Practically throughout whole of July the river flood remained from 75,000 cusecs to 1,25,000 cusecs. The canal was again closed after the floods of 25th June 1971 and 1st July 1971. The average silt content at the head of the canal during these closures remained of the order of 19,400 ppm. The silted bed level of the canal observed on 16th July 1971 showed silting of 1.5 ft above the theoretical bed level at mile 1-5 and 2.5 ft at mile 4-0 and 6-0. However, the water level did not show any rise. The canal was run after these closures upto end of July with a silt charge of 2500-to-5000 ppm.

Again, flood of 1,79,741 cusecs came on 2nd August 1971 when the silt contents rose to 24,000 ppm. Throughout August, the river was in flood with a discharge more than 1,00,000 cusecs. The canal was kept closed upto 23rd August. The silt charge in this period remained of the order of 7,000-to-15,000 ppm. Bed levels observed in the closure on 3rd September 1971 indicated silting of 1.5 ft at mile 1-5-0 while it rose to 3.72 ft at mile 4-0 and 4.17 ft at mile 6-0. At some places the silted bed was higher than the desilted bed of October 1970.

The canal was run thereafter only when the silt charge was below 5,000 ppm. From 24th August 1971 to 3rd September 1971, the silt charge was of the order of 3000-to-4000 ppm and thereafter it went on decreasing sharply and fell below 1,000 ppm. Even then the bed was showing signs of continuous silting. The water surface levels also showed rising tendency after first week of September 1971. The discharging capacity of the canal also dropped by 10-to-15 percent.

1.4.3. With the lowering of the silt charge, it was expected that the silt deposited in the bed would scour out quickly and the water levels will come down. But the process of flushing the silt in bed was slow and there was no perceptible fall in the water surface levels. From 12fth October 1971 onwards the byepass gates at Pathri power house were lowered completely for a week with the expectation to accelerate the flushing but this did not have much effect. Even after running with clear water till middle of January 1972 the canal bed could not attain the non-monsoon regime conditions. It could be attained only in May 1972. It would be seen that the canal bed went on silting even at low silt charges of the order of 2,000-to-3,000 ppm after the initial silting had occurred at higher silt charges.

1.4.4. The size of the silt particles in 1971 was found to be coarser than 1970 and it was thought possible that in years to come still coarser silt particles may come down from Alakhnanda Valley, which will have more tendency to settle in the bed.

1.5. Behaviour of Canal during Monsoon 1972

1.5.1. On the basis of recommendation of the Alakhnanda Enquiry Committee, further research, and experience gained during running of canal in 1971 monsoon, regulation orders for Ganga Canal Headworks were revised in June 1972. Standing orders regarding regulation of canal regulator were given as below:-

"During the period the silt content exceeds 5 gms/litre, the canal should be closed and opened only when the silt content falls below 5 gms/litre. The governing section for silting of canal is at Mile 4-0 and should the silting at Mile 4-0 exceed 913.00 (theoretical bed 1951 is 910.16 and bedlevel after desilting on 14th October 1970 was 913.80), the canal should be closed by the Assistant Engineer, Mayapur, immediately, intimating the closure to all concerned. He should obtain further orders for opening the canal from Superintending Engineer. If wave phenomenon is noticed at any place sounding should be taken to ascertain if there is excessive silting and orders of executive engineer obtained. The health of the canal will be the primary consideration in running the canal under silted conditions, demand for irrigation or power generation being a secondary consideration.

"When the silt content is within 3,000 ppm the canal should be run with a high discharge of, say, 9000 cusecs even in slack demand for increasing the silt carrying capacity of the canal and the excess escaped at Dhanauri o r down below at Jani escape at Mile 87-0. When the silt content is between 3,000 and 5,000 ppm the canal may be run according to irrigation demand subject to a minimum of 5,000 cusecs.

"If due to excessive silting in the canal the discharge of the canal for the same gauge at Mayapur falls by more than 15%, the sub-divisional officer, Headworks, should immediately seek orders of executive engineer to close the canal from Mayapur."

However, with this stringent control the behaviour of the canal during 1972 monsoon is being discussed dbelow.

1.5.2. Year 1972 was comparatively a dry year (kindly refer Appendix I, Accumulated silt deposit in different periods during monsoon.) There had been no closure of Ganga Canal upto 7th July 1972 while the canal had to be closed for 14 days till that date in 1971. As silt deposition was observed even at concentration lower than 3,000 ppm after the initial deposition took place during the monsoon of 1971, more stringent control was adopted for the rest of monsoon 1972. As the Alakhnanda and Ganga Valley conditions had improved during 1971 due to flushing of the accumulated sediment of 1970, it was anticipated that even at the permissible limit fixed at 5,000 ppm closure required would not be excessive. Actually, the canal was closed for a total of 12 days during the monsoon period of 1972.

1.5.3. The canal was run with a high discharge of 9,000 cusecs when the silt content was lower than 5,000 ppm. The usual daily observations of silt content, canal bed and the water surface levels were continued and careful watch was kept on the health of the canal.

1.5.4. With these regulation criteria, the extent of silting during 1972 was less (196 lakh cft) and normal bed levels were restored much earlier, i.e. by the end of September 1972. It was also noticed that the bed levels in December 1972 were about 2 ft lower and seem to correspond to normal clear water regime of the canal. The so-called 'theoretical' [illegible]' bed of 1951 does not seem to correspond to actual clear water regime of the canal in the reach of 2-6-0 to 7-0-0 mile.

1.5.5. Inspite of a considerably lower accumulation of silt, the feeding of canal with full supply during Spetember was only little better than the previous year.

1.6. Behaviour of the Canal during Monsoon 1973

1.6.1. With the experience of running the canal during 1971 and 1972 monsoons, the problem was studied in detail. It was reviewed whether the stringent control exercised during 1972 was essential for the health of the canal or could be moderated to some extent. Even in normal years, suspended sediment concentration in Ganga river is known to reach 10,000 ppm or more. If the regulation instructions specify the closure of the canal at a particular silt concentration (as was in practice during 1971 and 1972), the canal may have to be closed suddenly, more than once during the monsoon.

1.6.2. It was thought that with the large variations in the silt concentration of the river water, a stable regime on a canal cannot imply 'no deposition' at any time during the year. If there were no deposit during high silt concentration, it is bound to scour during clear-water period due to excessive tractive stress. For an erodible channel, a stable regime would mean pnly as much deposition during the monsoon period as can be cleared during the subsequent running of clear-water flows. Of course, the deposits should not be such as to prevent the canal from being run with full capacity at any time.

1.6.3. Keeping above facts in view the regulation instructions were modified and alongwith the permissible silt concentration, instructions were given regarding the permissible accumulated silt during different periods of monsoon. This was to avoid the frequent closing of canal for high silt concentration lasting for short time and preventing the canal from damage if a silt concentration little higher than its carrying capacity lasts for long time. The recommendation of permissible accumulated silt was based on the behaviour of canal on the monsoon of 1971 and 1972. Sufficient guidance was given for the site staff in the form of correlations of bed level at 4-0-0 mile with quantity of accumulated silt in length upto Pathri power house and correlation of average rate of daily silting with silt concentration. The detail of recommendation will be discussed later.

1.6.4. It was also instructed to have trial runs for the canal with only the necessary discharge at higher sediment concentrations instead of running it at the 9,000 cusecs or maximum possible discharge as was followed during 1971 and 1972 monsoons. This was because though the carrying capacity of the canal is less at smaller discharges, the total amount of sediment entering into the canal is also less. (This has been justified by the computation based on 1972 and 1973 data.)

1.6.5. The experience of 1972 shows that though the accumulated silt was low, there was difficulty in feeding the canal with full supply during September. It was found that as soon as the content of the fine silt in the water falls, by about the middle of September, the value of roughness n shows an appreciable rise. This requires a larger water-depth. It was found that problem of September feeding can only be solved by allowing more depth in the canal encroaching on freeboard. As the canal in the reach of the problem is in deep cutting, it did not pose any problem. For the full discharge, the increase depth of flow works out to be of the order of 1.35 to 1.5 ft.

1.6.6. The maximum accumulated silt during monsoon 1973 reached to 250 lakh cft against 196 lakh cft in 1972 and 333 lakh cft in 1971. However, trend of silt deposition during 1973 monsoon was not as expected. There was considerable rainfall during end of June and early July and this led to heavy influx of sediment, so much so that by 7th of July there was already a deposit of 131 lakh cft in the first seven miles in the canal against 20 lakh in the previous year 1972 (Appendix I). To ensure maintenance of canal capacity for the rabi irrigation, the canal was closed for a total of 40 days during the monsoon including a continuous stretch of 20 days from 9th to 28th August 1973. Even so, on the 20th September 1973 the canal bed levels at and beyond Mile 4-0 were appreciably higher than in 1972. (Kindly see Table 1.1. Bed levels at the end of the monsoons.)

1.7. Study of the Problem

1.7.1. The causes that led to the silting of the Ganga Canal, the current rules and regulations till 1970 for operation of the canal and the measures to be taken to control the situation more effectively was first taken up by the Alakhnanda Enquiry Committee consisting of six persons set up by the Government of India in consultation with the Government of Uttar Pradesh under the Chairmanship of Sri N. G. K. Murti, Chairman & Managing Director, Water & Power Development Consultancy Services (India), Ltd., New Delhi.

The problem was also studied at U.P. Irrigation Research Institute, Roorkee, and Bahadrabad. A further study of the problem has been made by Sarvashri Sharma, Varshney and Agrawal in a paper submitted to I.A.H.R.

After the monsoon running of the canal in 1972 the problem was studied in detail by Dr. Bharat Singh, Professor Designs, Water Resources Development Training Centre, University of

Table 11- Bed Levels at the End of Monsoons

Distance from Head (Miles)	Theoretical Bed (1951)	Bed on 21st Sept. 1971	Bed on 27th Sept. 1972	Bed on 20th Sept. 1973
0-3	921.47	920.56	920.48	920.27
1-5	916.52	917.98	916.98	916.52
2-6	913.96	915.51	913.22	912.05
4-0	910.16	913.73	911.36	911.60
5-0	909.16	913.51	907.36	912.96
6-0	907.94	913.21	907.96	912.56
7-0	907.13	908.41	907.42	908.51

Roorkee, and the preliminary report was submitted by him prior to monsoon 1973.

1.7.2. In the present volume the problem has been further studied mainly with the available new data of 1973 monsoon (prior to scheduled closure for maintenance, i.e. 5th October 1973).

Chapter 2

AVAILABLE DATA, ASSUMPTIONS AND STUDIES CARRIED OUT

2.1. Available Data

2.1.1. The existing canal operation rules and regulations till 1970 do not contain any mention of the sediment. So. no data relating to the problem was available at the time of 1970 happening. With the silt concentration in the Ganga river measured at Virbhadra and in the feeder channel at Bahadrabad, the silt concentration in 1970 happening has been estimated to be over 30,000 ppm. The total quantity of silt entered between 21st and 30th July 1970 was estimated to be 480 lakh cft.

2.1.2. During the monsoon 1971 data regarding discharge at 0-3-0 mile of canal was observed by actual sounding and current meter. The cross-section of the canal at 1-5-0, 4-0-0, 6-0-0 and 7-0-0 was also observed. Silt concentration at 0-3-0 of the canal has been observed at 6 a.m. and 6 p.m. When the silt concentration is higher than 5,000 ppm then the silt samples were taken four times in 24 hours. In addition to these, the data pertaining to gauges of canal at Mayapur, and maximum river discharge is available. These data are available from 1st June 1971 to 2nd October 1971 on daily basis and after that, weekly and fortnightly. Silt content at mile 6-0-0 of canal is also available from 30th June 1971 to 2nd August 1971.

The gauges upstream and downstream of Pathri power house are separately maintained.

2.1.3. During 1972 monsoon, daily data are available from

15th June 1972 to 30th September 1972. This year, in addition to previous gauge sites, cross-sections were observed at mile 2-6-0 and 5-0-0 also.

2.1.4. During 1973 monsoon, daily data are available from 15th June 1973 to 5th October 1973. This year, the gauge site at 2-6-0 was shiftedto 3-0-0 mile. For this year, data is available for 4 days when the canal was run with low discharges, while the silt content was moderately high (5th August 1973 to 8th August 1973).

2.2. Assumptions

2.2.1. Bed levels corresponding to clear water flow regime during May/June 1972 have been assumed as datum for computation for silt deposit. Silt deposit during 1971 has also been brought to this common datum.

2.2.2. The canal-bed width has been assumed constant at 180 ft from mile zero to 5-1 and 200 ft from 5-1 to 7-3. It is also assumed that the gauge sites at 0-3, 1-5, 3-0, 4-0, 5-0, 6-0, 7-0 miles represent the reach 0-0 to 1-0, 1-0 to 2-0, 2-0 to 3-0, 3-0 to 4-0, 4-0 to 5-1, 5-1 to 6-0, 6-0 to 7-3 miles, respectively. Any rise or fall in the bed levels at these gauge sites is assumed to be over the entire reach to which they correspond. Roughly speaking, each gauge site represents one mile. It will be seen afterwards that this is inadequate for knowing the silt deposition and scouring within a short interval of time. However, the observations are sufficient for study of other parameters.

2.2.3. The gauge and discharge observed at 9.00 a.m. in the morning have been assumed constant for 24 hours till 9.00 a.m.

of next day. The silt concentration observed at 6.00 a.m. and 6.00 p.m. has been averaged and assumed constant for 24 hours.

2.3. Studies Carried Out

2.3.1. After heavy silting in 1970, Alakhnanda Enquiry Committee studied the causes that led to the silting of Ganga Canal, the existing rules and regulations till 1970 for operation of the canal and the measures to be taken to control the situation more effectively.

Apart from the other measures regarding improvement in structures, gates etc. and the rules for operation of gates of Mayapur complex, the Committee suggested the criteria for running the canal on silt-concentration basis, that is, the canal should be closed as soon as the silt concentration exceeds the limit of 12,000 ppm. It was also suggested to run the canal with as high discharge as possible. The behaviour of the canal with these criteria has been already dealt in para 1.3.

2.3.2. The problem was also studied at U.P. Irrigation Research Institute, Roorkee and Bahadrabad by Sarvashri H. D. Sharma, D. V. Varshney and V. K. Agrawal. Model studies regarding effectiveness of providing under-shot byepass gates at Pathri and effect of providing a separate escape upstream of existing byepass indicated that undershot operation of byepass gates improves flushing of the canal bed. The same effect can be obtained by the provision of an additional escape with the discharging capacity of 75 m^3/sec. located at 11.2 km where flushing will be more effective. However, the model studies have shown that the flushing effects will be local and confined to a distance of about 1 km to 1.5 km. Thus the provision of additional byepass gate or undershot operation of existing gates will not affect the sediment transport capacity in upstream reaches above mile 6-0.

It was also found that the wash load in case of Ganga Canal varies from 50% to 70% and the coefficient of rugosity changes from 0.026 in case of clear water to 0.015 for sediment-laden water with a sediment content of 5 gms/litre, i.e. 5,000 ppm.

Regarding sediment transport capacity of the Ganga Canal, it has been found that the value of total sediment load as computed by Einstein's method is much higher than the observed data. The values as obtained by the methods suggested by Engelund-Hansen and Laursen yield result much closer to the observed data while the values obtained by Toffaleti's method are slightly higher than the observed data. (In the present study more reliance has been given on the values obtained by Laursen method.) A limit of 5 gms/litre was suggested as the permissible concentration of sediment entering the canal beyond which the canal should be closed at the head.

2.3.3. The problem was then referred to Dr. Bharat Singh, Professor, W.R.D.T.C., University of Roorkee, by Shri P. S. Yog, Addl. Chief Engineer (Ganga) in October 1972. The problem was analysed on a different line of thinking. The preliminary report on the problem was submitted by him in May 1973. The final report with detailed study and recommendations has also been submitted by him in March 1974. The present writer was associated with him in the computations for the final report . However, out of the various studies carriedout, only those of utility to the sponsor-

-ing Department were included in the Report given to them. Other aspects of interest have been included and discussed in the present dissertation.

HYDRAULIC ROUGHNESS

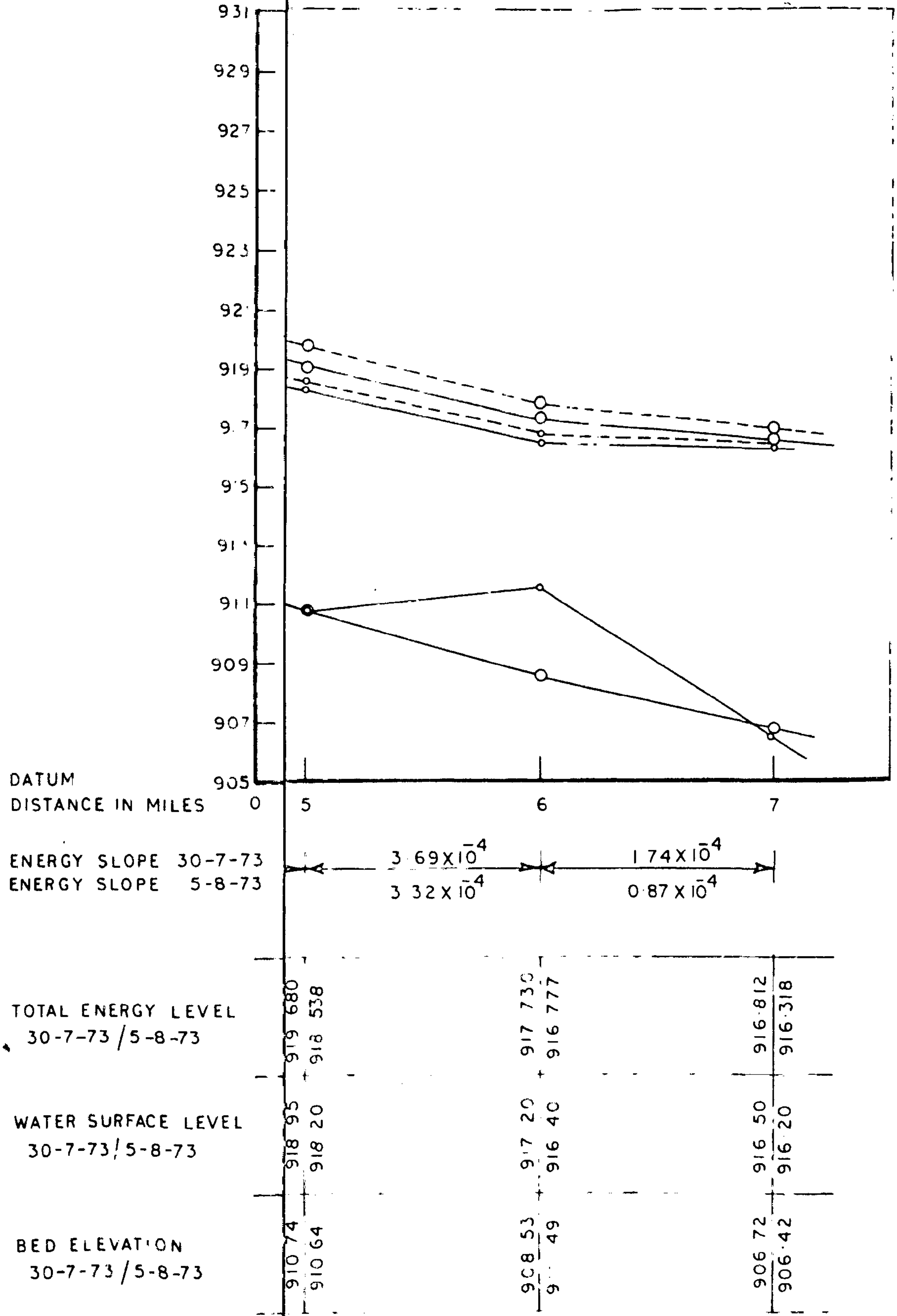
3.1. The first parameter studied in the problem is the hydraulic roughness. Both the water and sediment carrying capacity depend on hydraulic roughness. In a mobile bed channel, the hydraulic roughness is not a permanent characteristic of the channel but it varies from time to time and along the length of the channel. Besides the size gradation of the boundary material, there are two factors which influence the hydraulic roughness of the channel :

(1) The concentration and grading of the suspended sediment, and

(2) The changing pattern of the bed formations due to movement of bed load in the ripple-dune regime.

3.2. The value of rugosity coefficient in Manning's equation along the different reaches of the 7-mile length of the canal was already computed by Dr. Bharat Singh for selected 15 days (including monsoon aswell as non-monsoon periods) during the year 1971 and 1972. In the present study 19 days were chosen from data of 1973 for which adequate data for bed levels, Water surface levels etc. were available for different reaches of 7-mile length of the canal under study. The data included varying discharges and sediment concentrations.

