Institutionen för vattenbyggnad
Chalmers Tekniska Högskola

Department of Hydraulics
Chalmers University of Technology

ISSN 0348 - 1069

AN EXPERIMENTAL STUDY FROM FLUME TO STREAM TRACTION IN PIPE CHANNELS

by Gustavo Perrusquía

Report Series B:57

Göteborg 1993

Institutionen för vattenbyggnad
Chalmers tekniska högskola

Department of Hydraulics
Chalmers University of Technology

An experimental study from flume to stream traction in pipe channels

by
Gustavo Perrusquía

Report Series
B:57

Göteborg 1993

Adress: Institutionen för vattenbyggnad
Chalmers tekniska högskola
412 96 GÖTEBORG

Telefon: 031-772 10 00
Telefax: 031-772 21 28

ABSTRACT

This report deals with an experimental study on sediment transport from flume to stream traction. The runs started with a clean pipe, contrary to earlier experiments where the sediment bed had been levelled in between false floors prior to each run. The aim was to test whether the same results are achieved when the sediment bed is built through "natural" accumulation. The results show that this is possible and that the previous experiments are therefore valid.

An important issue in this study was the computation of flow resistance for the case of isolated dunes. In previous studies, when computing flow resistance for bedforms on a permanent deposit, the geometry of the bedforms was first determined and then an equivalent thickness for the sediment bed. The results were consistent and "reasonable" resistance values were obtained. However, this technique did not work for isolated dunes. Computing first the volume of the dunes along the pipe and then an equivalent sediment bed was not a satisfactory solution. A distinction had to be made between the two bed conditions, namely isolated dunes and continuous bed. Flow resistance was computed by means of a proportional resistance caused by both wall and sediment.

KEYWORDS

Bedforms; Bedload; Flow resistance; Flume traction; Isolated dunes; Pipe channels; Sediment transport; Stream traction.

PREFACE

In September 1992 I published a report entitled: "Sediment Transport in Pipe Channels", which marked the end of my experiments with a permanent deposit. The current series of experiments deals with the transition from isolated dunes (flume traction) to a permanent deposit (stream traction). I always considered this last series a necessary step to test the validity of my previous studies.

I want to acknowledge the support that the Swedish Council for Building Research has provided during all stages of my research studies at Chalmers. My colleagues Bengt Carlsson, Karl-Oskar Djärv and Lars-Ove Sörman gave me - once again - invaluable assistance at the laboratory.

The results are to be used in the calibration of a sediment transport model that is being developed at The University of Aalborg in Denmark.

Göteborg, January 1993 Gustavo Perrusquía

TABLE OF CONTENTS

NOTATION

Symbols:

A	hydraulic area
B	water width
C_v	volumetric concentration of sediment
D	pipe diameter
D_{50}	particle diameter of bed material 50% being finer
D_*	particle number
f	Darcy-Weisbach's friction factor
f_b	Darcy-Weisbach's friction factor of the bed
f_w	Darcy-Weisbach's friction factor of the wall
g	acceleration due to gravity
H	bedform height
k_b	equivalent bedform roughness
k_w	equivalent wall roughness
L	bedform length
n	Manning's roughness coefficient
n_b	Manning's bed roughness coefficient
n_w	Manning's wall roughness coefficient
P_b	bed wetted perimeter
P_w	wall wetted perimeter
Q	water discharge
Q_b	sediment transport rate
q_b	sediment transport rate per unit width
R	mean hydraulic radius
R_b	hydraulic radius of the bed
R_w	hydraulic radius of the walls
Re_*	grain Reynolds number
S	pipe slope/energy gradient
s	relative density of the sediment
t	sediment bed thickness
u_*	shear velocity
V	mean flow velocity
Y	flow depth
y	height above the sediment bed
Θ_b	dimensionless bed shear stress (bed mobility number)

ν	kinematic viscosity
ρ	density of water
ρ_s	density of sediment
τ_b	bed shear stress
Φ_b	transport parameter

Formulas:

Particle Reynolds number

$$Re_* = \frac{u_* D_{50}}{\nu}$$

Side wall elimination using Manning's equation

Manning's equation for both side walls and sediment bed

$$V = \frac{1}{n_w} R_w^{\frac{2}{3}} S^{\frac{1}{2}} \qquad \text{side wall}$$

$$V = \frac{1}{n_b} R_b^{\frac{2}{3}} S^{\frac{1}{2}} \qquad \text{sediment bed}$$

Side wall elimination using Darcy-Weisbach's equation

Friction factor using the Colebrook-White equation

$$f^{-\frac{1}{2}} = -2 \log \left[\frac{k_s}{14.8\ R} + \frac{2.51\ \nu}{R\sqrt{128\ g\ R\ S}} \right]$$

Bed shear stress

$$\tau_b = \rho\ g\ R_b\ S$$

Volumetric concentration

$$C_v = \frac{Q_b}{Q} \times 10^6 \text{ (ppm)}$$

Bed mobility number

$$\Theta_b = \frac{\tau_b/\rho}{g(s-1)D_{50}} = \frac{R_b\ S}{(s-1)D_{50}}$$

Dimensionless transport parameter

$$\Phi_b = \frac{q_b}{\sqrt{g(s-1)D_{50}^3}}$$

Relative density

$$s = \frac{\rho_s}{\rho}$$

1 BACKGROUND AND SCOPE OF THE STUDY

The study of sediment in sewers both in the field and in the laboratory has been one of the major research activities at the Department of Hydraulics at Chalmers for the past seven years. The activities in the laboratory have consisted of experiments where flow conditions and other parameters can be readily controlled. This has provided the author with the opportunity to undertake an extensive experimental programme without having to deal with real sewer situations in which too many parameters are involved. This does not mean in any way that those situations simulated in the laboratory are nothing but artificial events. On the contrary, by understanding simple flow conditions, it is possible to study and eventually solve more complicated cases. A summary of the experimental programme is shown in Table 1 below.

TABLE 1 Type of study for each experimental series

Type of study	Description of the experimental series
Flow capacity Stable, plane beds	Sand (size = 2.5 mm) was laid on the invert of a concrete pipe (diameter = 225 mm) until a perfectly levelled bed was formed over a length of 23 m. Three sand bed thicknesses (25, 48 and 85 mm) were tested. No sediment transport was observed.
Flow capacity Stable, plane beds	Same as previous series, except for the particle size (16 mm) and the bed thicknesses (60 and 77 mm).
Flow resistance and Bedform geometry	Sand (sizes = 0.5 and 0.9 mm) was laid on the invert of a concrete pipe (diameter = 225 mm) until a perfectly levelled bed was formed over a length of 23 m. Six sand bed thicknesses (25, 45, 55, 60, 85 and 100 mm) were tested. Sediment transport was observed though not recorded. Bedforms (developed along the sediment bed) were measured. No sediment supply into the pipe.
Sediment transport Chalmers series I	Same as previous series, except for the particle size (0.9 and 2.5 mm) and the bed thicknesses (45 and 90 mm). Also, the test section was only five meters long with fixed floors on both ends. Sediment transport rates and bedform geometry were measured and sediment was supplied from the uppstream end of the pipe.
Sediment transport Chalmers series II	Same as Chalmers series I, except for the sand bed thickness (45 mm) and for the fact that the work covered flow depths over the half-full condition.
Sediment transport Newcastle and Wallingford series	Complementary studies for various pipe diameters (154 and 450 mm), particle sizes (0.72 and 1.0 mm) and bed thicknesses (42 and 81 mm). Sediment transport rates and bedform geometry were measured.

In the present experimental series, which henceforth is referred to as Chalmers series III, the length of the test section was twenty meters. The purpose of this study is to verify the findings from previous series in which the test section was limited to five meters with fixed floors on both ends (Perrusquía, 1991 and 1992).

The scope of this and all previous studies, both at Chalmers and abroad, is limited to the following characteristics:

Part-full flow.
Non-cohesive material.
Steady, quasi-uniform flow.
Open-channel theory was applied.
Permanent deposited, loose sediment bed (except for some isolated dunes).
Bedload transport or stream traction (except for some flume traction runs).

2 EXPERIMENTAL PROGRAM

The concrete pipe, 225 mm in diameter and 20 m long, was set to a constant slope of 0.02% along the entire series of experiments. The only sand used had a mean size D_{50} = 0.9 mm. The flow discharge, Q = 8.33 l/s, was also the same for all runs. The water temperature for the final phase of each run was 25^{0} C.

The experimental rig as well as the detailed description of the measurements have been reported elsewhere (Perrusquía, 1991). An illustration of the experimental layout is shown in Figure 1.

Some clean pipe runs were carried out to check whether the roughness of the pipe walls had changed during the time this experimental programme has been undertaken (7 years). The value of Manning's coefficient for the pipe walls was found to be n_w = 0.0106, compared to the previous value of 0.0103. This result shows that the variation is insignificant.

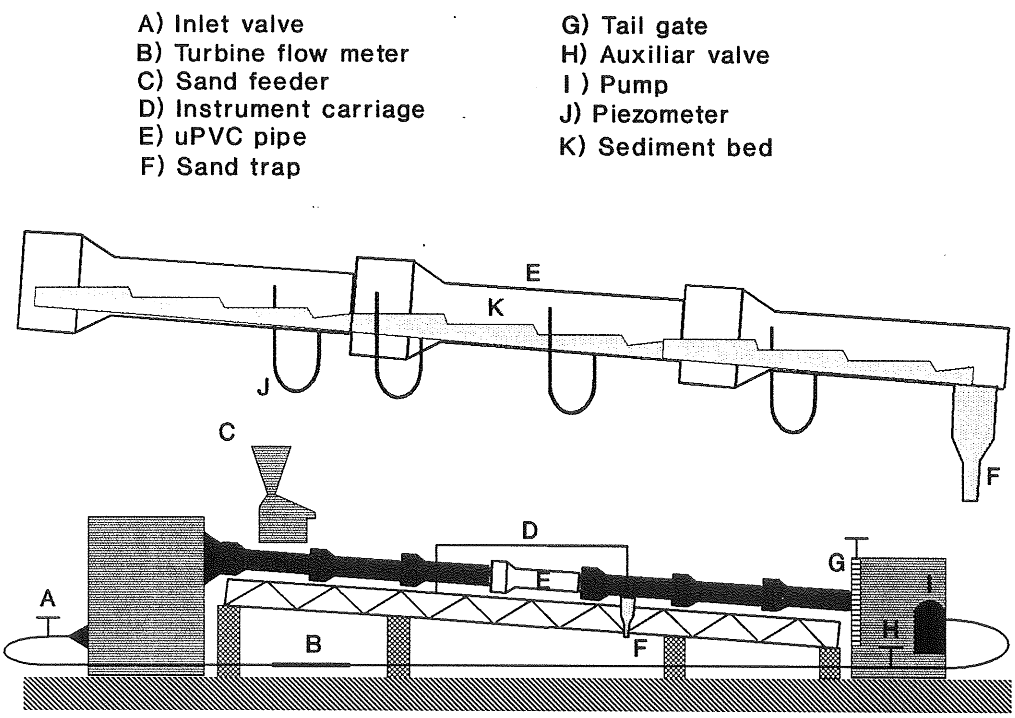


Fig.1 Illustration of the experimental rig

2.1 Build-up process

All runs were divided into two phases: preliminary and final. The former was designed to allow achievement of equilibrium in the sediment transport process.

The runs started by establishing a flow discharge in the empty pipe until quasi-uniform flow conditions were achieved, i.e. flow depths were measured along the pipe using piezometers until a constant water depth (±1 mm) was recorded. This process took almost one hour.

Sediment supply was then started using an electromagnetic vibrator located five meters downstream of the inlet. The sand started to be transported along the pipe. The run was continued until equilibrium in the sediment transport rate was accomplished, i.e. the amount of sand being fed into the pipe equalled the amount of sand leaving the pipe at the downstream end. This process is herein referred to as the preliminary phase which took several hours. This phase could be run for several days although not continuously. This means that the run could be interrupted by shutting off both water and sediment supply while keeping the sediment formation intact, only to continue the next day.

Sediment transport rates were measured by means of a sand trap located fifteen meters downstream of the pipe inlet. The mode in which the sediment was transported varied according to the rate of supply. Low rates produced individual particle motion, medium rates produced isolated dunes, and high rates produced a continuous sediment bed.

The final phase began once both transport mode and bedload development had stabilized, i.e. the buil-up process had ended. Even this phase was run several hours to guarantee the validity of the measurements.

At the end of the final phase, both water and sediment supply were cut off while the sediment bed was kept intact. The next day, both the longitudinal bed profile and the plan view were measured.

3 DISCUSSION OF THE EXPERIMENTAL RESULTS

The experimental data range, containing exclusively the final phases of each run, is summarized in Table 1. A complete listing of all data is shown in Appendix I.

TABLE 1 Range of the Experimental Data†

Run No.	Flow Depth Y (mm)	Flow + Sediment Depth / Pipe Diameter (Y+t)/D (mm)	Mode of Transport (Continuous bed or Isolated dunes)
1	101	0.45	Continuous (t = 14.5 mm)‡
2	94.0	0.42	Isolated dunes
3	96.0	0.43	Isolated dunes
4	98.0	0.44	Isolated-Continuous
5	107	0.48	Continuous (t = 23.8 mm)

†Pipe diameter, D = 225 mm; sand size, D_{50} = 0.9 mm; pipe slope, S = 0.002; flow discharge, Q = 8.33 l/s; water temperature, T_w = 25^0 C.
‡t = sediment bed thickness.