3.3. Due to considerable variation in bed levels, the bed slopes are different at different times. (Fig. 3.1a and 3.1b show the bed levels, water surface levels and energy lines on 30th July 1973; 5th August 1973 and 20th September 1973; 27th September



3 AND 5-8-73

20 feet

feet

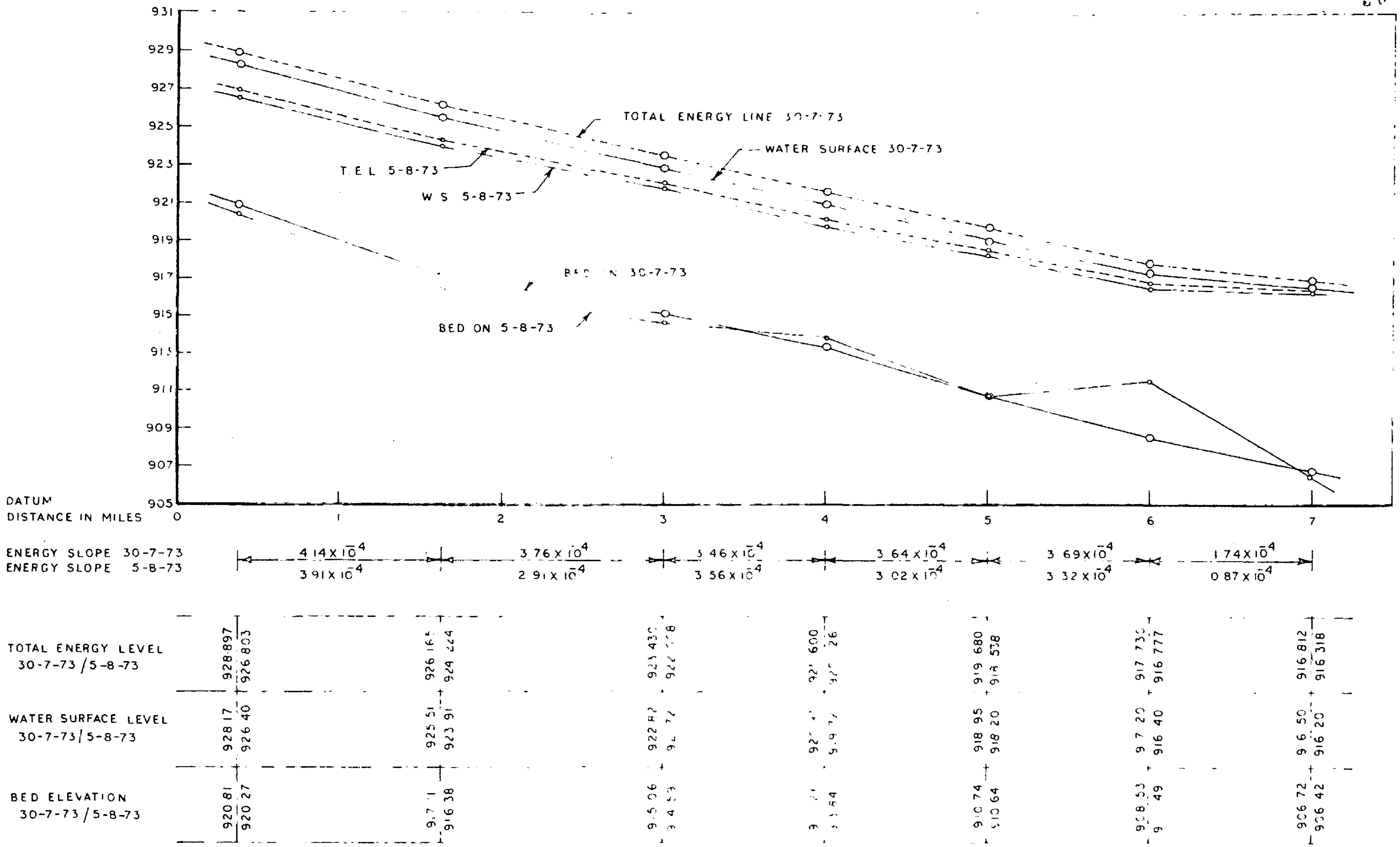
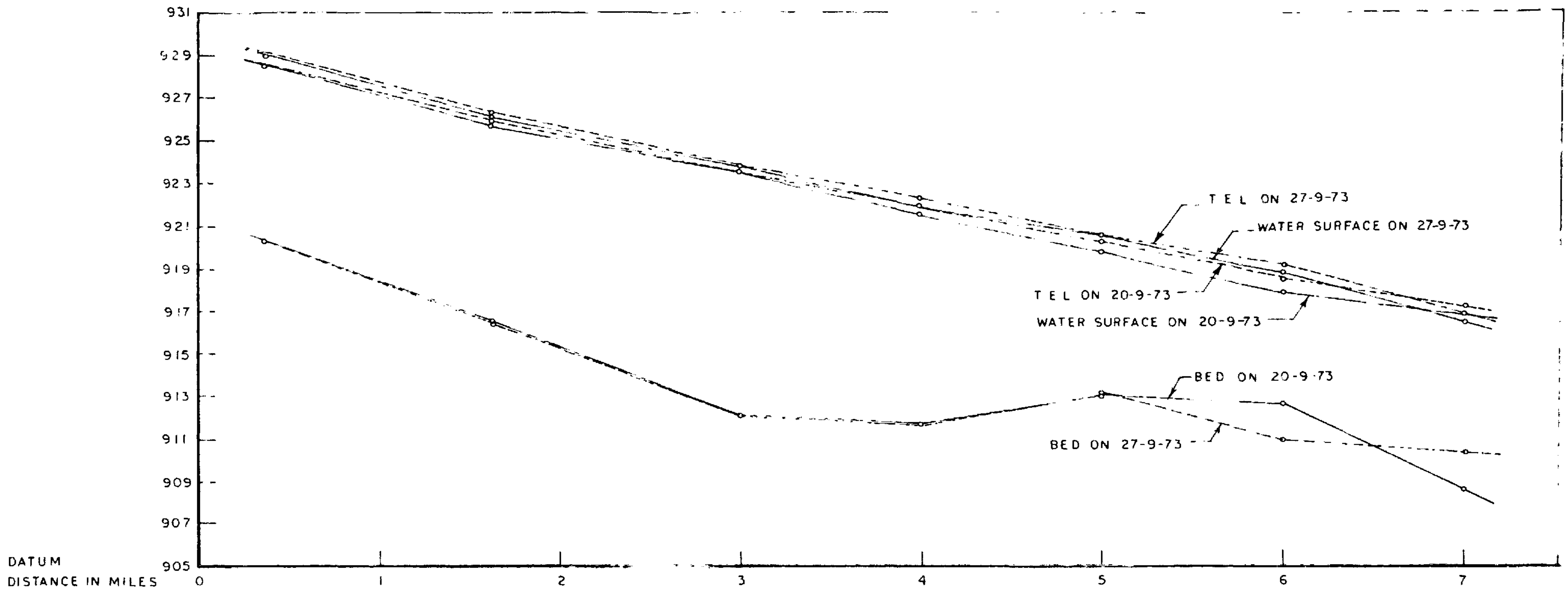


FIG.3.1(a)_ BED, WATERSURFACE AND ENERGY LINE ON 30-7-73 AND 5-8-73

SCALE HORZ 1 Cm 1320 feet
VERT 1 cm = 2 feet



Energy slope 20-9-73 / 27-9-73							
	4.44×10^{-4} / 4.26×10^{-4}	3.21×10^{-4} / 3.37×10^{-4}	3.64×10^{-4} / 3.02×10^{-4}	2.50×10^{-4} / 3.20×10^{-4}	3.79×10^{-4} / 2.64×10^{-4}	2.47×10^{-4} / 4.28×10^{-4}	

TOTAL ENERGY LEVEL 20-9-73/27-9-73	928 964 / 929 064	926 035 / 926 255	923 701 / 923 803	921 775 / 922 204	920.453 / 920 515	918 448 / 919 117	917 140 / 916.856
WATER SURFACE LEVEL 20-9-73/27-9-73	928 50 / 928 60	925 58 / 925.83	923 47 / 923 57	921 47 / 921 92	919 70 / 920.20	917 80 / 918 80	916 80 / 916.40
BED ELEVATION 20-9-73/27-9-73	920 27 / 920 32	916 52 / 916 44	912.05 / 912 07	911 60 / 911 55	912 96 / 913.11	912 56 / 910 82	908 51 / 910 36

FIG. 3·1(b)_BED, WATER SURFACE AND ENERGY LINE ON 20-9-73 AND 27-9-73

SCALE | HORZ 1cm = 1320 feet | VERT 1cm = 2 feet

Table 3.1a -

Date er depth at M 7-0-0 = 12.08

Discharge alues as computed separately

Silt contekwater curve M1 type

Location M-F-Ft	Wat Sur Elv	S_f 10^{-4})	$\bar{S}_f$ (in 10^{-4})	Δx	h_f ($\bar{S}_f \cdot \Delta x$)	H
7-0-0 (N=.0181)	918	79 50				919.001
6-0-0 (N=.0204)	919	2200	1.0070	5280	0.531	919.532
	919	1880	0.9910	5280	0.523	919.524
	919	1750	0.9850	5280	0.520	919.521
5-0-0 (N*.0159)	919	000	2.0380	5280	1.075	920.596
	919	5500	1.8630	5280	0.984	920.505
	919	5750	1.8750	5280	0.990	920.511
4-0-0 (N=.0161)	920	5400	3.0580	5280	1.615	921.126

The obse

upto M 4

Table 3.1a - Computation of Water Surface Profile at High Pond of Pathri Power House

Date = 30th July 1973

Discharge = 9074 cusecs

Silt content = 1516 ppm

Water level u/s of Pathri P.H. = 918.50

Assumed water level at M 7-0-0 = 918.80

Bed level at M 7-0-0 = 906.72

Energy gradient $S_f = (N^2/1.492)(V^2/R^{4/3})$

Water depth at M 7-0-0 = 12.08

N values as computed separately

Backwater curve M1 type

Location M-F-Ft	Water Surface Elv. Z	Water Depth D	Cross Sectional Area A	Mean velocity $\bar{V}$	Velocity Head $V^2/2g$	H $(Z+\frac{V^2}{2g})$	Wetted Perimeter P	H.M.R. R	$R^{4/3}$	S_f (in 10^{-4})	$\bar{S}_f$ (in 10^{-4})	Δx	h_f $(\bar{S}_f \cdot \Delta x)$	H
7-0-0 (N=.0181)	918.80	12.08	2506	3.62	0.201	919.001	228.52	10.95	24.30	0.7950				919.001
6-0-0 (N=.0204)	919.20	10.67	2445	3.71	0.213	919.413	247.80	9.89	21.15	1.2200	1.0070	5280	0.531	919.532
	919.30	10.77	2469	3.68	0.209	919.509	248.00	9.95	21.40	1.1880	0.9910	5280	0.523	919.524
	919.32	10.79	2474	3.67	0.208	919.528	248.04	9.98	21.50	1.1750	0.9850	5280	0.520	919.521
5-0-0 (N=.0159)	919.65	8.91	1448	6.27	0.609	920.259	185.08	7.82	15.50	2.9000	2.0380	5280	1.075	920.596
	919.95	9.21	1502	6.04	0.565	920.515	185.68	8.10	16.30	2.5500	1.8630	5280	0.984	920.505
	919.94	9.20	1500	6.05	0.567	920.507	185.66	8.09	16.20	2.5750	1.8750	5280	0.990	920.511
4-0-0 (N=.0161)	920.97	7.71	1425	6.37	0.629	921.599	203.46	7.01	13.40	3.5400	3.0580	5280	1.615	921.126

The observed water surface level at M 4-0-0 is 920.97, so backwater effect may be assumed upto M 4-0-0.

Table 3.1b - Computation of Water Surface Profile at High Pond of Pathri Power House

Date	= 7th August 1973	Water level U/S of Pathri P.H.	= 918.50
Discharge	= 4277 cusecs	Assumed water level at M 7-0-0	= 918.80
Silt content	= 1452 ppm	Bed level at M 7-0-0	= 906.63
		Energy gradient S_f	= $(N^2/1.492)(V^2/R^{4/3})$

Location M-F-Ft	Water Surface Elv. Z	Water Depth D	Cross Sectional Area A	Mean Velocity V	Velocity Head $V^2/2g$	H $(Z+\frac{V^2}{2g})$	Wetted Perimeter P	H.M.R. R	$R^{4/3}$
7-0-0 (N=.0221)	918.80	12.17	2560	1.670	0.043	918.843	230.5	11.10	24.70
6-0-0 (N=.0177)	922.50	10.50	2225	1.920	0.057	922.557	249.85	8.92	18.50
	919.50	7.50	1505	2.843	0.125	919.625	243.85	6.18	11.30
	919.20	7.20	1433	2.980	0.138	919.338	243.65	5.90	10.60
	919.15	7.15	1421	3.010	0.140	919.290	243.55	5.84	10.50
	919.10	7.10	1409	3.040	0.143	919.243	243.45	5.79	10.40
5-0-0 (N=.0190)	919.20	8.63	1478	2.900	0.130	919.330	185.30	7.97	15.90
	919.50	8.93	1550	2.760	0.119	919.619	185.90	8.35	16.90
	919.60	9.03	1574	2.720	0.114	919.714	186.10	8.45	17.20
	919.63	9.06	1581	2.700	0.113	919.743	186.16	8.50	17.40
4-0-0 (N=.0204)	920.00	6.33	1027	4.170	0.270	920.270	203.34	5.05	8.65
	920.80	7.13	1687	2.540	0.100	920.900	204.94	8.23	16.60
	920.40	6.73	1357	3.160	0.154	920.554	204.14	6.64	12.50
	920.30	6.63	1337	3.210	0.159	920.459	203.94	6.55	12.25
	920.25	6.58	1327	3.230	0.161	920.411	203.84	6.51	12.20
	920.20	6.53	1317	3.250	0.164	920.364	203.74	6.47	12.00
3-0-0 (N=.0165)	921.50	5.97	1094	3.910	0.237	921.737	204.65	5.35	9.38
	921.30	5.77	1054	4.060	0.255	921.555	204.25	5.16	8.90
	921.20	5.67	1034	4.130	0.265	921.465	204.05	5.07	8.70
	921.18	5.65	1030	4.150	0.268	921.448	204.00	5.05	8.67

The observed water surface level at M 3-0-0 is 921.12, so backwater effect may be assumed upto M

1973). As the cross-section of the canal also varies considerably along the length of the canal under study, the flow in the canal does not remain uniform. Also, at Pathri power house (at Mile 7-3), water level is controlled and computation of backwater effect has shown (Table 3.1a & 3.1b) that it has influence upto Mile 3-0. Moreover, hydraulically significant slope is the energy gradient. As such, for computing the values of rugosity coefficient in Manning's equation, firstly the cross-section and wetted perimeter at each gauge site on the selected dates wereworked out from the daily gauge discharge register. Knowing the discharge on that day, velocity, hydraulic mean depth (H.M.D.) R were computed. After this, knowing the canal bed level, water surface level from the gauge discharge register, total energy line (T.E.L.) at each gauging site were worked out andso the energy gradient S_f is found out. Averaging the velocity and hydraulic mean depth between the two sites, values of N in different reaches were found out from Manning's equation. A sample of computations for 7th August 1973 is shown in Appendix I. Values thus obtained for 19 days are tabulated in Table 3.2. A few erratic values of N which are impracticable and are presumably due to observational error in recording and maintaining gauge discharge registers are, however, ignored.

3.4. From the values of N for 19 days it is seen that on a particular date it varies considerably along the canal length and at a particular cross-section it varies from one date to another. To make the values meaningful and to study the trend, the values were sorted out considering the discharge and sediment consideration. Five categories were chosen and values plotted

Table 3.2 - Study of Hydraulic Roughness - 1973 (19 days)

Date	Discharge	Av. silt content	Computed values of Manning's N						Average N Reach as a whole
			0-3 to 1-5	1-5 to 3-0	3-0 to 4-0	4-0 to 5-0	5-0 to 6-0	6-0 to 7-0	
3.7.73	9917	1562	0.0207	0.0173	0.0167	0.0146	-	-	0.0173
5.7.73	9847	2095	0.0210	0.0190	0.0158	0.0156	-	-	0.0179
11.7.73	10070	2071	0.0181	0.0152	0.0144	0.0137	-	-	0.0154
12.7.73	9545	1717	0.0183	0.0149	0.0137	0.0106	-	-	0.0144
15.7.73	7526	3716	0.0173	0.0130	0.0146	0.0153	-	-	0.0150
30.7.73	9074	1516	0.0168	0.0171	0.0161	0.0159	0.0204	0.0181	0.0174
31.7.73	7772	1521	0.0216	0.0166	0.0181	0.0182	0.0182	0.0193	0.0187
3.8.73	8151	1052	0.0211	0.0135	0.0165	0.0158	0.0222	0.0059*	0.0179
5.8.73	5597	1111	0.0210	0.0203	0.0196	0.0174	0.0177	0.0140	0.0183
6.8.73	5413	1632	0.0127	0.0139	0.0127	0.0144	0.0184	0.0183	0.0151
7.8.73	4277	1452	0.0154	0.0165	0.0204	0.0190	0.0177	0.0221	0.0185
8.8.73	4515	1502	0.0144	0.0178	0.0193	0.0172	0.0142	0.0246	0.0180
31.8.73	7790	900	0.0207	0.0169	0.0176	0.0147	0.0156	0.0103	0.0160
7.9.73	7162	623	0.0230	0.0154	0.0232	0.0224	0.0255	(-ve) S_f	0.0218
20.9.73	8103	280	0.0230	0.0260	0.0312	0.0170	0.0138	0.0148	0.0210
21.9.73	6057	243	0.0219	0.0168	0.0380	0.0188	0.0119	0.0069*	0.0215
24.9.73	6333	245	0.0219	0.0254	0.0292	0.0240	0.0197	0.0123	0.0221
27.9.73	8127	323	0.0232	0.0243	0.0291	0.0202	0.0162	0.0230	0.0227
3.10.73	9209	115	0.0209	0.0140	0.0194	0.0091*	0.0063*	0.0165	0.0177

NOTE - Impracticable low values marked with an asterisk (*) are ignored.

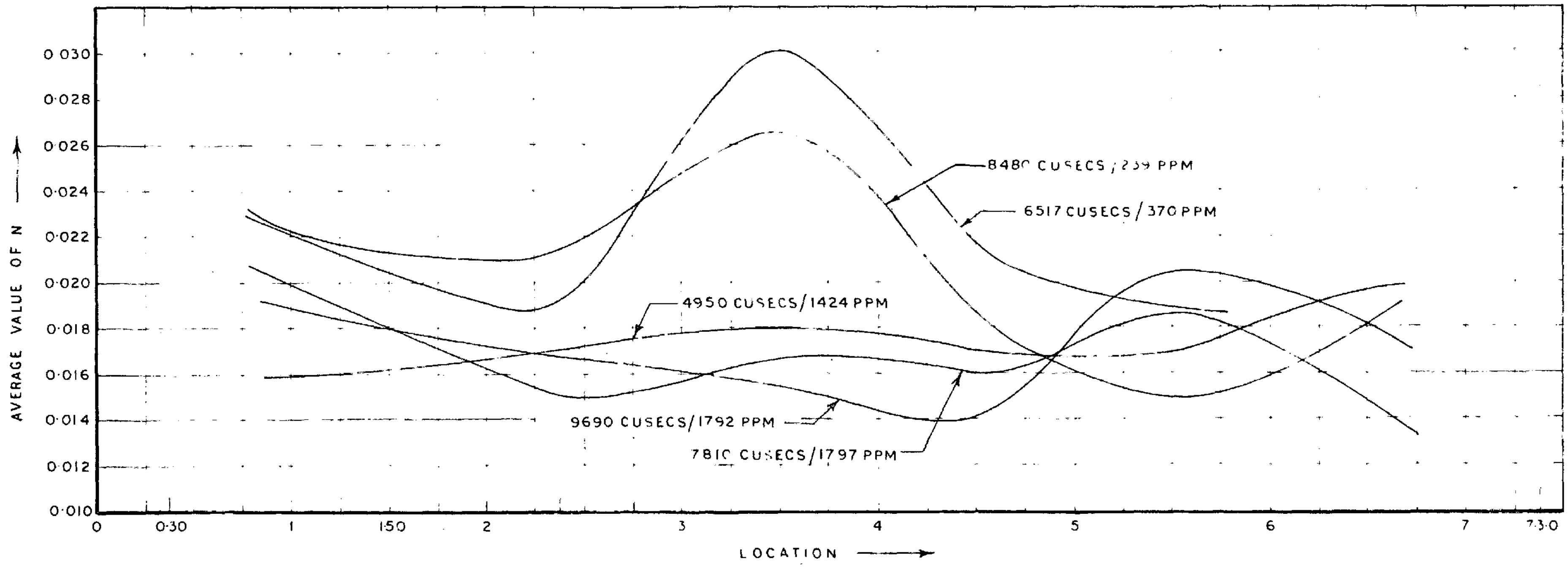


FIG.3·2_VARIATION OF VALUE OF N (AVERAGE) IN FIVE CATEGORY OF FLOW (1973)

(Fig. 3.2). The categories are -

(1) High discharge high silt content (9690 cusecs/1792 ppm)*

(2) Medium discharge and high silt content (7810 cusecs/1797 ppm),

(3) Low discharge and high-to-moderate silt content (4950 cusecs/1424 ppm),

(4) Medium discharge and low silt content (6517 cusecs/370 ppm),

(5) High discharge and low silt content (8480 cusecs/239 ppm).