Both the longitudinal bed profiles (Appendix II) and the plan views of the bed (Appendix III) show that the sediment bed is gradually being built in proportion to the rate of supply. It may appear to be some differences between the longitudinal bed profile and their corresponding plan view. This was mainly due to the grouping of the recorded points in the longitudinal bed profile in order to execute the statistical analysis for the determination of sediment thickness and dune height. It is the grouped profiles that are shown in Appendix II. In Appendix III the actual on-site measurements of the plan views are illustrated. they were used for the determination of both dune length and width.

The very first run was conducted applying an arbitrary rate of sediment supply (30%) which proved to be enough to create a permanent sediment bed. In run 2 the rate of supply was set to 15% beginning with a clean pipe. Thereafter, the rate of supply was increased for each particular run, to 20% for run 3, 25% for run 4 and 35% for run 5.

It was observed that the formation of the sediment bed by means of a gradually increasing rate of sediment supply along an originally empty, long pipe (present study) was very similar to the structure of the sediment bed contained between two false floors along a short pipe length (Chalmers series I and II). Also, the dunes' migration velocity as well as their transport mechanism over a continuous bed was almost identical in both long and short approaches. The only difference consisted in the time needed to achieve both a continuous bed and equilibrium in the transport process. A good way of showing these observations (regarding both transport and resistance mechanisms) is to plot a transport parameter versus a resistance parameter for the present study in a chart which shows the results form previous studies and to make a direct comparison. This is shown in Figure 2 after the flow resistance estimation has been discussed.

3.1 Hydraulic computations

Two Fortran programs were used for the calculation of the hydraulic parameters, namely MANNINGS.FOR and SEDIMENT.FOR. The former was developed by the author while the latter was used with permission from Dr. Sven Lyngfelt at the Department of Hydraulics, Chalmers University of Technology. Both programs are listed in Appendix IV.

MANNINGS.FOR uses Manning's coeficient as roughness parameter and both the methods of Einstein and Horton for side wall elimination while SEDIMENT.FOR uses Darcy-Weisbach's friction coefficient and both the methods of Vanoni-Brooks and Ackers for side wall elimination.

The output from both programs (obviously the geometric parameters turned out to be identical) regarding the hydraulic radius of the sediment bed, R_b, which is the most important parameter in the determination of the hydraulic resistance of the bed ($\tau_b = \rho\ g\ R_b\ S$) was very similar. However, this was the case only for those runs with a continuous bed (1 and 5). For the runs that presented isolated dunes (2, 3 and 4) a different approach was used. All computational procedures for flow resistance estimation are presented next.

3.2 Flow resistance estimation

To compute the shear stress of continuous sediment beds, a FORTRAN program, FREDSØES.FOR, was used for the hydraulically rough region, while a worksheet program, LOTUSEDIM, was used for the transitional region. The former uses Fredsøe's method and the latter uses Lau's method (Perrusquía, 1991). Both programs are also listed in Appendix IV.

When computing flow resistance for dunes on a permanent deposit, the geometry of the dunes was first determined and the equivalent thickness for the sediment bed was then computed. However, this technique did not work for isolated dunes. A distinction had to be made between the two bed conditions - isolated dunes and continuous bed - when calculating resistance. Computing the volume of the dunes along the pipe and an equivalent continuous sediment bed gave an overestimation of the flow resistance.

A different approach was used for this purpose which was very similar to that presented by May (1993):

1) The volume of the dunes and the equivalent sediment thickness were computed for the effective pipe length, i.e. the sum of partial lengths which were actually covered by sediment.

2) The resistance was calculated using SEDIMENT.FOR. This program makes use of the Darcy-Weisbach formula for the friction coefficient, the Colebrooke-White equation for the equivalent roughness and the Vanoni-Brooks technique for side wall elimination.

3) The resistance corresponding to the sediment bed and which is caused by both the isolated dunes and the pipe length that is free from sediment was estimated as:

$$k_b = k_w\,(1-r) + k_{eb}\,(r) \qquad (1)$$

in which r is the ratio of the pipe length which is actually covered by sediment and the total test pipe length. The equivalent roughness was selected in Eq. (1) but the same relationship can be applied to any other resistance parameter, namely friction coefficient (f_b), shear stress (τ_b), or mobility number (Θ_b).

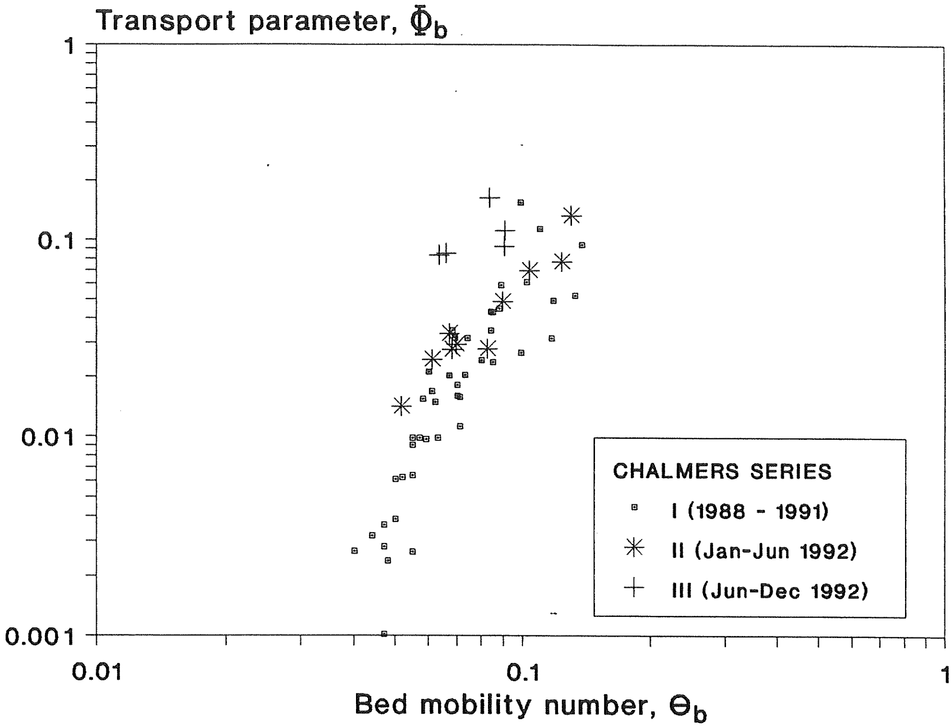


Fig.2 Comparison of results for all Chalmers series

Figure 2 is a plot of the mobility number (Θ_b) versus the transport parameter (Φ_b) in which all three Chalmers series were included. It can be seen that the results from the present study and from previous studies follow the same trend. However, it should be mentioned that the two observations from Chalmers series III that diverged most from the path were those belonging to runs 2 and 3 which were typical cases for isolated dunes and should therefore not be directly compared with the other cases which presented a continuous sediment bed.

This confirms the assumption that the experiments conducted on a short test section produce similar results to those found on long test sections. The only difference consisted in the time needed to achieve equilibrium in the sediment transport process.

4 CONCLUSIONS

An experimental study from flume to stream traction has been reported. The experiments were conducted on a 23-meter long pipe starting with a clean pipe, contrary to earlier experiments where the sediment bed was artificially built in between false floors 5 meters apart. The aim was to test whether the same results can be achieved when the sediment bed is built through "natural" accumulation.

The main conclusions can be listed as follows:

1) The transport mechanism and the formation of the sediment bed in a long test section occur in a similar way as they do in a confined short section.

2) Flow resistance on a permanent deposit can be calculated using an equivalent thickness for the sediment bed.

3) In the case of isolated dunes the resistance can be calculated by distributing the roughness among the two stages along the pipe channel, namely clean-pipe and sediment-bed resistance.

REFERENCES

May, R. (1993): Sediment transport in pipes and sewers with deposited beds, HR Wallingford, Report SR 320, England.

Perrusquía, G. (1991): Bedload transport in storm sewers, Chalmers University of Technology, Department of Hydraulics, Report A:22, Göteborg, Sweden.

Perrusquía, G. (1992): Sediment transport in pipe channels, Chalmers University of Technology, Department of Hydraulics, Report B:52, Göteborg, Sweden.

APPENDIX I

Experimental Data

Run number	Pipe slope	Sand size	Sediment thickness	Sediment width	Flow Discharge	Flow depth	Total depth
		m	m	m	m3 / s	m	m
	S	D50	t	Pb	Q	h	y = h + t
1	0.002	0.0009	0.0145	0.1100	0.00833	0.0865	0.1010
2	0.002	0.0009	0.0050	0.0448	0.00833	0.0890	0.0940
3	0.002	0.0009	0.0073	0.0555	0.00833	0.0888	0.0960
4	0.002	0.0009	0.0090	0.0875	0.00833	0.0890	0.0980
5	0.002	0.0009	0.0240	0.1390	0.00833	0.0830	0.1070

Run number	Transport rate samples		Mean transport rate	Mean rate of supply	Area water & sediment	Area sediment	Hydraulic area
	g / min		g / min	g / min	m2	m2	m2
			mtr		At	Ab	A
1	205, 217		211	207	0.0173	0.0011	0.0162
2	58.4, 59		59	54	0.0157	0.0002	0.0155
3	81.6, 80.8, 81.2		81	83	0.0162	0.0004	0.0158
4	161,158,112,147,115		139	116	0.0166	0.0005	0.0161
5	240,247,256		247	230	0.0186	0.0023	0.0164

Run number	Walls wetted perim	Bed wetted perim	Total Wetted perimeter	Water width	Hydraulic radius	Mean depth	Flow velocity
	m	m	m	m	m	m	m / s
	Pw	Pb	P	B	R	M	V
1	0.2149	0.1105	0.3254	0.2238	0.0498	0.0724	0.5137
2	0.2489	0.0663	0.3153	0.2219	0.0492	0.0699	0.5369
3	0.2391	0.0795	0.3186	0.2226	0.0496	0.0710	0.5274
4	0.2337	0.0882	0.3219	0.2231	0.0500	0.0721	0.5176
5	0.1927	0.1389	0.3316	0.2247	0.0494	0.0728	0.5089

Run number	Froude number	Water temp	Kinematic viscosity	Reynolds number	Equivalent Manning coefficient	Manning coefficient of the bed Einstein	Manning coefficient of the bed Horton
		° C	m^2/s				
	Fr	Tw	v	Re	ne	nbE	nbH
1	0.61	25	8.93E-07	114672	0.0118	0.0142	0.0144
2	0.65	25	8.93E-07	118355	0.0112	0.0140	0.0142
3	0.63	25	8.93E-07	117129	0.0114	0.0143	0.0146
4	0.62	25	8.93E-07	115906	0.0117	0.0149	0.0151
5	0.60	25	8.93E-07	112516	0.0118	0.0137	0.0138

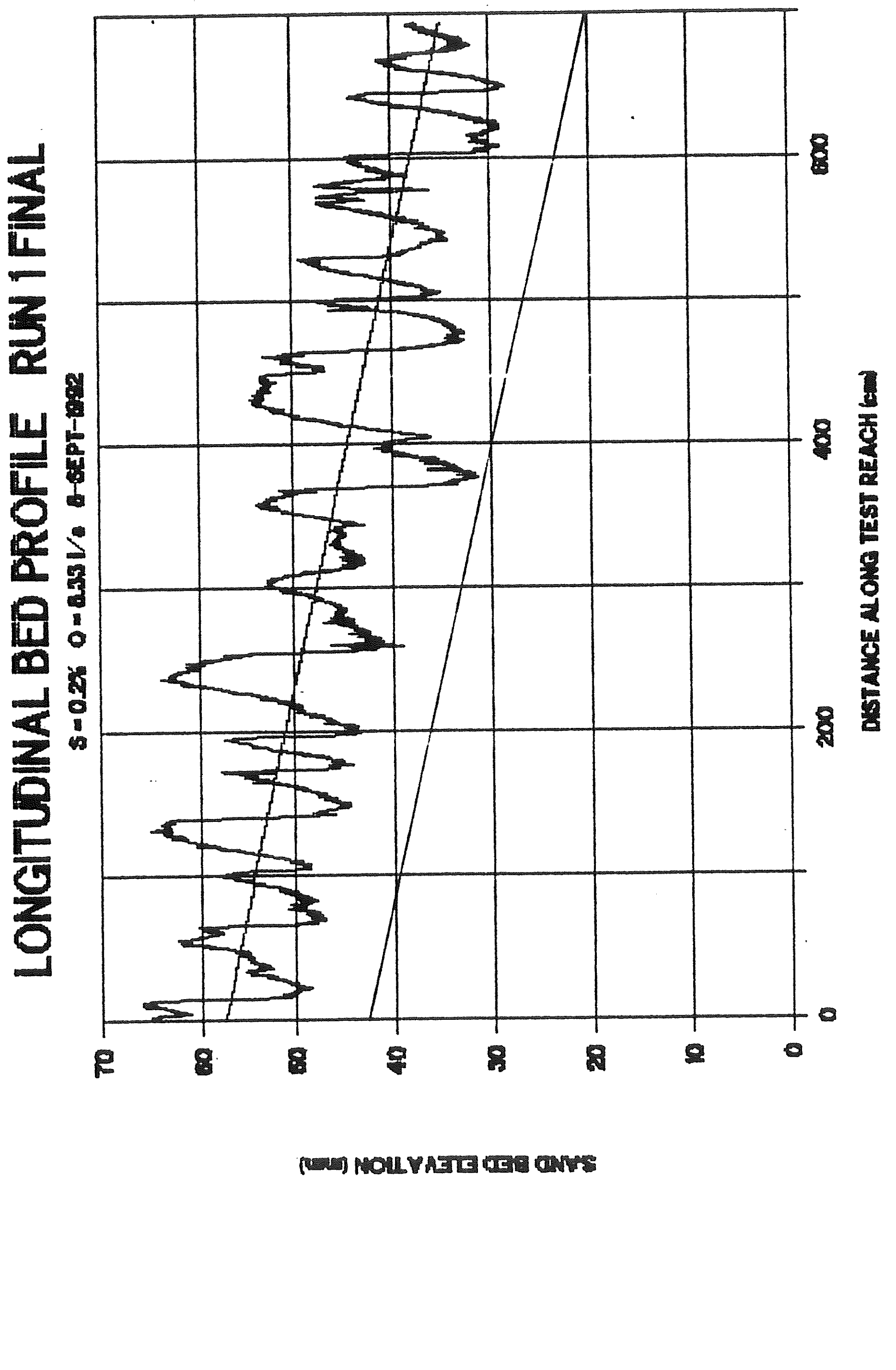
Run number	Hydraulic radius of the bed	Mobility number	Particle Reynolds number	Sediment transport rate	Volumetric sediment concentratio	Unit sediment transport rate	Sediment transport rate
	m			kg / s	ppm	g/min m	m3 / s
	Rb	Θb	Re *	Tb	Cv	tb	Qb
1	0.0676	0.09104	36.7	0.0035	159	1918	1.33E-06
2	0.0707	0.06365	37.5	0.0010	44	1311	3.69E-07
3	0.0714	0.06600	37.7	0.0014	61	1463	5.11E-07
4	0.0734	0.09090	38.2	0.0023	105	1589	8.74E-07
5	0.0622	0.08373	35.2	0.0041	186	1777	1.55E-06