[* Figures in brackets give the mean discharge and silt concentration of each category of data.]

The following observations were made from these curves :-

(a) Curves 1 and 2, i.e. 9690 cusecs/1790 ppm and 7810 cusecs/1797 ppm are following each other and may be considered as a band.

(b) Similarly, curves 4 and 5, i.e. 6517 cusecs/370 ppm and 8480 cusecs/239 ppm can be considered as a band.

(c) Curve 3, i.e. 4590 cusecs/1424 ppm has an intermediate value in the critical reach of Mile 2-0 to 5-0. However, curve 3 is very close to 1 and 2 and can be averaged with them.

(d) The curves show a low average value of N = 0.017 when the silt concentration is between 1400 to 1800 ppm.

(e) When the silt concentration is reduced to the order of 200-to-400 ppm, the N values increasesspecially in the reach of Mile 2-0 to 5-0. The increased value in the reach 3-0 to 4-0 is of the order of 0.0285.

(f) It is very clear that the value of N is not influenced much with discharge but it is sensitive to silt content.

3.5. The above observations led to the conclusion that it would be adequate to divide the values of N into two main categoies :

(1) High-to-Moderate silt content and low-to-high discharge (7653 cusecs/1680 ppm), and

(2) Low silt content and high-to-moderate discharge (7498 cusecs/305 ppm).

The values are arranged and averaged in Table 3.3 and two curves plotted in Fig. 3.3.

The following observations can be made from the curves of the two categories - 'high' and 'low' silt content (Fig. 3.3) :-

(1) Considering the characteristics of the reach in light of this curve, the length of the canal can be divided into 3 parts, namely, the upper reach (from head to M 2-3), the middle reach (from M 2-3 to M 5-0), and the lower reach (beyond M 5-0).

(2) Low-silt-content curve is always above the high-silt-content curve except beyond M 5-4 (lower reach) where the two curves approach the same value. There seems to be little influence of silt content beyond M 5-0.

(3) Both the curves fall in the downstream direction in upper reach and they are parallel.

(4) Both the curves have their rise in the middle reach , but the high-silt-content curve has a negligible rise whereas the low-silt-content curve has a high value (0.0283 against 0.0166 of high silt content). Thus, the influence of silt content is very prominent in the middle reach.

In the light of above observation, the behaviour of the

Table 3.3 - Study of Hydraulic Roughness

Date	Discharge in Cusecs	Sediment content at M 0-3 ppm	Manning's N Value						Remarks
			0-3 to 1-5	1-5 to 3-0	3-0 to 4-0	4-0 to 5-0	5-0 to 6-0	6-0 to 7-0	
High Silt Content to Moderate Silt Content, Low-to-high Discharge									
3.7.73	9917	1562	0.0207	0.0173	0.0167	0.0146	-	-	Impracticable low values of N have been ignored.
5.7.73	9847	2095	0.0210	0.0190	0.0158	0.0156	-	-	
11.7.73	10070	2071	0.0181	0.0152	0.0144	0.0137	-	-	
12.7.73	9545	1717	0.0183	0.0149	0.0137	0.0106	-	-	
15.7.73	7526	3716	0.0173	0.0130	0.0146	0.0153	-	-	
30.7.73	9074	1516	0.0168	0.0171	0.0161	0.0159	0.0204	0.0181	
31.7.73	7772	1521	0.0216	0.0166	0.0181	0.0182	0.0182	0.0193	
3.8.73	8151	1052	0.0211	0.0135	0.0165	0.0158	0.0222	0 -	
5.8.73	5597	1111	0.0210	0.0203	0.0196	0.0174	0.0177	0.0140	
6.8.73	5413	1632	0.0127	0.0139	0.0127	0.0144	0.0184	0.0183	
7.8.73	4277	1452	0.0154	0.0165	0.0204	0.0190	0.0177	0.0221	
8.8.73	4515	1502	0.0144	0.0178	0.0193	0.0172	0.0142	0.0246	
31.8.73	7790	900	0.0207	0.0169	0.0176	0.0147	0.0156	0.0103	
Mean Value	7653	1680	0.0184	0.0163	0.0166	0.0156	0.0180	0.0181	
Low Silt Content, High-to-Moderate Discharge									
7.9.73	7162	623	0.0230	0.0154	0.0232	0.0220	0.0255	-	
20.9.73	8103	280	0.0230	0.0260	0.0312	0.0170	0.0138	0.0148	
21.9.73	6057	243	0.0219	0.0168	0.0380	0.0188	0.0119	-	
24.9.73	6333	245	0.0219	0.0254	0.0292	0.0240	0.0197	0.0123	
27.9.73	8127	323	0.0232	0.0243	0.0291	0.0202	0.0162	0.0230	
3.10.73	9209	115	0.0209	0.0140	0.0194	-	-	0.0165	
Mean Value	7498	305	0.0223	0.0203	0.0283	0.0204	0.0174	0.0166	

NOTE - The curves for variation of N along the length of the canal in the above two cases (plotted with mean values) are given in Fig. 3.3.

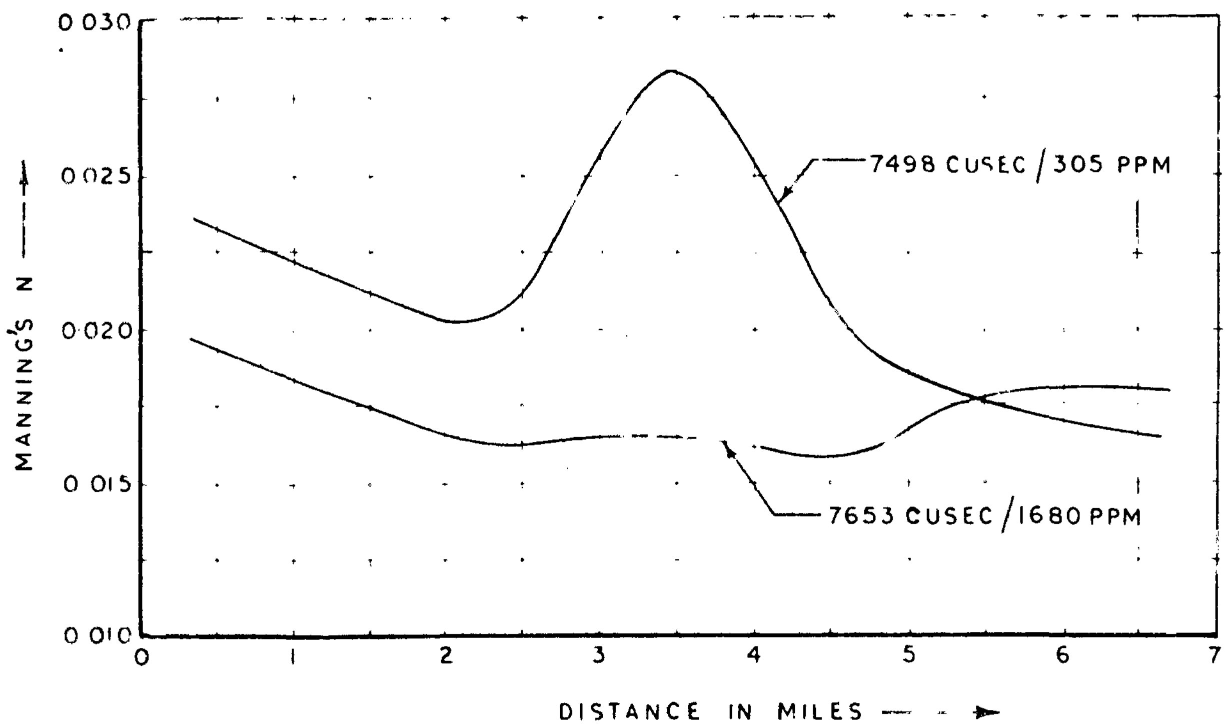


FIG.3·3 _VARIATION OF VALUE OF N (AVERAGE) WITH LOW AND HIGH SILT CONTENT.

canal (Fig. 3.3) can be explained as below :-

(1) Upper reach

As already indicated in Chapter 1, the canal has a steep slope of 3.6 ft/mile (1 in 1460) in the first mile and from M 1-0 to M 3-0 it has a bed slope of 2 ft/mile (1 in 2640) and then the slope becomes flatter for the remaining reach of the canal. The bed width of the canal is also less in the upper reach, than in the lower reach (less than 180 ft against 200 ft or more). This results in high velocity and sediment transporting capacity in the upper reach and there is little deposition. Only big pieces, i.e. pebbles (cobbles or gravels) may settle in this reach according to their sizes along the reach, the larger sizes first and smaller later. These settled pebbles might impart high value of N which will go on reducing according to the size of pebbles in the bed. The measured values in the range check well with gravel bed values given by Ven Te Chow. There do not seem to be bed formations in this reach due to high velocity and coarser grain-size (apparently greater than 2 mm) and only influence on value of N is due to the suspended silt concentration. This is the possible explanation of the two curves falling steadily from head reach upto M 2-3 and their being parallel.

(2) Middle reach

The bed forms contributed significantly to the hydraulic roughness of a channel. Presence of heavily sediment-laden water seems to dampen the eddy formation near the bed forms and to reduce the head loss, thus reducing the roughness due to presence of bed forms. Suspended sediment reduces roughness factor to some extent in all cases, but the significant reduction noticed in this reach may be due to a different cause explained below.

For explaining this phenomenon, it must be kept in mind that the middle reach of the canal is the reach of maximum deposition during monsoon. Sediment load is not much dropped in the upper reach due to high velocity; further, the lower feach has such a low velocity that it cannot transport much sediment. This results in an early heavy deposition of silt in the middle reach. As will be shown in Chapter 4, this deposited silt subsequently moves downstream inbulk (in form of sand bars) and washes away.

High silt-laden water while passingthrough the middle reach must drop its sediment load. This period is the bed-building period for the canal (i.e. deposition). Since the bed material is not moving much along the bed and there is downpour of silt particles on the bed, one can expect that the bed forms would not be so much prominent during the deposition and hence rise in value of N in the middle of reach is negligible at high silt concentration.

But, in the case of clear-water flow, the middle reach is subjected to scour. Bed particles are dragged (rolled) due to tractive stress and they are lifted up involving loss of head and they are carried with flowing water. During this stage of scour, one can expect very prominent bed forms due to movement of bed particles on the bed. These prominent bed forms may impart the high observed values of N. The process of deposition or scour depends on the silt content of flowing water, hence this reach is subjected to maximum influence of silt concen-

-tration. This phenomenon is also supported by the explanation given by Ven Te Chow (Open Channel Flow, Art. 5-8E) which reads -

"Generally speaking, silting may change a very irregular channel into a comparatively uniform one and decrease N, whereas scouring may do the reverse and increase N.

"Uneven deposits such as sand bars and sand waves are channel irregularities and will increase the roughness. . . . The energy used in eroding and carrying the material in suspension or rolling it along the bed will also increase the N value."

However, value of N depends on many other factors and apart from the factors discussed above, there might be some local factors also which contribute to such a high value of N in this reach.

(3) Lower Reach

The situation obtaining in the middle reach does not remain the same in the lower reach. Due to flat slope of 1.2 ft/mile (1 in 4,400) beyond M 3-0 and presence of Pathri power house which has its considerable backwater effect and also due to greater width of the canal, the velocity falls considerably. It can be expected under the circumstances, that brisk bedload movement does not exist beyond M 5-0, and bed forms are insignificant. Moreover, sediment-laden water while travelling, drops its sediment load continuously (specially, in the previous middle reach which is the reach of maximum deposition) and when it passes M 5-0, it is comparatively free from sediment load. On the other hand, clear-water while travelling, picks up silt from the bed by scour in the middle reach, and while reaching beyond M 5-0 it has some

Table 3.4 - Daily Average Value of N for the Reach As a Whole

Date	Silt Concentration ppm	Manning's N
3.7.73	1562	0.0173
5.7.73	2095	0.0179
30.7.73	1516	0.0174
11.7.73	2071	0.0153
12.7.73	1717	0.0144
15.7.73	3716	0.0150
31.7.73	1521	0.0187
3.8.73	1052	0.0179
5.8.73	1111	0.0183
6.8.73	1632	0.0151
7.8.73	1452	0.0185
8.8.73	1502	0.0180
31.8.73	900	0.0160
7.9.73	623	0.0218
20.9.73	280	0.0210
21.9.73	243	0.0215
24.9.73	245	0.0221
27.9.73	323	0.0227
3.10.73	115	0.0177

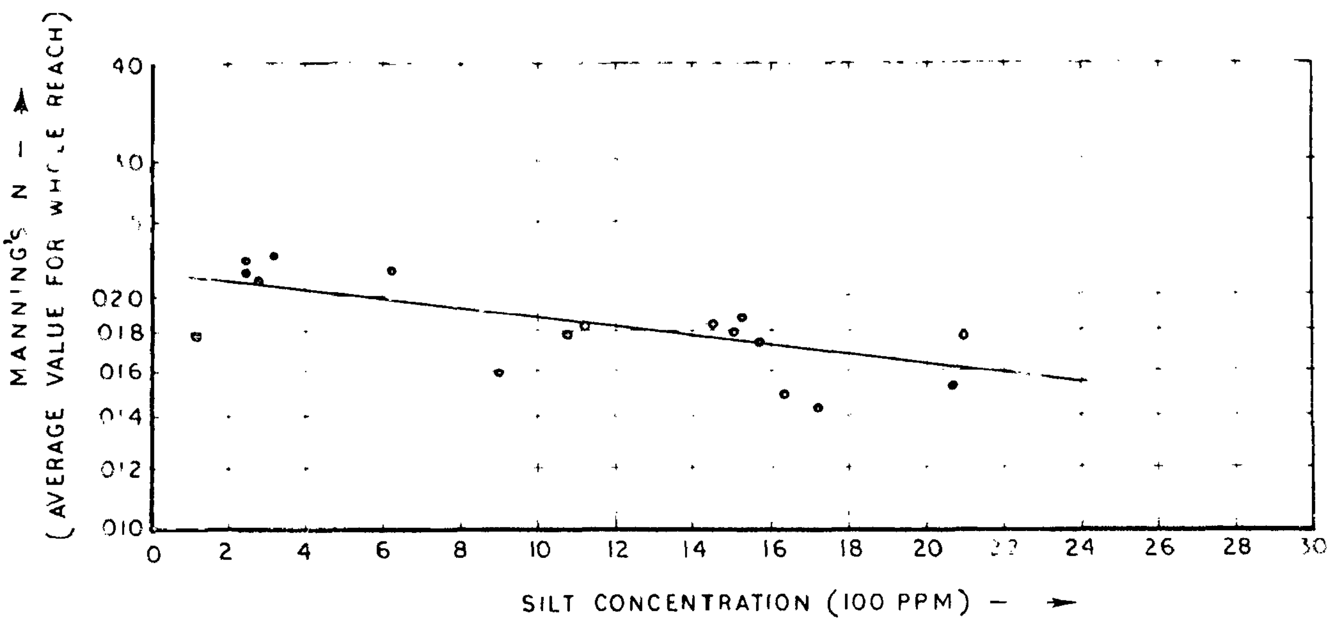


FIG. 3 4_VARIATION OF MANNING'S N WITH SILT CONCENTRATION silt charge. But the present curves are plotted on the basis of silt content at the head of the canal. Thus influence of silt content is not prominent in the last reach in which the fluctuation in actual sediment content is much smaller. This may be the possible reason for closeness of the two categories of ruves at M 5-4.

3.6. The observed influence of silt content on the value of N is an important observation and on that basis attempt was made to average the value of N considering the 7-mile reach as a whole for 19 days. The values of N are tabulated in Table 3.4 and plotted against sediment concentration in Fig. 3.4. The curve obtained is very similar to the studies made at U.P. Irrigation Research Institute, Roorkee.

3.7. The relatively large difference in value of N with low and high silt concentration will have important influence on the discharging capacity as well as the silt-carrying capacity of the canal. In fact, differences are beyond expectation and presumably involve some other effect, as already discussed, besides the influence of suspended silt. However, the behaviour of the canal is established and the difficulty in September feeding of the canal as experienced even in year 1972 (para 1.5.5) when the silt deposit was quite less (196 lakh cft), can be well explained with this characteristic of the canal.

Chapter 4

SEDIMENT TRANSPORT CAPACITY

4.1. Siltt Accumulation and Removal

4.1.1. Total silt accumulation in the length of the canal under study was worked out previously by Northern Division, Ganga Canal, Roorkee, but accumulation during 1971 and 1972 was not worked out on the same datum of bed levels. So, in the present study the total silt accumulation in different years, i.e. 1971, 1972, 1973 were found out from the gauge discharge registers of above three years on the basis of a common datum level taken as the bed levels during May/June 1972, so as to have a comparative idea of the behaviour of the canal in the above three monsoons. The computed values are listed in Appendix I. The trend of accumulation of silt can be seen from Fig. 41.

4.1.2. The maximum silt accumulation during the year 1971, 1972, and 1973 are 333, 196 and 250 lakh cft, respectively, on 30th September 1971, 20th August 1972 and 22nd September 1973. It may also be noted that during 1973, heavy silt deposition took place quite early, i.e. 131 lakh cft on 7th July 1973 and 183 lakh cft on 15th July 1973.

4.2. Assessment of Actual Sediment Transport Capacity and Its Correlation

4.2.1. Attempt was first made to assess the actual sediment transport rate of the canal. For this, assumptions were made as discussed in para 2.2. Groups of days were then selected considering the similar flow condition to minimise the effects due to

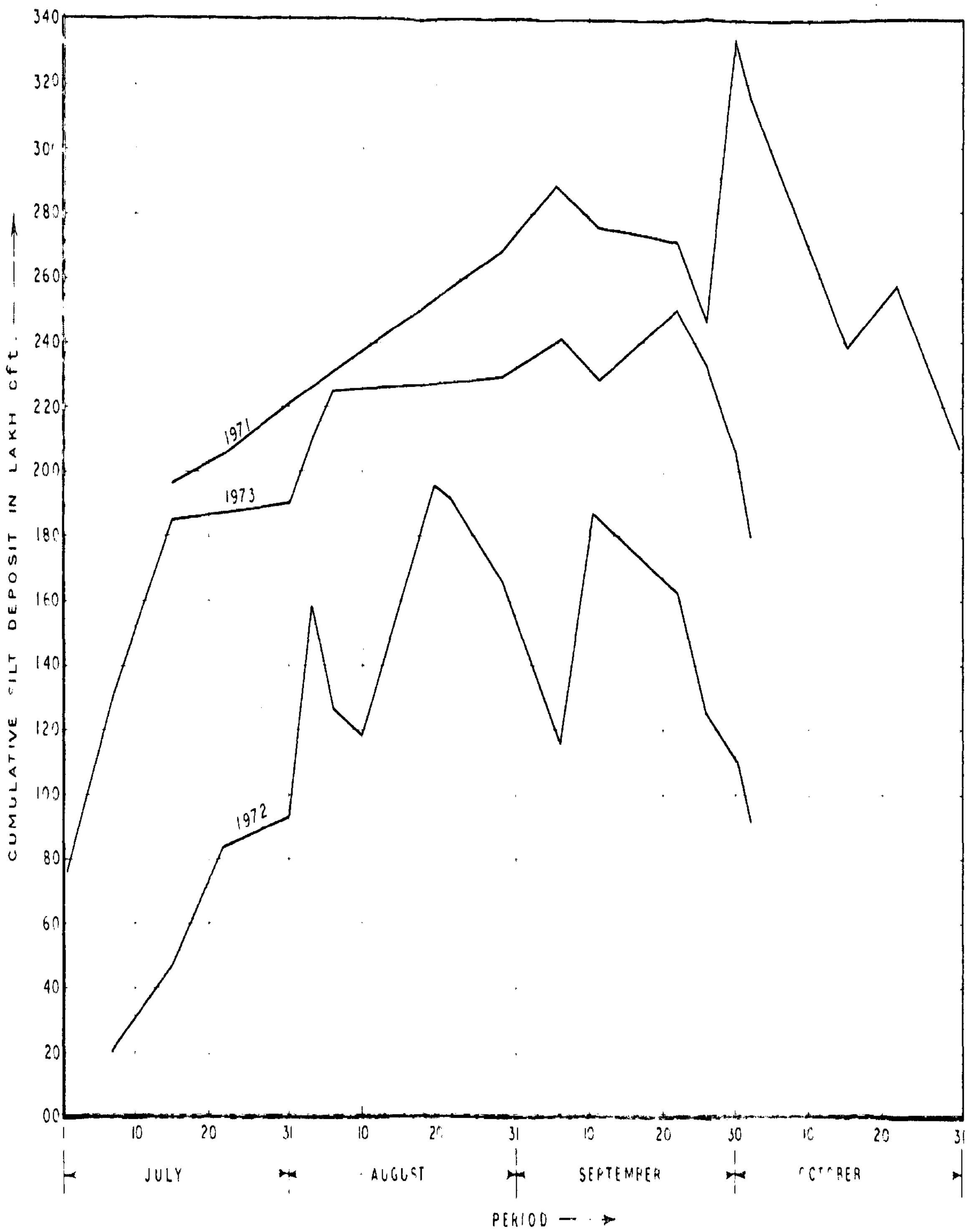


FIG. 4·1 _ TOTAL SILT ACCUMULATION OF DIFFERENT YEARS.

varying discharge and sediment concentration. Knowing the discharge and silt concentrations, total volume of silt in Lakh cft coming into the canal were found out during each of selected period. Actual deposit (or scour) during each period is also separately worked out for the reach as a whole from the gauge discharge registers. Taking the algebraic difference of the two, the actual silt carried in Lakh cft (and hence the silt-carrying capacity in ppm) was worked out. This was done for the three monsoon seasons of 1971, 1972 and 1973. The values obtained for 1971 range from 273 ppm to 3760 ppm, for 1972 from 532 ppm to 3770 ppm, and for 1973 from 75 ppm to 2825 ppm. A sample calculation for 1973 is shown in Appendix III. There are large variations in these values. However, this gives an idea of the range of sediment transporting capacity which can be compared with the values obtained from total load equations.