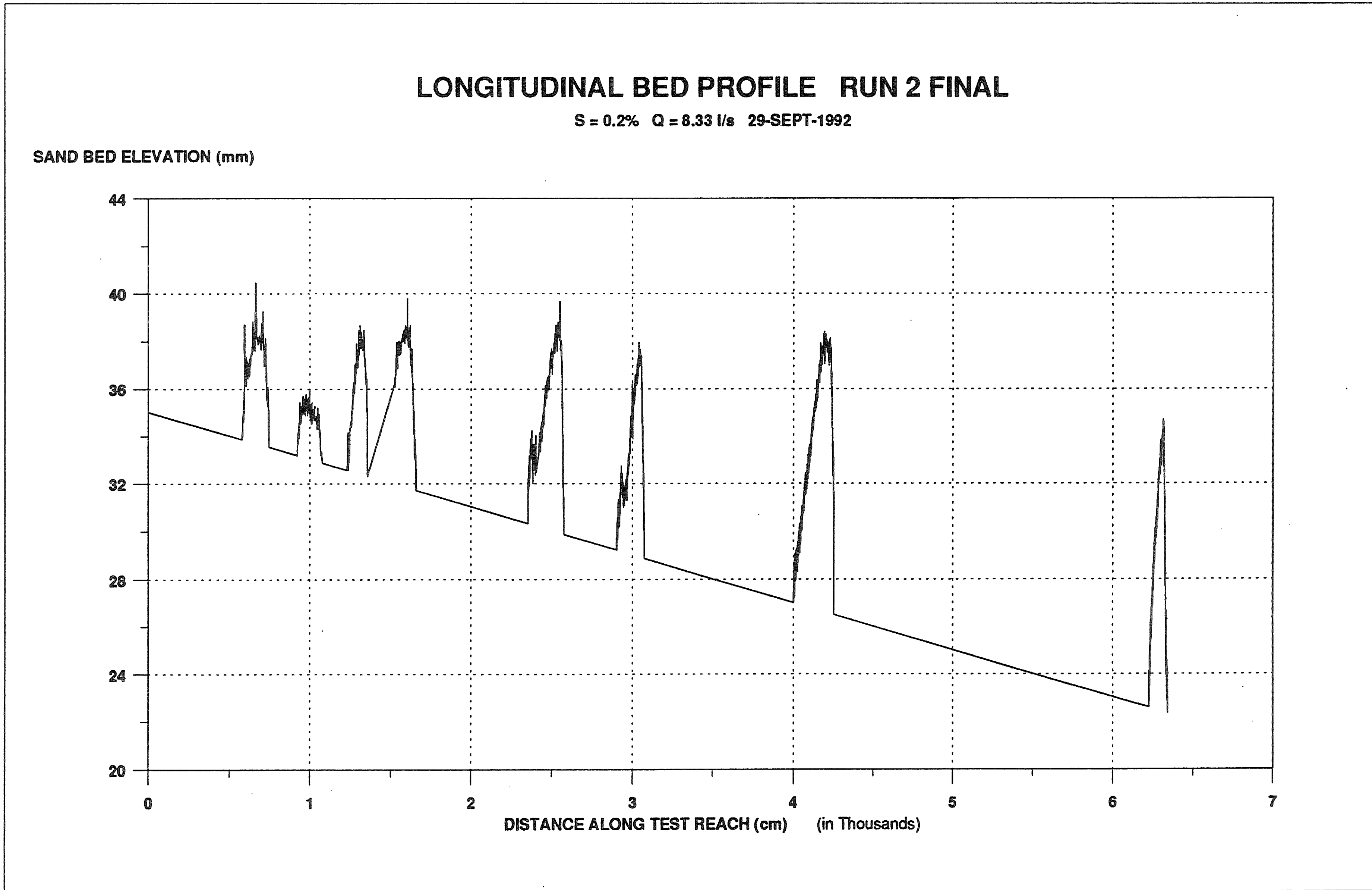
Run number	Unit sediment transport rate	Transport parameter	Bedform Height	dimensions Length	Bed friction coefficient	Equivalent bed roughness	Bed shear stress
	m3/s m		mm	mm		mm	N / m
	qb	Φb	H	L	fb	kb	Tb
1	1.21E-05	0.1111	11.4	330	0.04270	4.00	1.32622
2	8.25E-06	0.0759	6.6	180	0.02631	1.30	0.92730
3	9.20E-06	0.0847	13.6	215	0.02856	1.75	0.96150
4	9.99E-06	0.0920	20.0	450	0.03962	4.30	1.32380
5	1.12E-05	0.1029	22.8	600	0.03991	3.00	1.21975

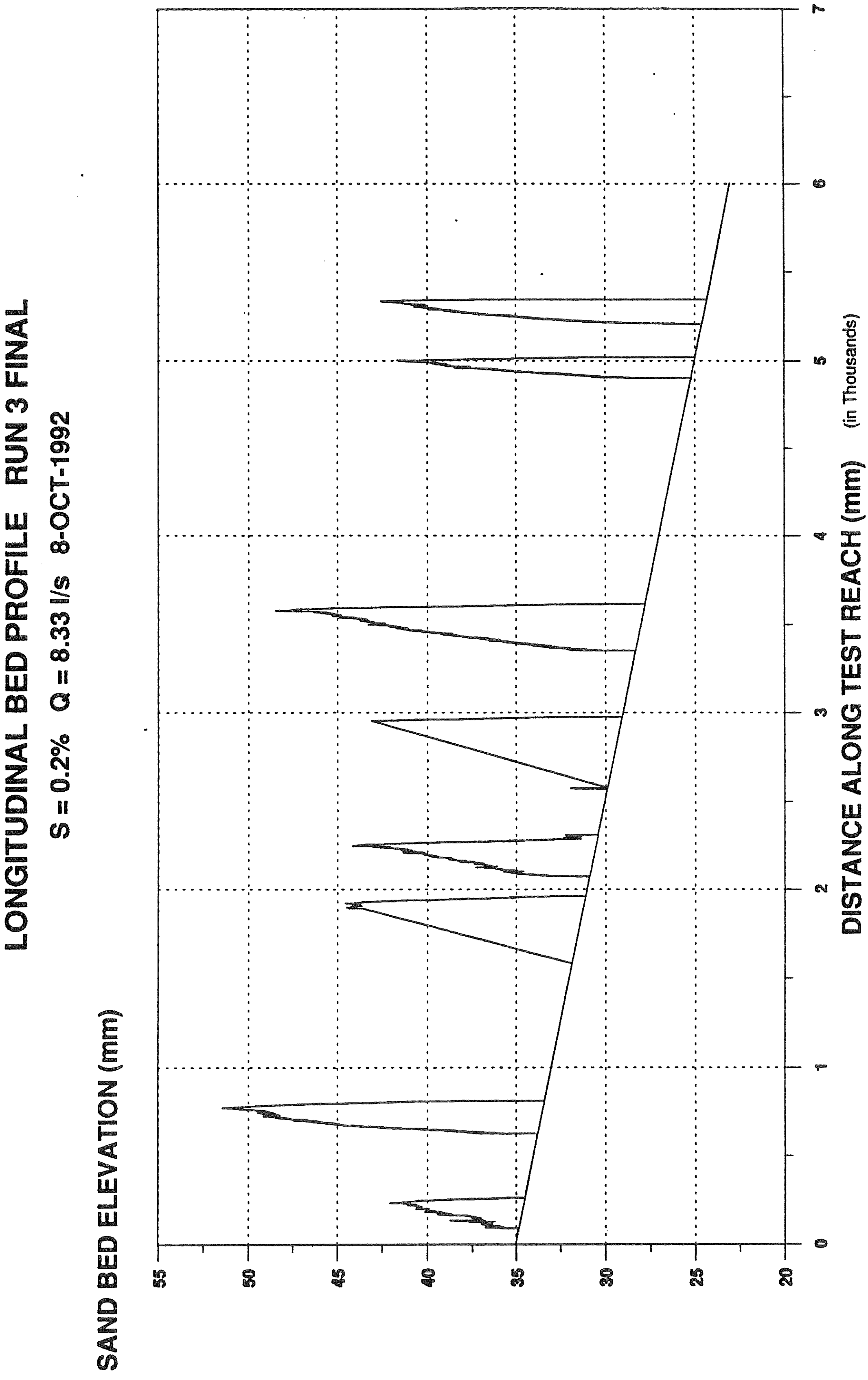
APPENDIX II

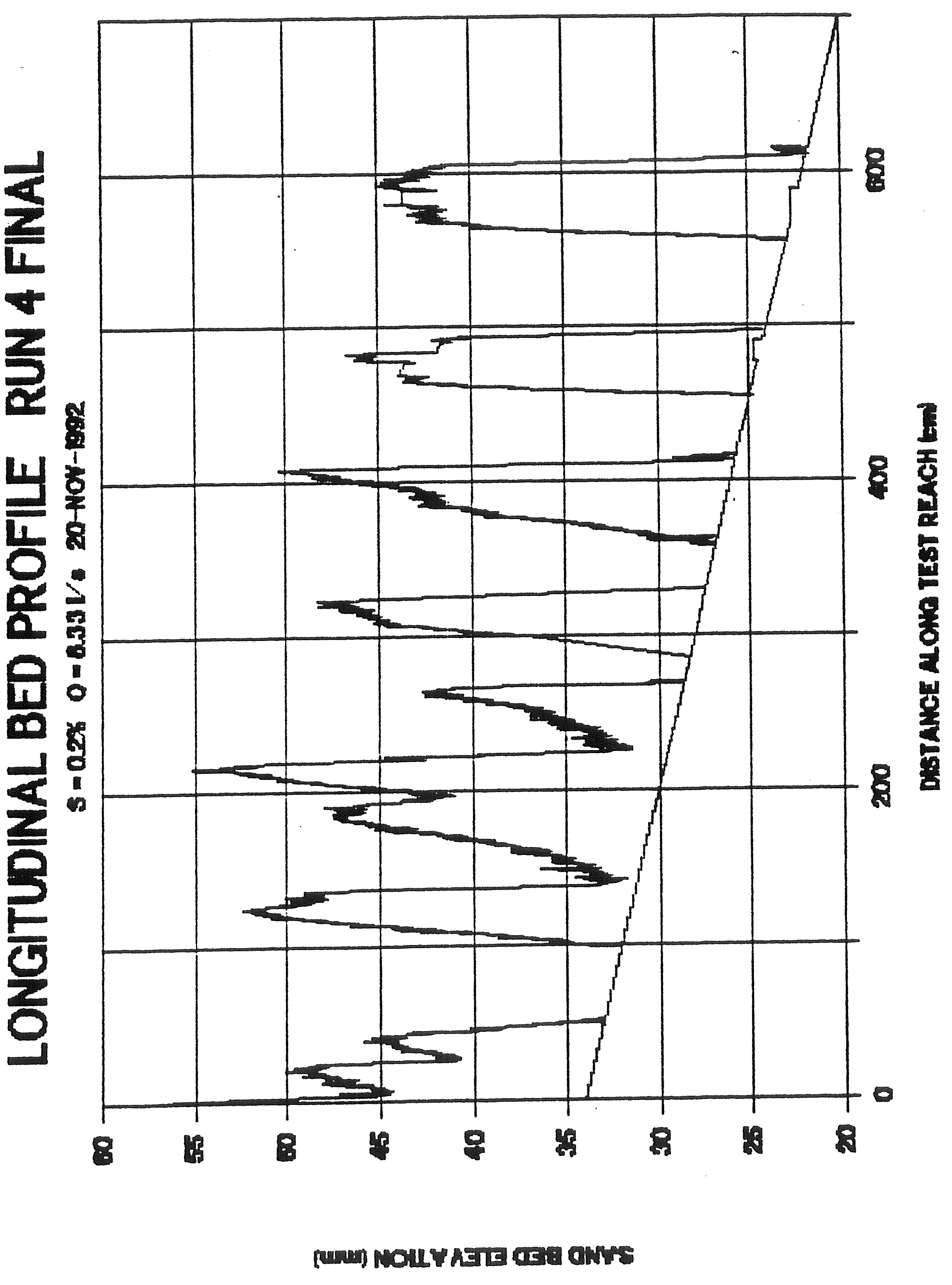
Longitudinal Bed Profiles

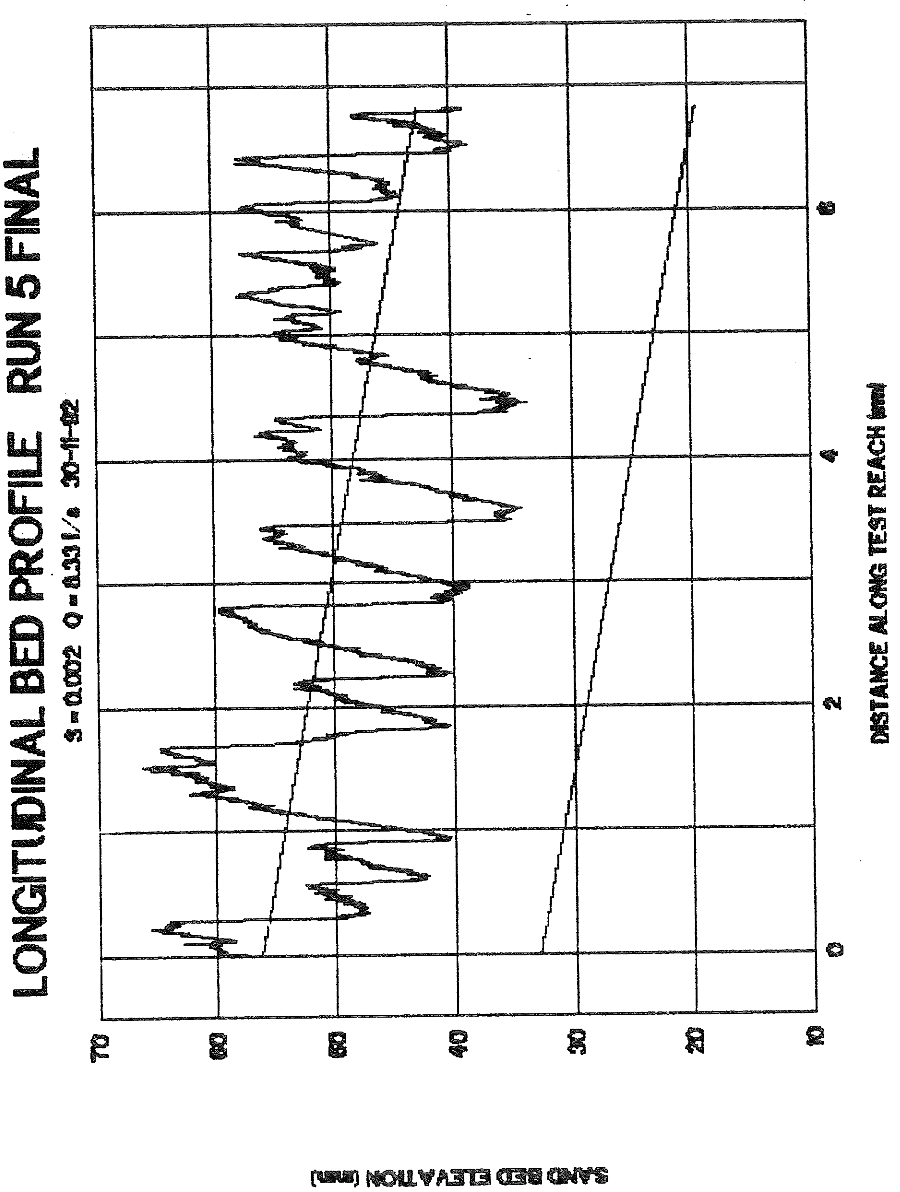
Runs 1-5


LONGITUDINAL BED PROFILE RUN 1 FINAL
DISTANCE ALONG TEST REACH (cm)
SAND BED ELEVATION (mm)
0
200
400
600
10
20
30
40
50
60
70


LONGITUDINAL BED PROFILE RUN 2 FINAL
S = 0.2% Q = 8.33 l/s 29-SEPT-1992
SAND BED ELEVATION (mm)
44
40
36
32
28
24
20
0
1
2
3
4
5
6
7
DISTANCE ALONG TEST REACH (cm) (in Thousands)


LONGITUDINAL BED PROFILE RUN 3 FINAL
S = 0.2% Q = 8.33 l/s 8-OCT-1992
SAND BED ELEVATION (mm)
DISTANCE ALONG TEST REACH (mm)
(in Thousands)
55
50
45
40
35
30
25
20
0
1
2
3
4
5
6
7