4.2.2. Seeing the great variation in the computed values of sediment transport rate, attempt was made to correlate it with some other parameters. The best parameter for such correlation was thought to be energy gradient S_f. Average values of S_f were found out for each of the periods taking 7-mile reach as a whole and a plot was made with S_f against actual silt carried in ppm. This was done for the monsoon of 1973. But the plot indicated that for the reach as a whole the silt carried in ppm could not be correlated to S_f over the reach. This is somewhat puzzling. Possible reason for not getting any correlation will be discussed later.

4.2.3. It was again though that since the 7-mile length of the canal has three reaches with different characteristics, it is not advisable to consider the entire 7-mile reach as a whole for the study of such correlation, Moreover, the value of energy gradient S_f has only a small variation considering the average on the entire 7-mile reach (it varies from 2.52×10^{-4} to 3.66×10^{-4}). So, to analyse the correlation, more detailed work was done. Energy gradient S_f was computed for the six reaches between seven gauging stations on daily basis for 1973 monsoon (Table 4.1). Five categories of flow were selected as below:

I. High discharge high silt content (9070 cusecs/1930 ppm).

II. High discharge with very high silt content (8515 cusecs/ 3110 ppm).

III. High discharge with moderate silt content (7233 cusecs/ 866 ppm),

IV. High discharge with low silt content (7000 cusecs/300 ppm).

V. Low discharge with moderate-to-high silt content (5821 cusecs/1380 ppm).

Average value of S_f and silt carried (ppm) in the individual reaches was worked out for the dates under each category (Table 4.2).

With the above five categories silt carried in different six reaches were plotted against the energy gradient S_f in that reach (Fig. 4.2). For interpretation of these curves, it may be kept in mind that the variables are S_f, silt carried (ppm), caegory, i.e. discharge and silt content, and the characteristics of different reaches.

Fig. 4.2 has been plotted to study the correlation for individual reaches. The following observations and interpretation can be had from these curves:

Table 4.1

Daily Variation of Energy Gradient in Different Reaches
(1973 Monsoon)

S_f (in 10^{-4})

Date	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6
July 1973						
8	4.80	3.73	3.42	1.98	-	-
9	4.94	3.93	2.82	1.77	-	-
10	4.53	3.92	3.30	2.20	-	-
11	5.04	3.58	2.96	2.22	-	-
12	4.95	3.52	2.80	2.42	-	-
13	4.86	3.50	3.15	2.21	-	-
14	5.07	3.47	3.14	3.02	-	-
15	5.02	2.56	2.65	2.53	-	-
Canal remained closed from 16th July 1973 to 29th July 1973						
30	4.14	3.76	3.46	3.64	3.69	1.74
31	4.93	3.53	3.65	3.20	3.52	1.39
Aug. 1973						
1	5.05	3.63	3.36	2.85	4.32	1.95
2	5.04	3.48	3.61	2.79	3.58	0.00
3	4.65	3.71	3.42	2.88	4.78	0.17
4	4.70	3.72	3.02	3.19	3.99	3.50
5	3.91	2.91	3.56	3.02	3.32	0.87
6	3.47	2.90	3.06	2.57	4.18	2.21
7	3.12	2.48	3.87	2.54	2.37	1.66
8	2.81	3.13	3.73	2.58	2.94	2.71
Canal remained closed from 9th Aug. 73 to 28th Aug. 73						
29	4.20	3.85	3.85	3.85	3.85	1.42
30	5.03	3.51	3.51	2.90	3.69	1.94
31	4.95	3.76	3.71	2.83	2.89	1.30
September 1973						
1	4.71	4.12	3.04	2.59	3.39	2.75
2	4.89	5.17	1.41	2.56	4.44	1.23
3	4.51	-	-	2.33	4.25	2.14
4	4.73	3.73	3.73	2.56	3.17	2.08

(continued)

S_f (in 10^{-4})

Date	Reach 1	2	3	4	5	6
Sept. 1973 (contd.)						
5	3.52	3.52	3.52	3.52	3.52	1.33
6	3.66	3.66	3.66	3.66	3.66	0.89
7	4.35	4.13	3.44	2.30	4.75	(-)0.21
8	4.07	4.07	3.45	1.80	4.14	0.98
9	3.59	4.16	4.16	2.24	3.28	0.34
10	4.50	3.87	3.68	2.58	2.87	0.10
11	4.42	3.87	3.30	3.25	3.27	1.07
12	4.33	3.76	3.67	2.64	2.86	1.11
13	4.50	3.34	3.84	3.04	3.27	1.90
14	4.38	3.21	3.89	2.73	3.19	2.96
15	4.42	3.26	4.07	2.62	3.62	3.00
16	4.10	3.28	3.54	2.91	3.43	1.83
17	4.51	3.24	4.10	2.24	3.43	2.68
18	4.44	3.31	3.49	2.81	2.47	2.72
19	4.59	3.31	3.46	2.55	4.66	2.41
20	4.44	3.21	3.64	2.50	3.79	2.47
21	3.91	1.43	5.33	2.61	3.25	0.22
22	4.20	3.11	2.56	2.05	4.43	1.95
23	4.54	2.62	2.56	2.77	4.53	2.09
24	4.15	2.95	2.77	3.14	3.50	1.27
25	3.94	3.10	2.24	2.25	3.62	2.09
26	3.36	3.36	3.36	3.36	3.36	2.76
27	4.26	3.37	3.02	3.20	2.64	4.28
28	3.29	3.29	3.29	3.29	4.12	3.06
29	3.96	3.96	3.53	3.02	3.08	2.49
30	4.58	3.46	3.20	2.92	3.68	1.34
October 1963						
1	4.29	2.86	2.86	3.56	3.78	0.26
2	-	-	-	-	-	-
3	9.34	3.48	3.12	0.75	0.35	2.21

Tbalderation - 1973

	-0-0		4-0-0		5-0-0		6-0-0		7-0-0
I - 9	1690		1150		1395		1265		1362
		1420		1272		1330		1313	
II - 8	2330		2210		1950		1900		1620
		2270		2080		1925		1760	
III - 7	1900		2370		2440		2780		2650
		2135		2405		2610		2715	
IV - 7	1415		2290		2960		3940		4920
		1852		2625		3450		4430	
V - 5	1900		2170		2010		1200		1000
		2035		2090		1605		1100	

I - 9	3.18	2.41	4.05	0.88
II - 8	2.98	2.59	-	-
III - 7	3.31	2.58	3.54	1.65
IV - 7	4.95	2.65	3.40	2.09
V - 5	3.45	2.78	3.36	2.19

NOTE -

t consideration, II, I, V, III and IV.

Tbale 4.2 - Observed Silt Carried (ppm) by Different Reaches during Different Periods of Consideration - 1973

Category	Dates under Category	0-3-0		1-5-0		3-0-0		4-0-0		5-0-0		6-0-0		7-0-0
I - 9070 Cusecs/1930 ppm	30/6 to 12/7 and 30/7 to 3/8	1995		1845		1690		1150		1395		1265		1362
			1920		1767		1420		1272		1330		1313	
II - 8515 Cusecs/3110 ppm	13/7 to 15/7	2640		2390		2330		2210		1950		1900		1620
			2515		2360		2270		2080		1925		1760	
III - 7233 Cusecs/866 ppm	29/8 to 15/9 and 25/9 to 26/9	885		1075		1900		2370		2440		2780		2650
			980		1487		2135		2405		2610		2715	
IV - 7000 Cusecs/300 ppm	16/9 to 24/9 and 28/9 to 3/10	570		660		1415		2290		2960		3940		4920
			615		1037		1852		2625		3450		4430	
V - 5821 Cusecs/1380 ppm	4/8 to 8/8	1590		1750		1900		2170		2010		1200		1000
			1670		1825		2035		2090		1605		1100	

Values of S_f (10^{-4}) in Different Reaches during Above Periods of Consideration

I - 9070 Cusecs/1930 ppm	30/6 to 12/7 and 30/7 to 3/8	4.89	3.77	3.18	2.41	4.05	0.88
II - 8515 Cusecs/3110 ppm	13/7 to 15/7	4.98	3.12	2.98	2.59	-	-
III - 7233 Cusecs/866 ppm	29/8 to 15/9 and 25/9 to 26/9	4.40	3.78	3.31	2.58	3.54	1.65
IV - 7000 Cusecs/300 ppm	16/9 to 24/9 and 28/9 to 3/10	4.72	3.06	4.95	2.65	3.40	2.09
V - 5821 Cusecs/1380 ppm	4/8 to 8/8	3.60	3.03	3.45	2.78	3.36	2.19

NOTE - 1. For a given reach variables are S_f , carried ppm, discharge, silt content.
Order of Category on discharge consideration will be I, II, III, IV, V; and on silt-content consideration, II, I, V, III and IV.

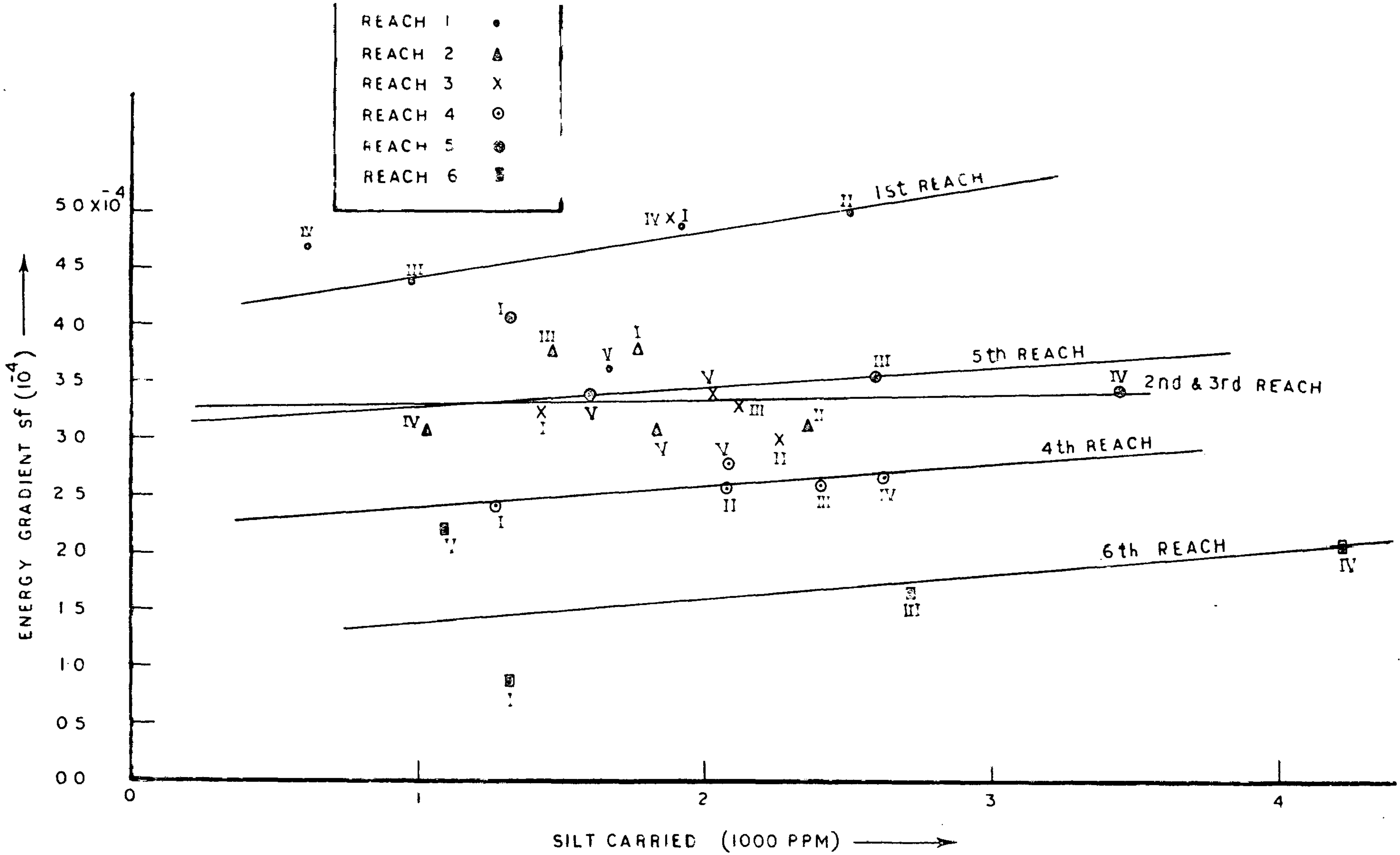


FIG. 4·2 _ SILT CARRIED AGAINST ENERGY GRADIENT (REACH WISE)

(1) The plot has large scatter excepting for reach 4 which falls reasonably in a straight line.

(2) The points of reaches, 2, 3, 4 and 5 are close.

(3) The first reach has a value of S_f much higher than the sixth reach for the same value of silt carried.

(4) Reaches 1 and 2 show that silt carried (in ppm) falls in order of falling silt concentration, i.e. the categories II, I, V, III & IV.

(5) Reaches 3 and 4 do not show this and seem to be independent of silt content.

(6) Reaches 5 and 6, however, show a reverse trend, i.e. carried ppm increases with fall in silt content.

(7) Reaches 1, 2 and 3 show that silt carried is independent of discharge.

(8) Reaches 4, 5 and 6 show that silt carried increases with fall in discharge except in Category V when the discharge falls to a low value of 5821 cusecs.

The trend of the curves indicates the distinct characteristics of three reaches, namely the upper reach, the middle reach, and the lower reach. It shows gradual change as we move from head to downstream. However, the first reach has shown some special features (observation 3 & 4), the reason for such high value of S_f is its steep bed slope. The silt carrying capacity of this reach is definitely high but silt actually entering into the canal may be less than its carrying capacity, i.e. this reach is not fully loaded with sediment. Flatter slope of the canal in the reech 4, 5, 6, and water level control at Pathri Power House may be the cause for decrease in the silt transport rate when the discharge falls to a low value such as 5821 cusecs.

4.2.4. Attempt was also made to plot the variation of silt carried with the value of Manning's N. for individual reaches. Each reach showed an increase in the value of silt carried with the fall in the value of N. The rate of increase of silt carried is more for lower values of N. However, to study the effect of a new variable N over and above many variables discussed above, tends to complicate the study rather than giving a better correlation.

4.2.5. With the failure in obtaining any clear correlation extensive work of analysing the deposition, scouring and movement of deposited silt was taken up for 1973 data. Computations were carried out on daily basis for silt entering into the canal, silt deposited in the first reach and taking the difference of two, silt carried by the first reach. The silt carried by the first reach was then assumed to enter the second reach. This process is repeated for all the seven reaches. This work gave better understanding of daily silt deposit or scour in every reach.

On examination of this it was noted that scouring and deposition may be taking place at the same time in different reaches. It also disclosed the different behaviour of the different reaches - the main feature being as noted below:

1. The maximum value of deposition (in Lakh cft) in the individual reaches and date of occurrence are as below (Table 4.3):

Table 4.3 .../

Table 4.3 - Maximum Value of Deposit in Individual Reaches

No.	Reach (Miles-Fur.)	Max.Deposit (Lakh cft)	Date	Remarks
(1)	0-0 to 1-0	15.10	9.8.73	Date 9.8.73
(2)	1-0 to 2-0	15.95	29.8.73	is thefirst
(3)	2-0 to 3-0	62.50	9.8.73	day after
(4)	3-0 to 4-0	67.50	14.9.73	canal clo-
(5)	4-0 to 5-1	85.70	22.9.73	sure.
(6)	5-1 to 6-0	51.10	22.9.73	
(7)	6-0 to 7-3	63.40	1.10.73	

2. In reach No. 1 for wholeof monsoon period deposit and scour continues alternately. Continuous deposit or scour has not exceeded 3 days. The quantity of deposition or scour in a day is also small.

3. In reach No. 2 also deposition or scour is present alternately for whole of monsoon period. Continuous deposition or scouring has not exceeded 5 or 6 days. The quantity of scouring or deposition in a day is also small.

4. In reach No. 3, excepting minor scouring of less than 1 lakh cft for a day or two, continuous deposition has taken place till 17th July 1973. This is followed by alternate scour and deposition for the rest of monsoon period. However, in the middle of September 1973, scouring has occurred continuously for 6 days and volume of deposited silt is reduced to 28.2 lakh cft from 58.25 lakh cft. This reach also records a maximum deposition of 24.35 lakh cft in a day and maximum scour of 17.2 lakh cft in a day.

5. Reach No. 4 is also similar to Reach No. 3. This includes

a continuous deposition for seven days and two continuous scours of 7 and 6 days. The maximum deposition in a day is 18.60 lakh cft and scour is 36.05 lakh cft.

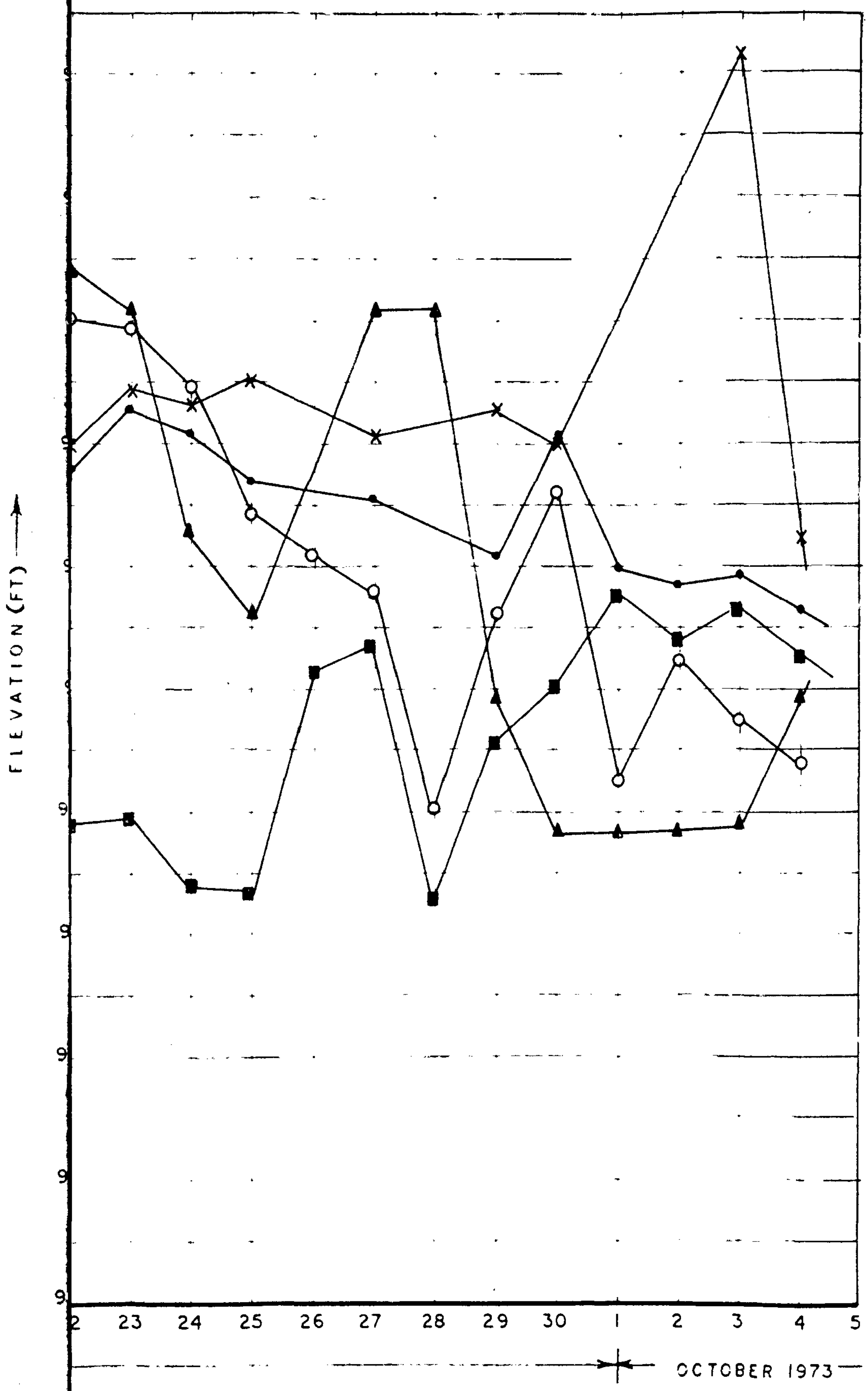
6. Reach No. 5 has alternate deposition and scouring period of 3-to-4 days for entire period of monsoon. This includes a maximum deposition in a day 36.65 lakh cft and scouring in a day 23.41 lakh cft.

7. Reach No. 6 is similar to Reach No. 5 with alternate deposition and scouring of 3-to-4 days throughout the monsoon. This includes maximum deposition in a day 35.54 lakh cft and scouring in a day of 22.00 lakh cft.

8. Reach No. 7 has also alternate deposition and scour throughout, the monsoon but it includes a continuous deposition of 9 days between 31st August 1973 and 8th September 1973 in which silt deposit has increased from 4.80 lakh cft to 59.00 lakh cft. The maximum deposit in a day is 26.10 lakh cft and maximum scour in a day is 36.50 lakh cft.

To illustrate the movement of sediment, bed levels at different gauge sites were also plotted (Fig. 4.3).

On the basis of above study it can be inferred that reach 1, 2, 5 and 6 is subjected to alternate deposition and scouring, while reach 3 and 4 is subjected to continous deposition for comparatively longer period. This accords with the observed fact of reach 3 and 4 being the reaches of heavy deposition. Variation of bed levels with time for different gauge sites (Fig.4.3) shows the erratic way of rise and fall of bed level. However, this study brought out a clearer picture of mode of movement of


ELEVATION (FT)
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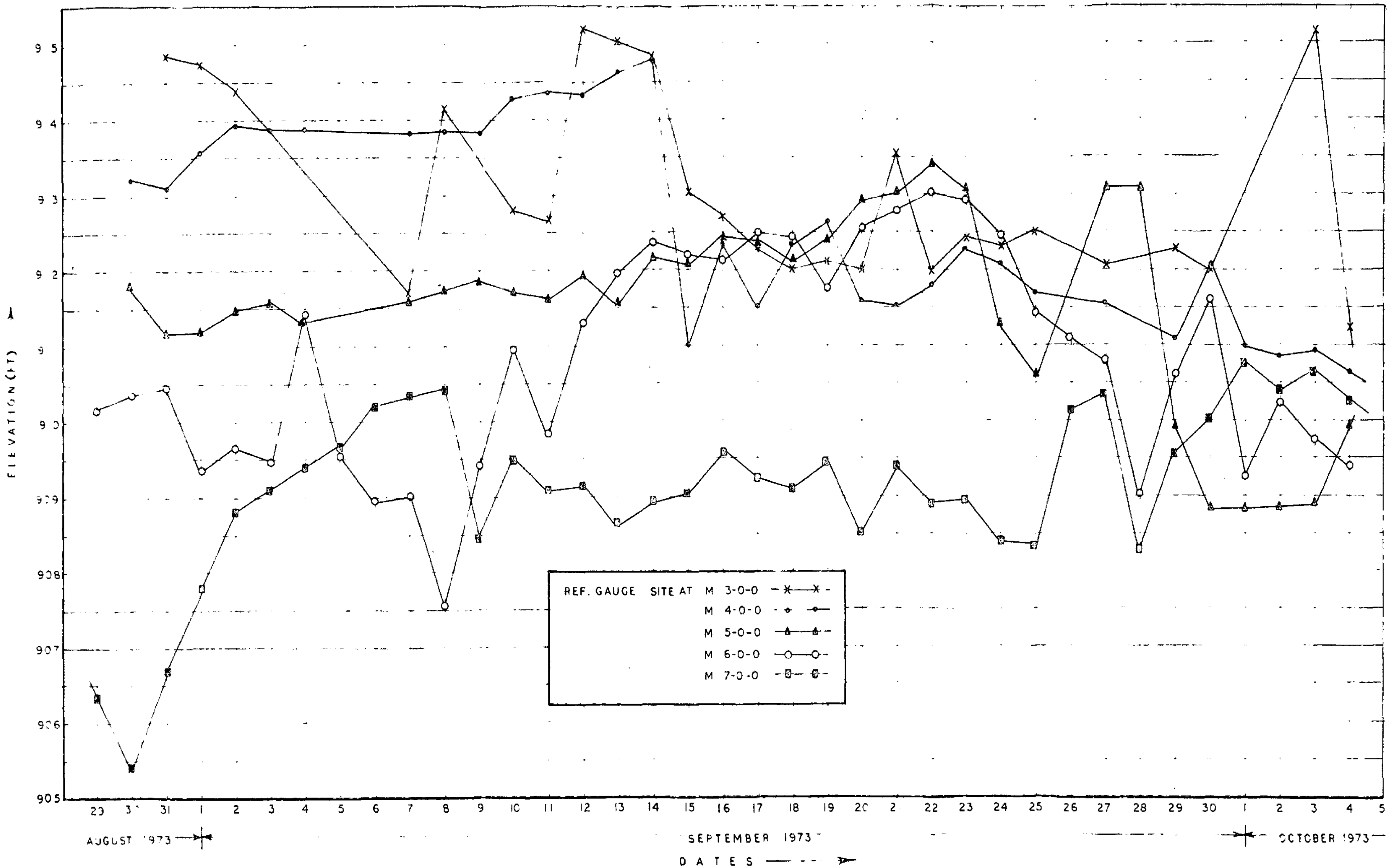

FIG. 4·3_VARIATION OF BED LEVELS WITH TIME silt. It seems that silt deposition continues for some time at a place till the bed rises sufficiently and is then rapidly scoured off following which the silt from the upper reach comes and again starts building up the bed. Thus the movement has a marked, though irregular, periodicity and does not take place at a uniform rate.

4.2.6. The net transport rate, i.e. considering the deposition and scouring in different seven reaches and taking the net value for the whole reach, was computed considering the period of similar flow condition Table 4.4. shows the average transport rates (for total silt content including wash load) over the full reach of seven miles and over the period of several days obtained on this basis. These values show large variations and in a few cases even imaginary values. However, it is considered a useful exercise. The range of the values ontained is of the same order of magnitude as the value computed by Laursen's method.

4.2.7. In fact, in assessing actual transport rate and correlating it with some parameter, attempt was made to arrive at certain correlation between transport rate and energy gradient for different silt concentrations in flowing water. Such correlation would have been a very good guide for prediction of behaviour of canal in different operation conditions.

Considering the marked movement of silt with irregular periodicity (para 4.2.5), erratic rise and fall of bed levels (Fig. 4.3), and distinct behaviour of different reaches, it is difficult to get any clear correlation. It has been seen that deposition is not uniform and thus assumptions made in para 2.2.

Table 4.4 - Statement of Net Silt Deposition (or Scour) in Reach As a Whole

(Daily for 1973)

(in Lakh cft)

Q/ppm at M O-3	Date	Deposit	Scour	Computation
8300/ 2126	30.7.73	-	14.13	Net deposit = +11.46
	31.7.73	-	4.07	Silt entered = 47.17
	1.8.73	12.94	-	Silt carried = 35.71 = 1590 ppm
	2.8.73	-	3.39	
	3.8.73	10.09	-	
5821/ 1383	4.8.73	6.30	-	Net deposit = + 25.26
	5.8.73	-	9.53	Silt entered = 21.31
	6.8.73	5.33	-	Silt carried = -ve
	7.8.73	13.22	-	
	8.8.73	9.94	-	
8128/ 1144	29.8.73	-	44.15	Net deposit = - 29.00
	30.8.73	-	32.28	Silt entered = 30.09
	31.8.73	17.43	-	Silt carried = 59.09 = 2245 ppm
	1.9.73	5.67	-	
	2.9.73	26.64	-	
	3.9.73	-	2.31	
7400/ 787	4.9.73	14.09	-	Net deposit = - 17.00
	5.9.73	-	19.37	Silt entered = 37.70
	6.9.73	2.80	-	Silt carried = 54.70 = 1245 ppm
	7.9.73	-	12.73	
	8.9.73	15.60	-	
	9 & 10.9.73	8.92	-	
	11.9.73	-	22.57	
	12.9.73	41.97	-	
	13.9.73	-	2.72	
	14.9.73	10.29	-	
	15.9.73	-	54.09	

(continued)

(in Lakh cft)

Q/ppm at M O-3	Date	Deposit	Scour	Computation
7685/ 366	16.9.73	24.96	-	Net deposit = - 2.45
	17.9.73	-	17.69	Silt entered = 7.55
	18.9.73	-	4.05	Silt carried = 10.00 = 483 ppm
	19.9.73	9.68	-	
	20.9.73	-	15.35	
6234/ 230	21.9.73	18.66	-	Net deposit = + 0.70
	22.9.73	2.83	-	Silt entered = 3.08
	23.9.73	4.00	-	Silt carried = 2.38 = 177 ppm
	24.9.73	-	24.79	
7292/ 517	25.9.73	-	19.14	Net deposit = + 6.78
	26.9.73	25.01	-	Silt entered = 4.03
				Silt carried = -ve
8155/ 273	27.9.73	18.51	- -	Net deposit = - 25.39
	28.9.73	-	43.90	Silt entered = 2.40
				Silt carried = 27.79 = 3150 ppm
9077/ 130	29.9.73	33.78	-	Net deposit = + 13.25
	30.9.73	14.77	-	Silt entered = 3.21
	1.10.73	-	6.39	Silt carried = -ve
	2.10.73	-	20.78	
	3.10.73	-	8.13	
9917/ 1562	30.6.73	-	20.64	Net deposit = + 12.87
	1.7.73	-	22.35	Silt entered = 32.46
	2 & 3.7.73	55.86	-	Silt carried = 19.59 = 916 ppm
9847/ 2095	4 & 5.7.73	22.71	-	Silt deposit = + 49.84
	6.7.73	27.13	-	Silt entered = 32.17
				Silt carried = -ve

(continued)

(in Lakh cft)

Q/ppm at M 0-3	Date	Deposit	Scour	Computation
9407/ 1873	7.7.73	-	8.86	Netdeposit = + 39.66
	8.7.73	-	5.71	Silt entered = 57.18
	9.7.73	-	1.56	Silt carried = 17.52 = 575 ppm
	10.7.73	-	1.13	
	11.7.73	25.83	-	
	12.7.73	31.09	-	
8515/ 3110	13.7.73	5.88	-	Net deposit =+ 1.85
	14.7.73	0.25	-	Silt entered= 42.35
	15.7.73	-	4.28	Silt carried= 40.50 = 2930 ppm

NOTE - (1) The initial group of dates are selected on the basis of similar discharge and silt-content consideration.

(2) Average silt carried from 30th June 1973 to 12fth July 1973 and from 30th July 1973 to 3rd August 1973 comes to 740 ppm (Average $S_f = 3.34 \times 10^{-4}$).

(3) Average silt carried from 13th July 1973 to 15th July 1973 comes to 2930 ppm (Av. $S_f = 3.24 \times 10^{-4}$).

(4) Average silt carried from 29th August 1973 to 3rd October 1973 comes to 1065 ppm (Av. $S_f = 3.12 \times 10^{-4}$).

i.e., the bed level at a particular gauge site represents about one-mile reach of the canal to which they correspond, seem to be inadequate for such correlation studies. Number of variables affecting transport rate, i.e. energy gradient, roughness, sediment concentration, discharge etc. have changing values from day to day and along the length of the canal. Moreover, the field data have their own limitations for accuracy and reliability. Under the circumstances, it would be toomuch to expect a clearcut correlation between transport rate and energy gradient.

4.3. Silt Transport Capacity by Total Load Formulae

4.3.1. As discussed earlier, the silt transporting capacity of Ganga Canal was worked out by Alakhnanda Enquiry Committee by Einstein, Laursen, Colby and Lacey methods. This was done for a discharge of 10,000 cusecs taking value of Manning's N = 0.022 and the reaches considered were (i) M 0 to M 1, (ii) M 1 to M 3, and (iii) M 3 to M 7 (Table 4.5). These reaches were selected on the basis of varying bed slopes of the canal. On the basis of this computation a tentative limit of 12,000 ppm was fixed as the permissible concentration of the sediment entering the canal beyond which the canal would be closed. But running of the canal during 1971 monsoon indicated that this value was on the higher side.

4.3.2. The silt transporting capacity of the canal at M 4-0 for different discharges was also worked out by I.R.I., Roorkee, by equations given by Einstein, Tofalleti, Engelund-Hansen and Laursen. Findings of I.R.I. are listed below:-

(1) Total load as computed by Einstein's method gives

Table 4.5 - Conveyance Capacity of Ganga Canal*

Sl. No.	Reach	In p.pm. by weight according to				Remarks
		Einstein	Laursen	Colby	Lacey	
1.	M 0-0 to M 1-0 Bed slope = 3.2 ft/mile Av. Bed Width = 180 ft	10,400	6,500	1,560	9,620	The conveyance capacity has been worked out for 10,000 cusecs taking value of Manning's N = 0.022
2.	M 1-0 to M 3-0 Bed slope = 2.0 ft/mile Av. Bed Width = 180 ft	6,350	2,780	1,180	2,800	
3.	M 3-0 to M 7-0 Bed slope = 1.2 ft/mile Av. Bed Width = 200 ft	5,720	1,748	890	1,560	

(* From Report of Alakhnanda Enquiry Committee 1971) much higher values than observed on Ganga Canal.

(2) The values computed by Engelund-Hansen's and Laursen's method lie within the range of observed data.

(3) The values obtained by Toffaleti's method are slightly higher than the observed data.

(4) The values obtained by the modified Einstein method are extremely low.

4.3.3. The problem was also studied by Dr. Bharat Singh. He considered the effect of 'low' and 'high' pond level of Pathri power house and worked out the silt transport capacity of the canal by different formulae, i.e. total load computation by Laursen's method, Bagnold's equation and Graf's equation (Table 4.6). He also made the bed load computation by Meyer-Peter equation (Table 4.7). His findings are -

(1) The values obtained by Bagnold's equation are of the same order of magnitude as Laursen.

(2) The transporting capacity obtained by Graf's equation is also of the same order of magnitude as above. He also observed that Graf's expression is very sensitive to slope.

(3) The values obtained by bed load computation by Meyer-Peter equation are compatible to the total load computations and the bed load computations further serve as an indirect corroboration of the total load computations.

4.3.4. Rate of Transport Computations

The total load equations, which aim to predict the transport of 'bed material' load, i.e. of the rangeof sizes obtainable

Table

Date	Dis Q	5-0 to 6-0		Reach 6-0 to 7-0		
		Bagnolds	Graf's	Laursens	Bagnolds	Graf's
16.7.71		123	66	562 68	306	705
22.7.71						
15.1.72						

Table (h)

Date	Dis arg Cu	$\tau_{cr} = \frac{4.5}{304.8} \times d_{50}$ mm	(11)-(12)	Transport $(13)^{3/2} \times 33500$ Rateof Bed load lbs/ft/hr	Av. Bed Width ft	Total transport of Bed Load ppm
1	2	12	13	14	15	16
22.7.71	9	0.0034	0.1001	1060	172.5	825
		0.0034	0.0778	725	150.0	520
		0.0034	0.0706	628	170.0	448
13.7.71	10	0.0028	0.0454	322	150.0	217
		0.0028	0.0406	285	189.0	244
		0.0028	0.0406	285	189.0	244
31.7.72	9	0.0016	0.0598	382	152.5	270
		0.0016	0.0461	335	120.0	187.5
		0.0016	0.0319	188	140.0	122.5

Table 4.6 - Abstract of Bed Material Transporting Capacity (ppm)

Date	Discharge Cusecs	Pond Level at Pathri Power House	Reach 2-6 to 4-0			Reach 4-0 to 50			Reach 5-0 to 6-0			Reach 6-0 to 7-0		
			Laursen's	Bagnold's	Graf's	Laursens	Bagnolds	Graf's	Laursens	Bagnolds	Graf's	Laursens	Bagnolds	Graf's
16.7.71	9215	915.50	1373	540	565	1134	595	245	227	123	66	562	306	705
		918.50	873			407			106			68		
22.7.71	9470	915.50	1751			711			103					
15.1.72	6500	917.50	149			144			165					

Table 4.7 - Bed Load Transporting Capacity according to Meyer-Peter Formulae (By Dr. Bharat Singh)

Date	Discharge	Reach	d_{50}	$N' = d_{50}^{1/6}/74$	Observed N	$(N'/N)^{3/2}$	Observed $R_b = R$	Observed S (in 10^{-4})	$\tau_b = 62.4 R_b S$	$(\frac{N'}{N})^{3/2}\tau_b$ (10)x(7)	$\tau_{cr} = \frac{4.5}{304.8} \times d_{50}$ mm	(11)-(12)	Transport $(13)^{3/2} \times 33500$ Rate of Bed load	Av. Bed Width	Total transport of Bed Load
	Cusecs	M-F	mm						lbs/ft^2				lbs/ft/hr	ft	ppm
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
22.7.71	9470	2-6 to 4-0	0.23	0.0106	0.0154	0.567	6.92	4.12	0.182	0.1035	0.0034	0.1001	1060	172.5	825
		4-0 to 5-0			0.0139	0.663	7.63	2.58	0.123	0.0812	0.0034	0.0778	725	150.0	520
		5-0 to 6-0			0.0156	0.558	7.68	2.67	0.135	0.0740	0.0034	0.0706	628	170.0	448
13.7.71	10000	2-6 to 4-0	0.19	0.0102	0.0287	0.212	11.08	3.65	0.252	0.0482	0.0028	0.0454	322	150.0	217
		4-0 to 5-0			0.0285	0.214	10.04	3.24	0.203	0.0434	0.0028	0.0406	285	189.0	244
		5-0 to 6-0			0.0285	0.214	10.04	3.24	0.203	0.0434	0.0028	0.0406	285	189.0	244
31.7.72	9737	2-6 to 4-0	0.11	0.0093	0.0152	0.480	7.6	2.7	0.128	0.0614	0.0016	0.0598	382	152.5	270
		4-0 to 5-0			0.0200	0.317	9.3	2.6	0.151	0.0477	0.0016	0.0461	335	120.0	187.5
		5-0 to 6-0			0.0300	0.175	10.45	3.0	0.191	0.0335	0.0016	0.0319	188	140.0	122.5

in the channel bed, are so far empirical and not of very high reliability. Different equations give results with considerable variations (sometimes two-fold or more between one theory and another). Nevertheless, the order of transporting capacity can be obtained, and what is more important, the relative changes with change in operating conditions can be predicted. The computed load does not include 'wash load' or part of the sediment load which consists of grain sizes finer than those present in the bed. It will also be seen that grain size analysis of collected sediment sampled by I.R.I. has shown that wash load formed 50% to 70% of the total load during 1971 and 1972 seasons.

On the basis of the findings by I.R.I. and Dr. Bharat Singh it was thought that the total load computation by Laursen's method yields result more close to the observed value of total load carried in the Ganga Canal. So, in the present study, to predict the relative changes in the transporting capacity with change in operating conditions, reliance is placed on Laursen's method.

So, in this study, on the basis of 1973 data, total load has been computed by Laursen's method for 30th July 1973 when Pathri power house level was maintained at 915.50 and the discharge was 9074 cusecs. To study the effect of 'high' pond level of Pathri power house, backwater computation by step method has been made for water level at Pathri power house raised to 918.50 (Table 3.1a) and transport capacity computed again. Also to study the effect of low discharges, computation has been carried out for 7th August 1973 on which the discharge was 4,273 cusecs and water level at Pathri Power House was 915.00. To see the effect of 'high' pond of power house during low discharges, backwater was again worked out for Pathri power house level 918.50 (Table 3.1b) and total load transporting capacity computed. (1973 data include 4 days in which discharge is low while silt content is moderately high.)

The assumptions and the main aspects required in the computation for total load transport capacity are discussed eblow :-

1. Bed material size -

Grain size distribution curve for bed load and suspended load were available from the records of I.R.I., Roorkee. From these plots, a mean grain size distribution curve was adopted and the percentage of material in different size ranges determined. The adopted size distribution curve is given in Fig. 4.4. It may be noted that actual sampling of sediment is done at 0.6 depth in the canal and measured ppm include wash load. According to sample analysis by I.R.I., the wash load constitutes 50%-to-70% of the total. In succeeding seasons as fines are washed away from Alakhnanda and Ganga Velleys, while the total sediment concentration would decline, the proportion of coarser fraction may actually increase. Hence, it would be safe to consider the measured concentrations about twice those obtained by total load formula as representing the transporting capacity of the canal.

2. Tractive Stresses -

For working out tractive stresses the energy gradient has been used so as to take into account the non-uniformity of flow, However, the energy gradient and mean velocity etc. for individual

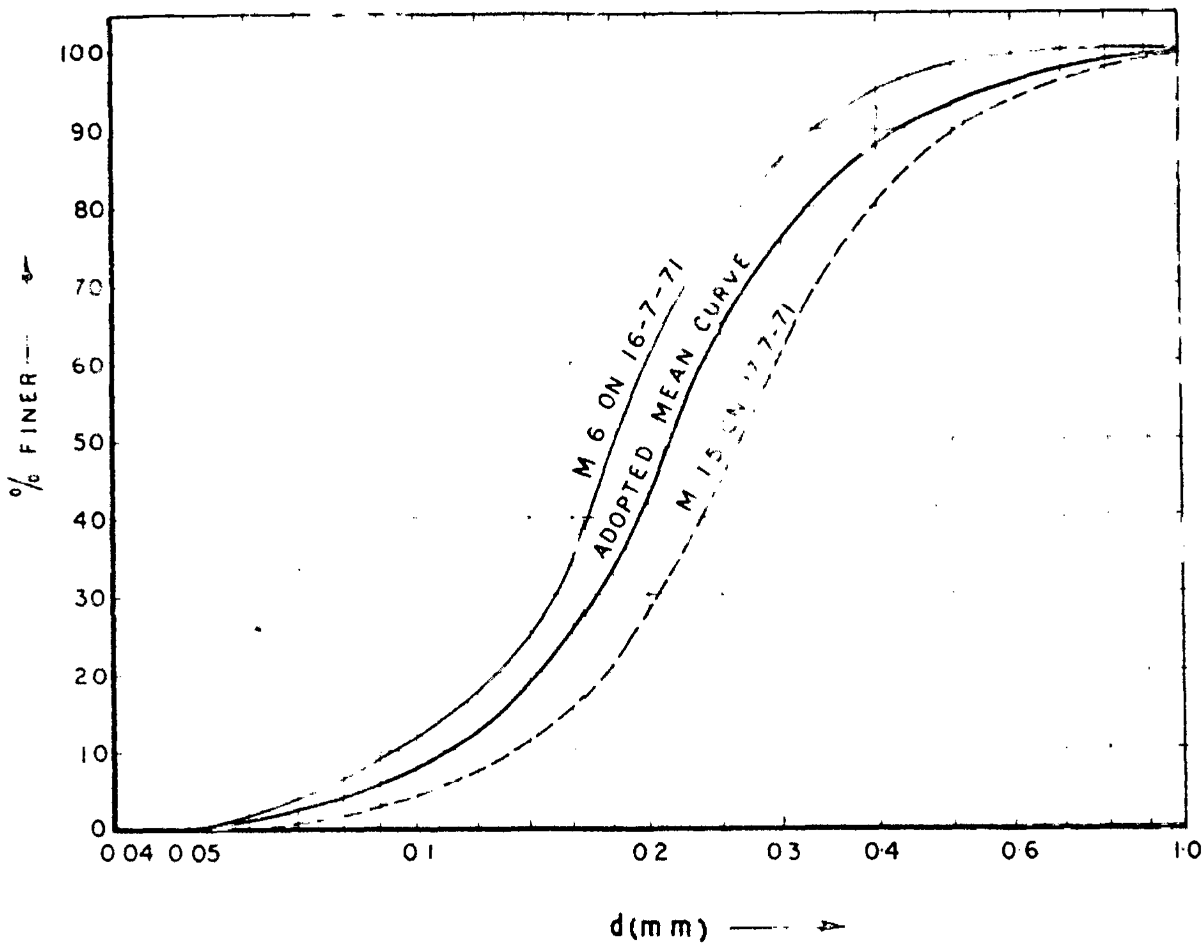

FIG 4·4_SIZE DISTRIBUTION OF BEDLOAD (GANGA CANAL) reaches has already been worked out while computing the rugosity coefficients (Chapter 3).

3. Backwater Calculations -

Backwater computations were carried out by standard step method for the 'high' stage Pathri Power House for 30th July 1973 and 7th August 1973 (Table 3.1a & 3.1b), respectively. It was assumed that while the other conditions, i.e. discharge, hydraulic roughness etc., remain the same the pond level at Pathri is raised to 918.50. Actual values of cross-sections, velocity, roughness etc. in different reaches on those dates were used in the computations. Normal depth computations yield M1 type of backwater curve.

4. Total Load Computations by Laursen's Method -

On the basis of laboratory experiments with coarse and fine sand (d_{50}=0.10 mm and d_{50}=0.04 mm), Laursen (1958) linked the hydraulic and sediment characteristics in their parameters and gave the following functional relationship between the flow conditions and resulting total sediment load movement.

$$\frac{\bar{C}}{\left(\frac{d_m}{D}\right)^{7/6}\left(\frac{\tau_o'}{\tau_c} - 1\right)} = f\left(\frac{U_*}{w}\right)$$

where,

$\bar{C}$ = The percent concentration of total bed material load by weight,

U_* = Shear velocity ($\sqrt{gRS_f}$),

w = Settling or fall velocity of grains,

d_m = Grain size diameter,

D = Water depth,

τ_c = Critical tractive stress for the particle,

τ'_o = Effective tractive stress (same for all fractions, taking d_m as the mean diameter of the entire sample)

$$= \frac{\bar{V}^2 \, d_m^{1/3}}{30 \, D^{1/3}} \text{ in lbs/ft}^2$$

$\bar{V}$, being the mean velocity of the channel.

The above functional relationship has been plotted by Laursen. A characteristic of the curve is that it is very steep in the range of U_*/w from 1 to about 40, the range in the present case, and a small change in U_*/w results in a large change in the left-hand term of the equation.

To take into account the non-uniformity of the sediment, a computational procedure has been suggested by Laursen which is represented by the equation

$$\bar{C} = \Sigma p\left(\frac{d_m}{D}\right)^{7/6}\left(\frac{\tau'_o}{\tau_c} - 1\right) f\left[\frac{U_*}{w}\right]$$

wherein the contribution of each fraction p of size d_m are summed to obtain the mean contribution. Values of τ_c and w are determined for the mean diameter d_m of each fraction, but the same values of τ'_o and U_* are to be used for all fractions, τ'_o being determined from the mean diameter of the total sediment sample.

In the present study total load computations have been carried out for 'high' and 'low' pond levels at Pathri Power House for 7th August 1973 and 30th July 1973 (Appendix IV). Seven-mile length of the canal has been divided into six reaches for study and total load transport rate has been computed for them. Values of R, S_f , velocity, depth etc. have been taken from backwater computation (Table 3.1a & 3.1b) and from study of Manning's N (Chapter 3).

To take into account the non-uniformity of sediment, bed material was divided into four size ranges as follows - Less than 0.1 mm, 0.1 to 0.2 mm, 0.2 to 0.4 mm and more than 0.4 mm. The detailed computations are given in Appendix IV.

4.3.5. Abstract of Total Load Computations

Abstract of total load computations by Laursen's is given in Table 4.8 below.

Table 4.8 - Abstract of Total Load computation by Laursen's method

Date	Disch. Cusecs	Level at Pathri P.H.	Transporting Capacity (ppm)					
			0-3 to 1-5	1-5 to 3-0	3-0 to 4-0	4-0 to 5-0	5-0 to 6-0	6-0 to 7-0
30.7.73	9074	915.50	1616	1189	1138	1255	1068	231
		918.50	1616	1189	1138	543	326	81
7.8.73	4277	915.00	636	390	589	458	311	112
		918.50	636	380	248	78	50	22

NOTE - Detailed computations for all 4 cases are given in Appendix IV.

As already stated total load equations are not of very high reliability and lack precision. However, the following conclusions can be reasonably drawn: -

(1) The total bed material load (excluding wash load) transporting of the Ganga Canal is of the following order in the different reaches during monsoon season when average roughness is low

(around 0.020) and for discharges above 9000 cusecs and when pond at Pathri is maintained at 915.50 (low pond level).

Reach	Transporting Capacity (ppm)
2-6 to 4-0	1200 to 1600
4-0 to 5-0	800 to 1200
5-0 to 6-0	250 to 1000
6-0 to 7-0	250 to 500

Transporting capacity for the reach head to M 2-6 would be high enough to meet normal contingencies. However, due to appreciable variations in roughness and energy gradient from day to day due to movement of deposited silt, the above values of transporting capacity may have considerable variation from day to day.

(2) Other conditions remaining the same as in (1) above if the pond at Pathri is raised to 918.50 there is serious reduction in transporting capacity in the entire reach from M 2-6 downstream. The values with high pond at Pathri and nearly full stage during monsoon will be around as given below:

Reach	Transporting Capacity (ppm)
2-6 to 4-0	1000
4-0 to 5-0	500
5-0 to 6-0	200
6-0 to 7-0	75

As the backwater effect due to high pondlevel of Pathri Power House is appreciable upto M 5-0, the maximum reduction is in the reach downstream from M 5-0.

4.3.6. Influence of Canal Stage

The available data does not include periods when canal was run with relatively low discharges and high sediment concentrations. As per orders canal was to be run with full discharge at high sediment concentrations. Such data would give information about actual roughness of canal under these conditions. However, during 1973 canal was run at low discharge while the sediment concentration was moderately high for 4 days from 5th August to 8th August 1973.

The values of N for these four days are calculated and tabulated as below.

Table 4.9 - Values of Manning's N during Low Stage of Canal

Date	Q(Cfs)/ppm	Reach					
		0-3 to 1-5	1-5 to 3-0	3-0 to 4-0	4-0 to 5-0	5-0 to 6-0	6-0 to 7-0
5.8.73	5597/1111	.0210	.0203	.0196	.0174	.0177	.0140
6.8.73	5413/1632	.0127	.0139	.0127	.0144	.0184	.0183
7.8.73	4277/1452	.0154	.0165	.0204	.0190	.0177	.0221
8.8.73	4515/1502	.0144	.0178	.0193	.0172	.0142	.0246
Mean	4950/1428	.0159	.0171	.0180	.0170	.0170	.0197

Two approaches have been used to analyse the effect of canal stage on transporting capacity so that the results can also be compared.

(1) A typical cross-section has been taken assumed on the basis of observed section on a particular date, and then assuming other factors to remain constant change only the discharge.

(2) Transport rates have been computed from actual data of

low running (7th August 1973) included in Table 4.8, Para 4.3.5.

1. Approach (1) -

For this approach, let the following be assumed:

Side slope	1.5:1
Bed width	160 ft
Energy gradient S_f =	2.5×10^{-4} at full stage (10000 Cfs)
	2.0×10^{-4} at 3/4 stage (750 Cfs)
	1.67×10^{-4} at 1/2 stage (5000 Cfs)
Manning's N =	0.0150 at full stage (10000 Cfs)
	0.0160 at 3/4 stage (7500 Cfs)
	0.0175 at 1/2 stage (5000 Cfs)

The above values are representative of the reach M 4-0 to M 5-0 during monsoon.

First, water depths, cross-sectional area, hydraulic mean depths and velocities for the three stages are computed and tabulated below:

Q(Cusecs)	D(feet)	A(Sft)	R(feet)	V(ft/sec.)
10,000	9.0	1562	8.20	6.4
7,500	8.5	1468	7.70	5.1
5,000	7.0	1194	6.45	4.2

From these values and above assumptions, the total rates of transport were computed by Laursen's method and tabulated as below (detailed calculations in Appendix V).

Table 4.10 - Effect of stage variation on Total Bed Material Load Transport Capacity

Discharge (Cusecs)	Total bed material load transport capacity(ppm)
10,000	559
7,500	314
5,000	177

Thus it is seen that on the basis of above assumptions, which are considered to be possible, there is considerable fall in carrying capacity of the canal. However, it is important to keep in mind, that though the carrying capacity of the canal is less at smaller discharges, the total amount of sediment brought into the canal is also less. Thus at concentrations, only slightly in excess of carrying capacity, there is a definite advantage in running higher gauges so far as depositions are concerned. But, at higher concentrations, it may not be so. This will be evident from the following table (Table 4.11).

It will eb clear from the table (4.11) that while at 500 ppm bed material load (or about 1000 measured ppm which also include wash load) the per day deposit increases at discharge 5000 cusecs, the case is reversed at 1000 ppm. However, this position could be materially altered if increases in N values with reduction in stage are appreciably more than those assumed above. However, the values of roughness observed at low discharges during 1973 monsson are close to the assumed values.

2. Approach (2) -

For the second approach, the computation results in Table 4.8 for a discharge of 4277 cusecs (7th August 1973) may be referred to. The transporting capacity in reach M-4 to M 5-0 is 458 ppm, M-5 to M 6-0 is 311 ppm, and M 6-0 to M 7-0 is 112 ppm. So, the values assumed for idealised cross-section in first approach are not unrealistic and the results may be used for further discussion.

This work is further extended for different reaches taken

Table 4.11 - Effect of stage and silt concentration on silt deposit

Bed Material Load concentration in the canal (ppm)	10,000 Cusecs			7,500 Cusecs			5,000 Cusecs		
	Con-veyed ppm	Depo-sited ppm	Deposit cft/day	Con-veyed ppm	Depo-sited ppm	Deposit cft/day	Con-veyed ppm	Depo-sited ppm	Deposit cft/day
500	559	Nil	Nil	314	186	75,000	177	323	87,300
1000	559	441	238,000	314	686	277,000	177	823	221,00

NOTE - 1. Bulk unit weight of deposited material assumed as 100 lbs/cft.

2. Value of conveyed ppm from Table 4.10 (Appendix V).

Tabl

Measured silt con- tent (Tot ppm	6-0		6-0 to 7-0			Total deposit in reach. Lakh cft/ day
	t	Deposit Lakh cft/ day	Carrying Capacity ppm	Deposit ppm	Deposit Lakh cft/ day	
Dischai						
6000		2.160	400	200	1.080	14.040
5000		2.160	400	200	1.080	11.350
4000		2.160	400	200	1.080	8.640
3000		2.160	400	200	1.080	5.940
2000		2.160	400	200	1.080	3.240
1200		nil	400	200	1.080	1.080
Dischai						
6000		0.346	100	200	0.462	6.694
5000		0.346	100	200	0.462	5.534
4000		0.346	100	200	0.462	4.389
3000		0.346	100	200	0.462	3.234
2000		0.346	100	200	0.462	2.079
1200		0.346	100	200	0.462	1.154

NOTE - 1 s the balance will get deposited in the upper reach.

2.

Table 4.12 - Effect of Full and Half Stage and Silt Concentration on Silt Deposit (Reachwise)

Measured silt content (Total) ppm	Bed material load (50% of Total) ppm	2-6 to 4-0 Carrying Capacity	2-6 to 4-0 Deposit ppm	2-6 to 4-0 Deposit Lakh cft/day	4-0 to 5-0 Carrying Capacity ppm	4-0 to 5-0 Deposit ppm	4-0 to 5-0 Deposit Lakh cft/day	5-0 to 6-0 Carrying Capacity ppm	5-0 to 6-0 Deposit ppm	5-0 to 6-0 Deposit Lakh cft/day	6-0 to 7-0 Carrying Capacity ppm	6-0 to 7-0 Deposit ppm	6-0 to 7-0 Deposit Lakh cft/day	Total deposit in reach. Lakh cft/day
Discharge 10,000 Cusecs														
6000	3000	1400	1600	8.640	1000	400	2.160	600	400	2.160	400	200	1.080	14.040
5000	2500	1400	1100	5.950	1000	400	2.160	600	400	2.160	400	200	1.080	11.350
4000	2000	1400	600	3.240	1000	400	2.160	600	400	2.160	400	200	1.080	8.640
3000	1500	1400	100	0.540	1000	400	2.160	600	400	2.160	400	200	1.080	5.940
2000	1000	1400	-	-	1000	nil	nil	600	400	2.160	400	200	1.080	3.240
1200	600	1400	-	-	1000	nil	nil	600	nil	nil	400	200	1.080	1.080
Discharge 4,277 Cusecs														
6000	3000	600	2400	5.540	450	150	0.346	300	150	0.346	100	200	0.462	6.694
5000	2500	600	1900	4.380	450	150	0.346	300	150	0.346	100	200	0.462	5.534
4000	2000	600	1400	3.235	450	150	0.346	300	150	0.346	100	200	0.462	4.389
3000	1500	600	900	2.080	450	150	0.346	300	150	0.346	100	200	0.462	3.234
2000	1000	600	400	0.925	450	150	0.346	300	150	0.346	100	200	0.462	2.079
1200	600	600	nil	nil	450	150	0.346	300	150	0.346	100	200	0.462	1.154

NOTE - 1. The inflow ppm in a lower reach is taken equal to the carrying capacity of the upper reach as the balance will get deposited in the upper reach.

2. Measured value of bed material 50% to 70% of Total.

into account for full and half stage (i.e. 10,000 cusecs and 4,277 cusecs) for total silt content (measured) ranging from 1200 ppm to 6000 ppm (Table 4.12). The computation tends to show that at higher sediment concentrations (say for bed material load values above 1000 ppm) the deposit at lower discharges would be smaller. On the other hand, at lower concentrations (say for bedmaterial load values 600 to 700 ppm), low stage running leads to greater deposits. As stated earlier, during 1973 the canal was actually run at low stages for the period 5th to 8th of August with an average measured sediment influx of about 1400 ppm (or bed material load about 700 ppm) and the rate of deposit was appreciably higher than at high discharges running during the preceding 5 days. This tends to support a part of the above findings.

4.3.7. Permissible Deposition during Monsoon Months

4.3.7.1. The actual cumulative deposit of silt of seven-mile reach (upto Pathri Power House) has been workedout on a common datum (bedlevels during May/June 1972) and is tabulated in Appendix I. The trend of deposit durkng monsoon months for the three years 1971, 1972 and 1973, is shown in Fig. 4.1. It may be noted that the peak accumulation reached 333 Lakh cft on 30th September in 1971 whereas the peak accumulation was only 196 Lakh cft on 20th Augustin 1972. This low deposit was due to less sediment influx as well as more cautious running of the canal in 1972 monsoon. During 1973 the peak accumulation was not allowed to exceed 250 Lakh cft. This value was attained on 22nd of September.

As mentioned earlier (Chapter 1), in 1971 it was not possible to feed the canal with full supply during September, inspite of running higher gauges. The situation was only a little better in 1972 inspite of a considerably lower accumulation of silt. It may also be noted that during 1972 though the silt accumulation was considerably smaller the roughness values were higher canelling out much of the advantage.

It seems that the problem of September feeding cannot be solved by restricting the silt deposition during July-August. As soon as the content of fine silt in the water falls, by about middle of September, the N values show an appreciable rise. This requires a larger water-depth at the same time there cannot be an appreciable erosion of deposited silt in September. Hence, if the canal is to be fed in September, there seems to be no alternative to encroachment on freeboard, and increase of freeboard wherever necessary.

Other things remaining constant, the depth in a channel is roughly proportional to $N^{3/5}$. Thus, an increase of 25% in value of N requires an increase of 14% in depth. In the case of Ganga Canal it comes to 1.5 ft. So, if the canal is to be run at full discharge during September, a rise of this magnitude will have to be accepted in the water surface as compared to that during July-August.

4.3.7.2. The second criterion for permissible silt accumulation is that the accumulated silt should be fully washed out by, say, the end of March and the canal be ready to receive the silt influx of next monsoon. This will enable to meet the high irrigation demand for sugar cane.

It is reported that during 1972 silt deposition was largely washed out by middle of October (Appendix I). Hence, the level of accumulation of 1972 can certainly be acceptable from thks criterion. On the other hand, the 1971 accumulation was excessive, as it was cleared only by succeeding May.

On the basis of 1972 data, the actual rate of erosion works out to be 243,000 cft/day while 1971 data yields 216,000 cft/day. This means an approximate average movement rate of 450-tp-500 ppm. Therefore, it appears that the erosion is not purely as bed load which would permit movement at the rate of about 100 ppm only. (Bed load calculation according to Meyer-Peter during winter running gives a value of 85.5 ppm for reach M-4 to M-5, and 81.1 ppm for reach M-5 to M-6.)

A better or more reliable criterion for permissible deposition cannot be devised by theoretical means than that indicated by actual experience of past years. On this basis, an accumulation of upto 300 lakh cftof silt should be considered acceptable, as this can reliably be expected to be washed out in a period of 4.1/2 months.

Normally, the first floods of July should be expected to bring more sediment than the later floods of August while silt concentration falls considerably by the middle of September. However, keeping some margins the deposits may be permitted according to the following schedule:

Upto 31st July   Not more than 150 Lakh cft

Upto 31st August   Not more than 250 Lakh cft.

Upto 15th September - Not more than 300 Lakh cft

A plot of mean bed level at M 4-0 against accumulated deposit has been made in Fig. 4.5 from the data of 1971, 1972 and 1973 monsoon and it shows a rough correlation. An estimate of the deposit can be made from observations of cross-sections taken daily during the period 1st July to 30th September. According to this correlation the mean level at M 4-0 should be maintained as below:

Upto 31st July	-	913.0
Upto 31st August	-	914.0
Upto 15th September	-	914.5

4.3.7.3. The control on canal operation has to be on the basis of permissible deposition by particular dates, rather than by silt content of water on a particular day. A high silt content may well be allowed for a short period provided that the total limits of deposition are not exceeded. A high silt concentration for a short period may be less harmful than a less high silt concentration (above the transporting capacity of the canal) for very long period. However, some idea of probable rates of deposition at different silt contents will be found useful in regulation of the canal. The effect of stage (10,000 cusecs and 4,277 cusecs) with the variation of sediment content (1,200 ppm to 6,000 ppm measured) has also been given in Table 4.12. The bed material load is assumed to be 50% of the total on a conservative basis. For the different measured total silt concentrations the total deposit per day in the 7-mile reach of the canal is estimated as below:

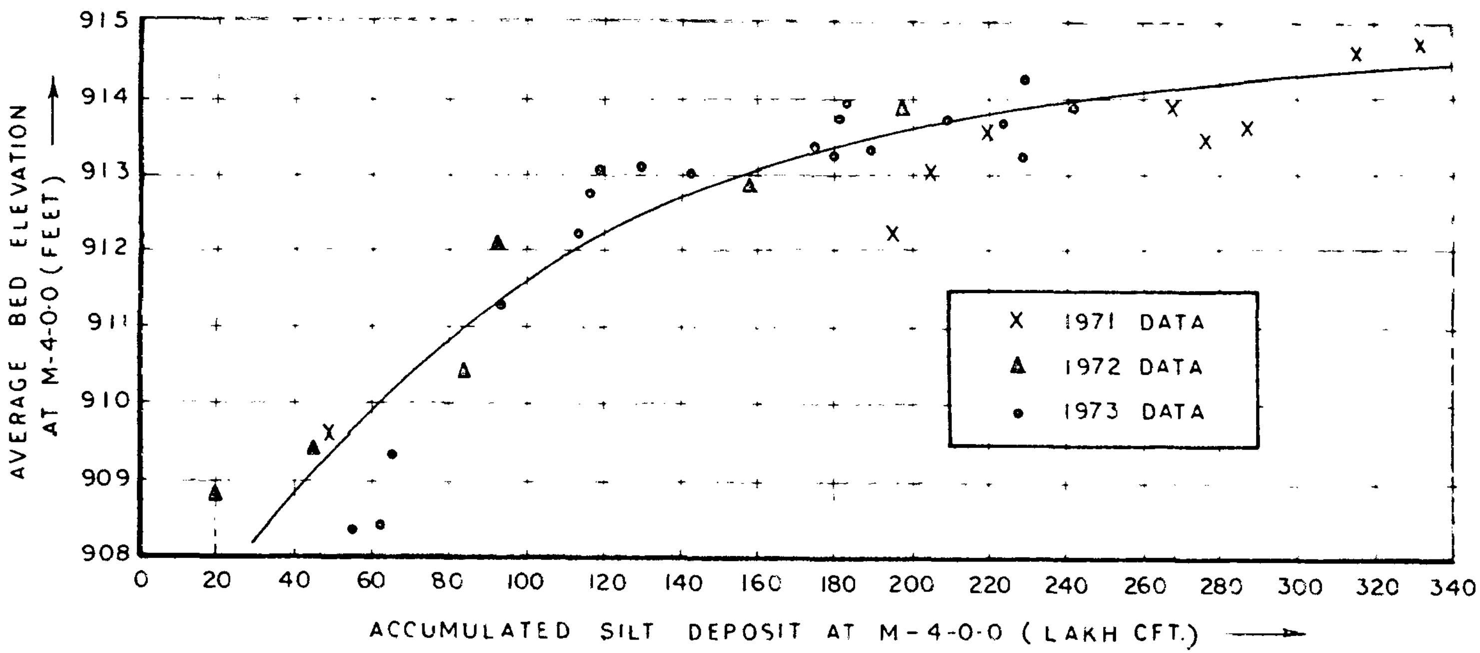

FIG. 4·5 _ MODIFIED STAGE AND ACCUMULATED SILT FOR M 4-0-0

(PERIOD TILL MAXIMUM DEPOSITION ONLY IS CONSIDERED)

Measured silt content (Total)	Total estimated deposit upto M 7-0 in one day in Lakh cft (Discharge of 10,000 cusecs)
6000	14.04
5000	11.35
4000	8.64
3000	5.94
2000	3.24
1200	1.08

Taking that by the end of July, 150 Lakh cft deposit can be allowed at an average daily rate of 4 Lakh cft (to be on safer side), it is seen that at 4000 ppm the silting rate is twice the average, at 5000 ppm about three times, and at 6000 ppm nearly three-and-a-half times the permissible average silting rate. Thus, while the canal may be kept open at 5000 or 6000 ppm, it would be risky to do so for more than a day or two at a time as the remaining silting capacity will then be small and may impose undue restrictions on the running of the canal. However, as discussed under para 4.3.6 (influence of stage), the rate of silting may well be kept down by running only the necessary discharge at very high sediment concentrations.

Chapter 5

DISCUSSION OF RESULTS AND CONCLUSIONS

5.1. Discussion of Results

5.1.1. As discussed in Chapter 1, sediment influx in Upper Ganga Canal due to Alakhnanda hill slides posed a severe and challenging problem for canal design and research engineers. The field data have their own limitations and reliability for such studies. However, the problem became more and more interesting as it was being studied in greater detail. During the study, some times it became difficult to draw clear and useful conclusions even after handling voluminous data of three monsoons. It is a fact that though rivers and canals have been the concern of man since the dawn of history, even today their behaviour cannot be predicted with complete satisfaction and certainty. Science of movement of sediment in flowing water is yet a partly-known subject. In fact, we are in the midst of growth of this science. The results of the work done in studying the problem may be discussed as below:

5.1.2. Hydraulic Roughness

Due to variation of the bed slope and cross-section (bed width and side slope) along the length of the canal, different reaches selected in the study showed different behaviours regarding hydraulic roughness. It is worth mentioning here that while studying the cross-section registers it was noticed that the bed at a particular cross-section does not remain horizontal. Along the width of the canal there are scours or deposits which vary prominently with time. These are channel irregularities which also increase the roughness.

Formation and geometry of the bedforms depends on various flow parameters and in turn, the various flow parameters are influenced by the bedforms. It was difficult to establish in which reach and when bedforms are prominent. However, while discussing the 'low' and 'high' silt concentration curves (para 3.5), it was anticipated that bedforms do not exist in upper reach dueto coarser particle sizes in the bed and due to high velocity. Bedforms can be expected to be more prominent in the middle reach. This reach is most influenced with silt concentration of flowing water. Rugosity coefficient increases significantly with the reduction in silt concentration. This is expected to be due to presence of prominent bedforms during scour. At the time of deposition the bedforms seem to be less prominent. Again, the lower reach seems to have insignificant bedforms due to low velocity in that reach. It is concluded that increase in silt concentration in flowing water substantially reduces the rugosity coefficient. (See Fig. 3.4)

5.1.2. Sediment Transport Capacity

As discussed in Chapter 2, it has been assumed that the rise and fall of bed level at a particular gauge site is assumed to be the rise and fall in the whole reach to which the gauge site corresponds (approx. 1 mile). It is also seen that rise and fall of bed level is very irregular and without any periodicity. Moreover, deposition and scouring seem to go together in the 7-mile length of the canal. The rate of transport depends on flow conditions (mean velocity, depth and slope) and sediment characteristics (mean size, gradation, specific gravity and shape). The flow conditions vary along the 7-milelength of the canal. Under the circumstances mentioned above one should not expect to arrive at a reasonably good value of transport rate of the canal. However, the computations done in Chapter 4 yield a range of transported sediment rate from 900 ppm to 1900 ppm bedmaterial load (total load) excluding wash load and this is considered to be representative of the actual range. The transport rates obtained by Laursen's method for full stage of the canal range from 250 ppm in the lowest reach, to 1600 ppm in the head reach, and for half stage it ranges from 100 ppm in the lowest reach, to 600 ppm in the head reach. This is considered to tally well with the observed values.

5.1.3. Canal Regulation

The present study has successfully provided some guidelines for proper regulation of the canal and the standing orders for operation of the canal can be modified keeping in view the conclusions derived. The operation of canal should be based on the permissible silt deposits during the specified periods rather than on simple sediment-concentration basis. The curve of variation of bed level at M 4-0 with total silt deposit in entire reach (Fig. 4.5) is supposed to be a good guide for quick assessment of total silt deposit.

5.2. Conclusions

5.2.1. The hydraulic roughness of the canal varies from day-to-day and also along the length of the canal (Table 3.2).

5.2.2. The silt concentration in the flowing water shows significant influence on thé hydraulic roughness of the canal (Fig. 3.4).

5.2.3. The middle reach (M-2-3 to M 5-0) is subjected to maximum variation of roughness due to variation in silt concentration of flowing water. In this reach bedforms seem to be most prominent. (Fig. 3.3)

5.2.4. The total bed material laod transporting capacity (about half the measured concentration) at full stage during monsoon and when the pond at Pathri Power House is maintained at 915.50 is of the following magnitude:

Reach Miles-Furlongs	Total Bed Material Load Transporting Capacity (ppm)
2-6 to 4-0	1200 to 1600
4-0 to 5-0	800 to 1200
5-0 to 6-0	250 to 1000
6-0 to 7-0	250 to 500

5.2.5. The high pond level at Pathri Power House (918.50) has significant backwater effect upto M 4-0 during full stage of canal running (Table 3.1a). This effect of backwater extends to M 3-0 at half stage of canal running (Table 3.1b).

5.2.6. The high pond level at Pathri Power House (918.50) has significant influence on the total bed material load transporting capacity of the canal. At full stage running of the canal during monsoon and pond level at Pathri House maintained at 918.50 the total bed material transport capacity (about half the measured concentration) is of the following order:

Reach (Miles-Furlongs)	Total Bed Material Load Transporting Capacity (ppm)
2-6 to 4-0	1000
4-0 to 5-0	1500
5-0 to 6-0	200
6-0 to 7-0	75

Thus, the maximum reduction due to high pond level is in the reach M 5-0 downwards.

5.2.7. At ~~full~~ half stage running of the canal and pond level at Pathri Power House maintained at 918.50, the total bed material transporting capacity is of the following order:

Reach (Miles-Furlongs)	Total Bed Material Load Transporting Capacity (ppm)
2-6 to 4-0	500
4-0 to 5-0	80
5-0 to 6-0	50
6-0 to 7-0	25

These reductions are due to high pond level at Pathri Power House and also due to half stage of the canal. The effect of canal stage is separately discussed in para 5.2.10.

5.2.8. The pond level of Pathri Power House has important influence on transporting capacity. Pond level should be maintained at 915.50 from 1st July (or even earlier if there is evidence of deposition) to at least the 31st of October. This will keep down the siltation, and allow appreciable clearance during October.

After 31st October, the pond may be gradually raised while the rate of clearance of deposited silt is watched. Normally, full pond should be maintained after 31st January.

5.2.9. During clear-water season when channel roughness is high, and high pond level is maintained at Pathri Power House, the transport rates would be considerably lower.

5.2.10. Low stage of canal running also reduces the transport rate considerably. With the low stage of the canal, the reduction in reach M 4-0 to M 5-0 (para 4.3.6) is of the following order:

Discharge (cusecs)	Total Bed Material Load Transporting Capacity (ppm)
10,000	559
7,500	314
5,000	177

However, it should be kept in mind that greater total deposit is likely to take place at higher discharges than at lower discharges, when the silt concentrations are considerably higher than the carrying capacity of the canal (Table 4.11 and 4.12).

5.2.11. Considering the bed level of May/June 1972 as datum, the permissible total accumulation of silt upto M 7-3 (i.e. Pathri Power House) is considered to be 300 Lakh cft. The folowing schedule of accumulation of silt can be followed:

Date	Maximum Accumulation of silt (Lakh cft)	Corresponding approximate mean bed level at M 4-0
31st July	150	913.00
31st August	250	914.00
15th September	300	914.50

5.2.12. Considering the regulation of canal on totalsilt accumulation basis, a watch on silt deposit has to be maintained whenever the canal is running above 2,500 ppm measured concentration during July, as above this concentration the rate of silting increases rapidly above the average permissible rate for July. Later on, the corresponding figure would be 2000 ppm.

R E F E R E N C E S

[1] Alakhnanda Enquiry Committee Report, Vol. I & II - Shri N. G. K. Murti (Chairman), and other members.

[2] A Study of the Siltation Problem of Ganga Canal, interim report May 1973. Dr. Bharat Singh, Professor, Water Resources Development Training Centre, University of Roorkee.

[3] A Study of the Siltation Problem of Ganga Canal, final report March 1974. Dr. Bharat Singh, Professor, Water Resources Development Training Centre, University of Roorkee.

[4] A Study of Sediment Transport Capacity of Ganga Canal - H. D. Sharma, D. V. Varshney and V. K. Agrawal - Accepted I.A.H.R. XV, Istanbul, Sept. 1973.

[5] "The Total Sediment Load of Streams" - Emmett M. Laursen, P.A.S.C.E. (Hy.1 Vol. 84), February 1958.

[6] "The Sediment Problem" - Flood Control Series No. 5, United Nations Economic Commission for Asia and the Far East.

[7] "Hydraulics of Sediment Transport" - Walter H. Graf, McGraw-Hill, N.Y.

[8] Gauge, Discharge and Cross Section records of Northern Division, Ganga Canal, Roorkee.

[9] Notes of Shri B. D. Rathi, Superintending Engineer, I Circle, Irrigation Works, Meerut, on the behaviour of Ganga Canal.

[10] Study of total transport capacity of Ganga Canal at M 4-0-0 by H. D. Sharma, Director, Irrigation Research Institute, Roorkee.

[11] Report on study of under-shot gates at Pathri or providing a separate escape for increasing the transport rate - I.R.I., Roorkee.

[12] Correspondence file of Dr. Bharat Singh dealing with siltation problem of Ganga Canal.

Appendix I

SILT ACCUMULATION AND REMOVAL

(Total silt accumulation in different years. Datum level same for three years, i.e. May/june 1972 levels)

(in lakh cft)

Date	1971	1972	1973
30th June	-	-	63
7th July	-	20	131
15th July	196	47	185
22nd July	205	84	-
31st July	221	93	190
3rd August	-	158	210
7th August	-	126	225
10th August	-	118	-
20th August	-	196*	-
22nd August	-	191	-
29th August	268	166	229
6th September	288	116	242
11th September	276	187	229
22nd September	271	162	250*
26th September	247	125	232
30th September	333*	110	205
2nd October	316	92	179
15th October	239	-	-
22nd Octomber	258	-	-
31st October	205	-	-
15th November	197	-	-
30th November	188	-	-
15th December	118	-	-
31st December	134	-	-

*Maximum accumulation

Appendix II

SAMPLE CALCULATION FOR MANNING'S N

Date - 7th August 1973 Discharge = 4277 Cfs Silt concentration = 1452 ppm

Location M-F-Ft	Length Ft	Cross Sec. Sft	Perimeter Ft	H.M.R. R(ft)	$(R)^{2/3}$	V	$V^2/2g$	C.B.L.	F.S.L.	T.E.L.	S_f (in 10^{-4})	$\sqrt{S_f}$	N	Remarks
0-3-0		797.40	197.33	4.03	2.53	5.37	0.447	920.28	924.75	925.197				All values of N accepted
	6600	893.70	189.74	4.71	2.81	4.79				1.997	3.12	0.0176	0.0154	
1-5-0		990.00	182.15	5.43	3.09	4.32	0.290	916.89	922.91	923.200				
	7260	1004.00	192.97	5.21	3.00	4.26				1.805	2.48	0.0157	0.0165	
3-0-0		1018.00	203.89	4.99	2.92	4.21	0.275	915.53	921.12	921.395				
	5280	1011.00	202.73	5.00	2.92	4.18				2.043	3.87	0.0196	0.0204	
4-0-0		1005.00	201.58	4.99	2.92	4.26	0.282	913.67	919.07	919.352				
	5280	1083.50	192.13	5.64	3.16	3.95				1.342	2.54	0.0159	0.0190	
5-0-0		1162.00	182.69	6.37	3.44	3.68	0.210	910.57	917.80	918.010				
	5280	1103.50	212.54	5.19	3.00	3.88				1.260	2.37	0.0154	0.0177	
6-0-0		1045.00	242.39	4.31	2.65	4.10	0.260	912.00	916.50	916.760				
	5280	1457.50	234.40	6.21	3.38	2.94				0.879	1.66	0.0129	0.0221	
7-0-0		1870.00	226.42	8.28	4.09	2.29	0.081	906.63	915.80	915.881				

Appendix III - Assessment of Actual Sediment Transport Rateof Canal (Reach as a Whole) - 1973

Period	Average Discharge Cusecs	Total silt coming into the canal Lakh cft	Actual deposit observed Lakh cft.	Silt carried by the canal Lakh cft	Silt carrying capacity ppm	Average S_f (in 10^{-4})
30.6.73 to 7.7.73 (7 days)	9261	63.15	68.45	-	-	-
7.7.73 to 15.7.73 (8 days)	9110	93.39	53.35	40.04	1016	3.300
15.7.73 to 31.7.73 (2 days)	8423	13.79	5.61	8.18	900	3.130
31.7.73 to 3.8.73 (3 days)	8215	33.38	19.54	13.84	1040	3.390
3.8.73 to 7.8.73 (4 days)	6148	21.24	15.25	5.99	552	3.235
7.8.73 to 29.8.73 (2 days)	6407	8.72	4.14	3.58	512	2.680
29.8.73 to 6.9.73 (8 days)	7933	35.09	12.44	22.65	661	3.196
6.9.73 to 11.9.73 (5 days)	7416	13.07	(-) 12.78	25.85	1248	2.990
11.9.73 to 22.9.73 (11 days)	7263	23.75	20.67	3.08	71	3.160
22.9.73 to 26.9.73 (4 days)	6807	5.49	(-) 18.02	23.51	1600	3.010
26.9.73 to 30.9.73 (4 days)	8427	3.93	(-) 26.17	30.10	1650	3.140
30.9.73 to 2.10.73 (2 days)	8946	1.11	(-) 26.17	27.28	2825	2.960

(-) denotes Scour

1. Total Load Computation by Laursen Method - Low Pond at Pathri Power House

Date	=	7th August 1973
Discharge of Canal	=	4,277 Cusecs
Observed silt content at M 0-3	=	1452 ppm
Water level upstream of Pathri Power House	=	915.00
Water level at M 7-0	=	915.80

Reaches -	1st	M 0-3 to M 1-5	4th	M 4-0 to 5-0
	2nd	M 1-5 to M 3-0	5th	M 5-0 to M 6-0
	3rd	M 3-0 to M 4-0	6th	M 6-0 to M 7-0

(1) Proportion and Mean Size - Based on bed material size distribution average of M 1-5 and M 6-0 (Fig. 4.4).

Size	% Fine	% of size	d_m (mm)	% to which d_m corresponds	Range
0.055 mm to 0.1 mm	8%	8%	0.080	4%	< 0.1
0.1 mm to 0.2 mm	43%	35%	0.155	22%	0.1 to 0.2
0.2 mm to 0.4 mm	88%	45%	0.250	63%	0.2 to 0.4
Upto 2.5 mm	100%	12%	0.520	94%	> 0.4

For the entire sample d_m = 0.244 mm

(2) Settling (Fall) velocities w: (Values read from curves Fig. 4.4 'Hydraulics of Sediment Transport' by Walter H. Graf at 20°C)

d_m (mm)	w in cm/sec	w in ft/sec.
0.080	0.52	1.70×10^{-2}
0.155	1.50	4.90×10^{-2}
0.250	3.00	9.85×10^{-2}
0.520	8.00	26.20×10^{-2}
0.244	3.00	9.85×10^{-2}

(3) Shear Velocity ($U_* = \sqrt{gR\,S_f}$) and U_*/w:

Reach	R(feet)	$\sqrt{S_f}$	U_*	U_*/w: d_m=0.08	=0.155	=0.250	=0.520
1st	4.71	0.0176	0.2165	12.75	4.42	2.200	0.826
2nd	5.21	0.0157	0.2035	11.95	4.15	2.065	0.776
3rd	5.00	0.0196	0.2480	14.60	5.06	2.520	0.947
4th	5.64	0.0159	0.2140	12.60	4.37	2.175	0.817
5th	5.19	0.0154	0.1990	11.70	4.06	2.020	0.760
6th	6.21	0.0129	0.1820	10.70	3.71	1.850	0.695

(continued)

(4) Computation for d_m/D (in 10^{-6}):

Reach	D(Feet) (from C/S Register)	d_m=0.080	=0.155	=0.250	=0.520
1st	5.25	50.00	97.00	156.00	325.00
2nd	5.80	45.25	88.00	141.50	294.00
3rd	5.50	47.75	92.70	149.00	310.00
4th	6.37	41.20	80.00	129.00	268.00
5th	5.86	44.80	86.80	140.00	291.00
6th	6.84	38.40	74.30	120.00	249.00

(5) Laursen Function $f(U_*/w) = \dfrac{\bar{C}}{(d_m/D)^{7/6}\left[\dfrac{\tau'_o}{\tau_c} - 1\right]}$

(from Laursen Curve)

Reach	d_m = 0.080		=0.155		=0.250		=0.520	
	U_*/w	$f(\frac{U_*}{w})$	U_*/w	$f(\frac{U_*}{w})$	U_*/w	$f(\frac{U_*}{w})$	U_*/w	$f(\frac{U_*}{w})$
1st	12.75	1500	4.42	150	2.200	35	0.826	14
2nd	11.95	1400	4.15	130	2.065	32	0.776	13
3rd	14.60	2000	5.06	200	2.520	45	0.947	15
4th	12.60	1500	4.35	150	2.175	35	0.817	14
5th	11.70	1400	4.06	130	2.020	32	0.760	13
6th	10.70	1200	3.71	100	1.850	28	0.695	12

(6) Critical Tractive Stress ($\tau_c = \dfrac{4.5\, d_m \text{ (mm)}}{304.8}$) in lbs/ft^2:

d_m	= 0.08	= 0.155	= 0.250	= 0.520
τ_c	= 0.118	= 0.228	= 0.369	= 0.767 (in 10^{-2})

(7) Boundary Shear $\tau'_o = \dfrac{\bar{V}^2}{30} (d_m/D)^{1/3}$ [for entire silt sample, d_m=0.244]

Reach	$\bar{V}$(ft/sec)	(d_m/D)	τ'_o
1st	4.79	152.0×10^{-6}	4.08×10^{-2}
2nd	4.26	138.0×10^{-6}	3.12×10^{-2}
3rd	4.18	145.5×10^{-6}	3.06×10^{-2}
4th	3.95	125.8×10^{-6}	2.60×10^{-2}
5th	3.88	136.5×10^{-6}	2.58×10^{-2}
6th	2.94	116.7×10^{-6}	1.41×10^{-2}

(8) Ratio of Bounday Shear to Critical Tractive Stress τ'_o / τ_c

Reach	d_m= 0.08	=0.155	= 0.25	=0.52
1st	34.6	17.9	11.10	5.33
2nd	26.4	13.7	8.46	4.07
3rd	25.9	13.4	8.30	3.99
4th	22.0	11.4	7.05	3.39
5th	21.8	11.3	7.00	3.36
6th	12.0	6.2	3.80	1.84

(continued)

(9) Mean Concentration $\bar{C} = (d/D)^{7/6}(\frac{\tau'_o}{\tau_c} - 1)\ f\ (\frac{U_*}{w})$

Reach	d_m = 0.08	= 0.155	= 0.25	= 0.52
1st	0.4840	0.0530	0.0127	0.00515
2nd	0.3060	0.03085	0.00745	0.00304
3rd	0.4530	0.0491	0.0112	0.00377
4th	0.4200	0.0262	0.0061	0.00258
5th	0.2450	0.0244	0.00595	0.00230
6th	0.0928	0.00795	0.00210	0.00062

(1) Fraction multiplied with concentration $\bar{C}p$

d_m = 0.08	= 0.155	= 0.25	= 0.52
p = 0.08	= 0.35	= 0.45	= 0.12

$\bar{C}p$:-

Reach						$\Sigma\bar{C}p$	ppm
	1st	0.03872	0.01855	0.00572	0.00062	0.06361	636
	2nd	0.02448	0.01080	0.00335	0.00036	0.03899	390
	3rd	0.03624	0.01718	0.00504	0.00045	0.05891	589
	4th	0.03360	0.00917	0.00275	0.00031	0.04583	458
	5th	0.01960	0.00854	0.00268	0.00028	0.03110	311
	6th	0.00742	0.00278	0.00095	0.00007	0.01122	112

2. Total Load Computation by Laursen Method - High Pond at Pathri Power House

Date	-	7th August 1973
Discharge of canal	=	4,277 Cusecs
Observed silt content at M 0-3	=	1452 ppm
Water level upstream of Pathri Power House	=	918.50
Water Level at M 7-0	=	918.80 (Assumed)

(1) & (2) same as Low Pond Computation on 7th August 1973.

(3) Shear Velocity $(U_* = \sqrt{gRS_s})$ and U_*/w:

Reach	R(feet)	$\sqrt{S_f}$	U_*	U_*/w: d_m=0.08	=0.155	=0.250	=0.520
1st	4.71	0.0176	0.2165	12.75	4.42	2.20	0.826
2nd	5.76	0.0157	0.2040	12.00	4.16	2.07	0.779
3rd	5.76	0.0143	0.1945	11.45	3.97	1.98	0.743
4th	7.485	0.0108	0.1675	9.85	3.42	1.70	0.640
5th	7.145	0.0098	0.1490	8.75	3.04	1.51	0.569
6th	8.445	0.0087	0.1435	8.44	2.93	1.46	0.448

(4) Computation for (d_m/D) (in 10^{-6})

Reach	D(in feet)	d_m=0.08	=0.155	=0.250	=0.520
1st	5.25	50.0	97.0	156.0	325
2nd	5.84	45.0	87.2	140.5	292
3rd	6.09	43.1	83.6	134.8	280
4th	7.795	33.3	65.3	105.2	219
5th	8.08	32.5	63.0	101.5	211
6th	9.635	27.2	52.8	85.2	177

(5) Laursen Function $f(U_*/w) = \dfrac{\bar{C}}{(d_m/D)^{7/6}\left[\dfrac{\tau_o'}{\tau_c} - 1\right]}$

Reach	d_m=0.080		=0.155		=0.250		=0.520	
	U_*/w	$f(\frac{U_*}{w})$	U_*/w	$f(\frac{U_*}{w})$	U_*/w	$f(\frac{U_*}{w})$	U_*/w	$f(\frac{U_*}{w})$
1st	12.75	1500	4.42	150	2.20	35	0.826	14
2nd	12.00	1400	4.16	130	2.07	32	0.779	13
3rd	11.45	1300	3.97	120	1.98	30	0.743	13
4th	9.85	900	3.42	80	1.70	26	0.640	12
5th	8.75	700	3.04	60	1.51	22	0.569	10.5
6th	8.44	650	2.93	55	1.46	20	0.448	10.0

(continued)

(6) Same as Low Pond Computation on 7th August 1973.

(7) Boundary Shear $\tau'_o = \frac{\bar{V}^2}{30} (d_m/D)^{1/3}$ [for entire silt sample, d_m=0.244]

Reach	$\bar{V}$(ft/sec.)	(d_m/D)	τ'_o
1st	4.79	152.0 x 10^{-6}	4.08 x 10^{-2}
2nd	4.235	137.0 x 10^{-6}	3.07 x 10^{-2}
3rd	3.700	131.5 x 10^{-6}	2.32 x 10^{-2}
4th	2.975	102.5 x 10^{-6}	1.38 x 10^{-2}
5th	2.870	99.0 x 10^{-6}	1.27 x 10^{-2}
6th	2.355	83.0 x 10^{-6}	0.81 x 10^{-2}

(8) Ratio of Boundary Shear to Crtical Tractive Stress τ'_o / τ_c

Reach	d_m=0.08	=0.155	=0.250	=0.520
1st	34.6	17.9	11.1	5.33
2nd	26.0	13.5	8.3	4.00
3rd	19.6	10.2	6.3	3.02
4th	11.7	6.1	3.7	1.80
5th	10.8	5.6	3.4	1.66
6th	6.9	3.5	2.2	1.06

(9) Mean Concentration

$$\bar{C} = (d_m/D)^{7/6} \left(\frac{\tau'_o}{\tau_c} - 1\right) f\left(\frac{U_*}{w}\right)$$

Reach	d_m=0.08	=0.155	=0.250	=0.520
1st	0.48400	0.05300	0.01270	0.00515
2nd	0.29800	0.02985	0.00753	0.00292
3rd	0.19580	0.01920	0.00490	0.00186
4th	0.05775	0.00668	0.00182	0.00052
5th	0.03980	0.00345	0.00116	0.00036
6th	0.01805	0.00150	0.00042	0.00003

(10) Fraction multiplied with concentration $\bar{C}$ p

		d_m=0.08	=0.155	=0.250	=0.520		
		p =0.08	=0.35	=0.45	=0.12		
	$\bar{C}$ p : -					$\Sigma\bar{C}$ p	ppm
Reach	1st	0.03872	0.01855	0.00572	0.00062	0.06361	636
	2nd	0.02385	0.01045	0.00339	0.00035	0.03804	380
	3rd	0.01565	0.00672	0.00223	0.00022	0.02482	248
	4th	0.00462	0.00234	0.00082	0.00006	0.00784	78
	5th	0.00318	0.00121	0.00052	0.00004	0.00495	50
	6th	0.00144	0.00052	0.00019	0.00000	0.00215	22

3. Total Load Computation by Laursen Method - Lond Pond at Pathri Power House

Date	-	30th July 1973
Discharge of Canal	=	9,074 Cusecs
Observed silt content at M 0-3	=	1516 ppm
Water level upstream of Pathri Power House	=	915.50
Water level at M 7-0	=	916.50

(1) and (2) same as Low Pond Computation for 7th August 1973.

(3) Shear Velocity ($U_* = \sqrt{gRS_f}$) and U_*/w :-

Reach	R(feet)	$\sqrt{S_f}$	U_*	U_*/w: d_m=0.08	=0.155	=0.250	=0.520
1st	7.08	0.0203	0.3060	18.0	6.25	3.11	1.17
2nd	7.31	0.0194	0.2980	17.5	6.08	3.03	1.14
3rd	7.06	0.0186	0.2800	16.5	5.71	2.84	1.07
4th	7.10	0.0191	0.2880	16.9	5.88	2.92	1.10
5th	7.70	0.0192	0.3020	17.8	6.16	3.07	1.15
6th	8.52	0.0132	0.2190	12.9	4.47	2.22	0.84

(4) Computation of (d_m/D) (in 10^{-6}) :-

Reach	D (in feet)	d_m=0.08	=0.155	=0.250	=0.520
1st	7.88	33.3	64.5	104.0	216
2nd	8.08	32.5	63.0	101.5	211
3rd	7.74	33.9	65.6	106.0	220
4th	7.96	32.9	63.8	103.0	214
5th	8.44	31.1	60.3	97.3	202
6th	9.22	28.5	55.1	89.0	185

(5) Laursen function

$$f(U_*/w) = \frac{\bar{C}}{(d_m/D)^{7/6}\left[\frac{\tau_o'}{\tau_c} - 1\right]}$$

Reach	d_m=0.080		=0.155		=0.250		=0.520	
	U_*/w	$f(\frac{U_*}{w})$	U_*/w	$f(\frac{U_*}{w})$	U_*/w	$f(\frac{U_*}{w})$	U_*/w	$f(\frac{U_*}{w})$
1st	18.0	3600	6.25	380	3.11	60	1.17	17
2nd	17.5	3000	6.08	310	3.03	59	1.14	17
3rd	16.5	2800	5.71	280	2.84	50	1.07	16
4th	16.9	2900	5.88	300	2.92	55	1.10	16
5th	17.8	3400	6.16	540	3.07	60	1.15	17
6th	12.9	1500	4.47	180	2.22	35	0.84	13

(continued)

(6) Same as Low Pond Computation on 7th August 1973.

(7) Boundary Shear $\tau'_o = \frac{\bar{V}^2}{30} (d_m/D)^{1/3}$ (for entire silt sample, $d_m = 0.244$)

Reach	$\bar{V}$(ft/sec.)	d_m/D	τ'_o
1st	6.67	101.5×10^{-6}	6.90×10^{-2}
2nd	6.38	99.0×10^{-6}	6.27×10^{-2}
3rd	6.32	103.5×10^{-6}	6.25×10^{-2}
4th	6.61	100.5×10^{-6}	6.77×10^{-2}
5th	5.49	95.0×10^{-6}	4.58×10^{-2}
6th	4.53	86.8×10^{-6}	3.03×10^{-2}

(8) Ratio of Boundary Shear to Critical Tractive Stress τ'_o / τ_c

Reach	d_m=0.08	=0.155	=0.250	=0.520
1st	58.5	30.25	18.70	9.00
2nd	53.2	27.50	17.00	8.17
3rd	52.9	27.40	16.93	8.15
4th	57.4	29.70	18.35	8.83
5th	38.8	20.10	12.40	5.98
6th	25.7	13.30	8.20	2.95

(9) Mean Concentration

$$\bar{C} = (d_m/D)^{7/6} \left(\frac{\tau'_o}{\tau_c} - 1 \right) f\left(\frac{U_*}{w} \right)$$

Reach	d_m=0.08	=0.155	=0.250	=0.520
1st	1.240000	0.14500	0.02420	0.00720
2nd	0.91000	0.10280	0.02080	0.00634
3rd	0.88500	0.09690	0.01833	0.00630
4th	0.95500	0.11100	0.02150	0.00664
5th	0.66800	0.13000	0.01440	0.00498
6th	0.18500	0.02390	0.00479	0.00117

(10) Fraction multiplied with concentration $\bar{C}$ p

d_m	=0.08	=0.155	=0.250	=0.520
p	=0.08	=0.35	=0.45	=0.12

$\bar{C}$ p :-

						$\Sigma\bar{C}$ p	ppm
Reach	1st	0.09920	0.05060	0.01090	0.00087	0.16157	1616
	2nd	0.07280	0.03600	0.00935	0.00076	0.11891	1189
	3rd	0.07090	0.03390	0.00825	0.00075	0.11380	1138
	4th	0.07650	0.03850	0.00967	0.00080	0.12547	1255
	5th	0.05425	0.04550	0.00646	0.00060	0.10681	1068
	6th	0.01480	0.00597	0.00216	0.00014	0.02307	231

4. Total Load Computation by Laursen Method - High Pond at Pathri Power House

Date	- 30th July 1973
Discharge of canal	= 9074 Cusecs
Observed silt content at M 0-3	= 1516 ppm
Water level upstream of Pathri Power House	= 918.50
Water level at M 7-0	= 918.80 (assumed)

(1) & (2) same as Low Pond computation for 7th August 1973.

(3) Shear Velocity ($U_* = \sqrt{gRS_f}$) and U_*/w :-

Reach	R(feet)	$\sqrt{S_f}$	U_*	U_*/w: d_m=0.08	=0.155	=0.250	=0.520
1st	7.08	0.0203	0.3065	18.00	6.25	3.12	1.17
2nd	7.31	0.0194	0.2980	17.50	6.08	3.02	1.14
3rd	7.06	0.0186	0.2800	16.50	5.71	2.84	1.07
4th	7.55	0.0144	0.2100	12.35	4.28	2.13	0.80
5th	9.04	0.0137	0.2340	13.78	4.77	3.38	0.89
6th	10.47	0.0099	0.1820	10.70	3.72	1.85	0.70

(4) Computation of (d_m/D) (in 10^{-6}) :-

Reach	D (in feet)	d_m=0.08	=0.155	=0.250	=0.520
1st	7.88	33.3	64.5	104.0	217.0
2nd	8.08	32.5	62.9	101.5	211.5
3rd	7.74	33.9	65.7	106.0	220.5
4th	8.45	31.0	60.2	97.0	202.0
5th	10.00	26.2	50.8	82.0	170.5
6th	11.43	22.9	44.4	71.7	149.0

(5) Laursen function $f(U_*/w) = \dfrac{\bar{C}}{(d_m/D)^{7/6}\left[\dfrac{\tau'_o}{\tau_c} - 1\right]}$

Reach	d_m=0.080		=0.155		=0.250		=0.520	
	U_*/w	$f(\frac{U_*}{w})$	U_*/w	$f(\frac{U_*}{w})$	U_*/w	$f(\frac{U_*}{w})$	U_*/w	$f(\frac{U_*}{w})$
1st	18.00	3600	6.25	380	3.12	60	1.17	17
2nd	17.50	3000	6.08	310	3.02	59	1.14	17
3rd	16.50	2800	5.71	280	2.84	50	1.07	16
4th	12.35	1500	4.28	160	2.13	35	0.80	14
5th	13.78	1800	4.77	190	3.38	80	0.89	15
6th	10.70	1150	3.72	100	1.85	30	0.70	13

(continued)

(6) Same as Low Pond Computation on 7th August 1973.

(7) Boundary shear $\tau'_o = \frac{\bar{V}^2}{30} (d_m/D)^{1/3}$ (for entire silt sample, d_m=0.244)

Reach	$\bar{V}$(ft/sec.)	d_m/D	τ'_o
1st	6.67	101.5×10^{-6}	6.90×10^{-2}
2nd	6.38	99.0×10^{-6}	6.27×10^{-2}
3rd	6.32	103.5×10^{-6}	6.25×10^{-2}
4th	6.21	94.7×10^{-6}	5.86×10^{-2}
5th	4.86	80.0×10^{-6}	3.41×10^{-2}
6th	3.65	70.0×10^{-6}	1.85×10^{-2}

(8) Ratio of Boundary Shear to Critical Tractive Stress τ'_o / τ_c

Reach	d_m=0.08	=0.155	=0.250	=0.520
1st	58.5	30.25	18.70	9.00
2nd	53.2	27.50	17.00	8.17
3rd	52.9	27.40	16.93	8.15
4th	49.7	25.70	15.90	7.65
5th	28.9	14.95	9.24	4.45
6th	15.7	8.10	5.02	2.41

(9) Mean Concentration $\bar{C} = (d_m/D)^{7/6}(\frac{\tau'_o}{\tau_c} - 1)\, f(\frac{U_*}{w})$

Reach	d_m=0.08	=0.155	=0.250	=0.520
1st	1.24000	0.14500	0.02420	0.00720
2nd	0.91000	0.10280	0.02080	0.00634
3rd	0.88500	0.09690	0.01833	0.00630
4th	0.40200	0.04740	0.01095	0.00461
5th	0.22750	0.02600	0.01120	0.00207
6th	0.06510	0.00596	0.00176	0.00062

(10) Fraction multiplied with Concentration $\bar{C}$ p

d_m=0.08	=0.155	=0.250	=0.520
p =0.08	=0.35	=0.45	=0.12

$\bar{C}$ p :—

						$\Sigma\bar{C}$ p	ppm
Reach	1st	0.09920	0.05060	0.01090	0.00087	0.16157	1616
	2nd	0.07280	0.03600	0.00935	0.00076	0.11891	1189
	3rd	0.07090	0.03390	0.00825	0.00075	0.11380	1138
	4th	0.03220	0.01660	0.00493	0.00055	0.05428	543
	5th	0.01820	0.00910	0.00504	0.00025	0.03259	326
	6th	0.00521	0.00209	0.00079	0.00007	0.00816	81

Effect of Stage Variation on Total Load Transport Capacity

(1) Calculation of Shear Velocity ($U_* = \sqrt{gRS_f}$) and U_*/w :-

Discharge Cusecs	(H.M.R) R(ft)	S_f (in 10^{-4})	$\sqrt{S_f}$ (in 10^{-2})	U_* ft/sec	U_*/w: d_m=0.080 w =0.017	=0.180 =0.082	=0.250 =0.131	=0.520 =0.262
10,000	8.20	2.50	1.58	0.256	15.0	3.12	1.95	0.975
7,500	7.70	2.00	1.41	0.220	12.9	2.68	1.68	0.840
5,000	6.45	1.67	1.29	0.181	10.6	2.21	1.38	0.690

(2) Laursen function $f(\frac{U_*}{w}) = \frac{\bar{C}}{(d_m/D)^{7/6}\left[\frac{\tau_o'}{\tau_c} - 1\right]}$

Discharge Cusecs	d_m=0.080		=0.180		=0.250		=0.520	
	$\frac{U_*}{w}$	$f(\frac{U_*}{w})$	$\frac{U_*}{w}$	$f(\frac{U_*}{w})$	$\frac{U_*}{w}$	$f(\frac{U_*}{w})$	$\frac{U_*}{w}$	$f(\frac{U_*}{w})$
10,000	15.0	2200	3.12	60	1.95	32	0.975	14.0
7,500	12.9	1800	2.68	55	1.68	23	0.840	11.0
5,000	10.6	1050	2.21	40	1.38	20	0.690	10.5

(3) Boundary Shear $\tau_o' = \frac{\bar{V}^2}{30} \times (d_m/D)^{1/3}$ (for entire silt sample, d_m=0.244)

Discharge Cusecs	$\bar{V}$ (ft/sec)	$\frac{\bar{V}^2}{30}$	D (ft)	(d_m/D) (in 10^{-6})	$(d_m/D)^{1/3}$ (in 10^{-2})	τ_o' (lbs/ft^2) (in 10^{-2})
10,000	6.4	1.37	9.0	88.9	4.46	6.11
7,500	5.1	0.87	8.5	94.2	4.55	3.96
5,000	4.2	0.59	7.0	114.3	4.86	2.87

(4) Calculation of τ_o' / τ_c

Discharge Cusecs	τ_o'/τ_c: d_m=0.080 τ_c=0.118	=0.180 =0.266	=0.250 =0.369	=0.520 =0.767
10,000	51.80	23.00	16.55	7.98
7,500	33.60	14.90	10.73	5.17
5,000	24.35	10.80	7.78	3.74

(5) Calculation for $(d_m/D)^{7/6}$ (in 10^{-7}) :-

Discharge Cusecs	D (feet)	d_m=0.080	=0.180	=0.250	=0.520
10,000	9.0	51	130	190	425
7,500	8.5	54	140	205	460
5,000	7.0	69	178	260	600

(continued)

Discharge (Cusecs)	d_m=0.080	=0.180	=0.250	=0.520
10,000	0.57000	0.01715	0.00845	0.00416
7,500	0.31700	0.01070	0.00456	0.00210
5,000	0.16900	0.00692	0.00352	0.00172

(7) Fraction multiplied with Concentration $\bar{C}\,p$:-

Discharge Cusecs	$\bar{C}\,p$				$\Sigma\bar{C}\,p$	ppm
	d_m=0.80 p =0.08	=0.180 =0.350	=0.250 =0.450	=0.520 =0.120		
10,000	0.04560	0.00600	0.00380	0.00050	0.05590	559
7,500	0.02535	0.00375	0.00205	0.00025	0.03140	314
5,000	0.01350	0.00242	0.00158	0.00021	0.01771	177