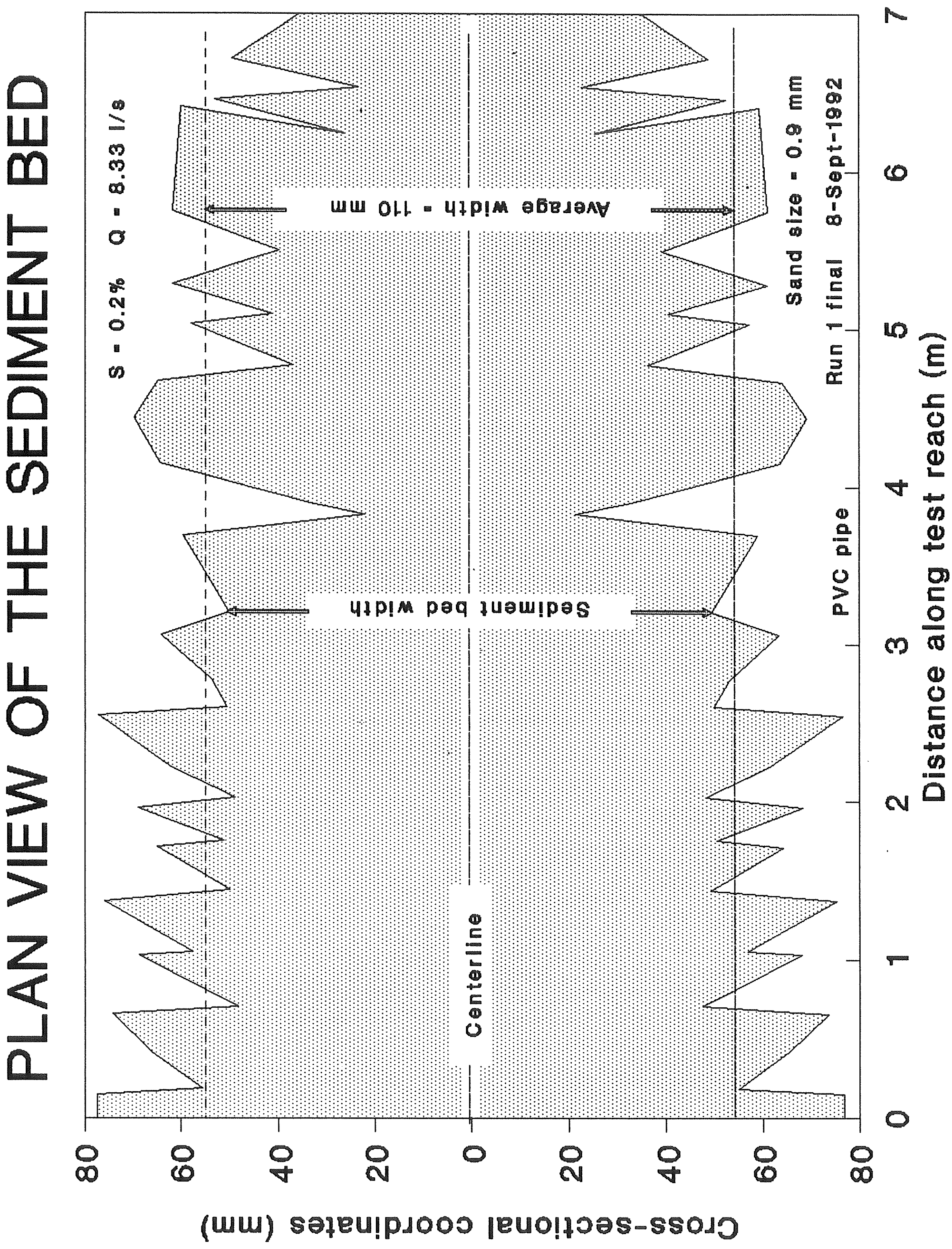

LONGITUDINAL BED PROFILE RUN 4 FINAL
S = 0.2% Q = 6.33 l/s 20-NOV-1992
DISTANCE ALONG TEST REACH (cm)
SAND BED ELEVATION (mm)
0
200
400
600
60
55
50
45
40
35
30
25
20


LONGITUDINAL BED PROFILE RUN 5 FINAL
S = 0.002 Q = 8.33 l/s 30-11-92
DISTANCE ALONG TEST REACH (m)
0
2
4
6
SAND BED ELEVATION (mm)
70
60
50
40
30
20
10

APPENDIX III

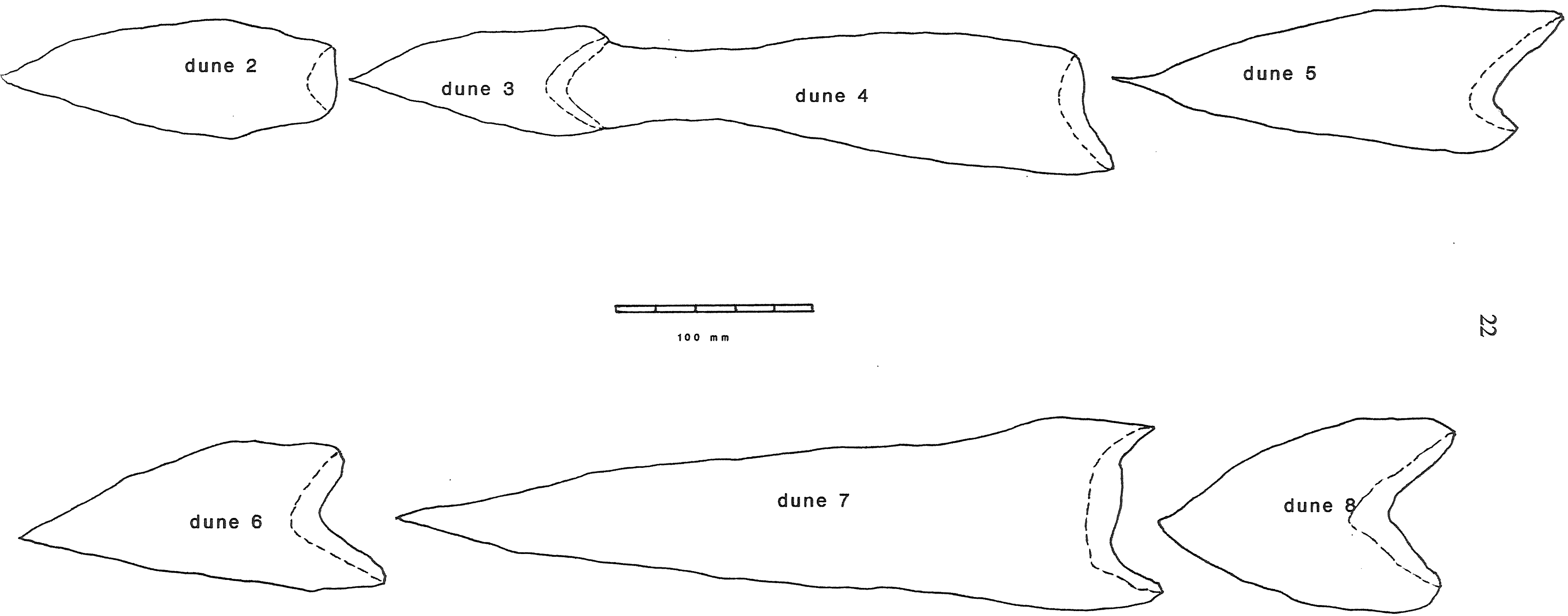
Plan Views of the Sediment Bed

Runs 1-3


PLAN VIEW OF THE SEDIMENT BED
S = 0.2%   Q = 8.33 l/s
Sand size = 0.9 mm
Run 1 final   8-Sept-1992
Average width = 110 mm
Sediment bed width
PVC pipe
Centerline
Distance along test reach (m)
Cross-sectional coordinates (mm)
0
1
2
3
4
5
6
7
80
60
40
20
0
20
40
60
80

PLAN VIEW OF THE ISOLATED DUNES

(See longitudinal bed profile for actual location) S = 0.2% Q = 8.33 l/s

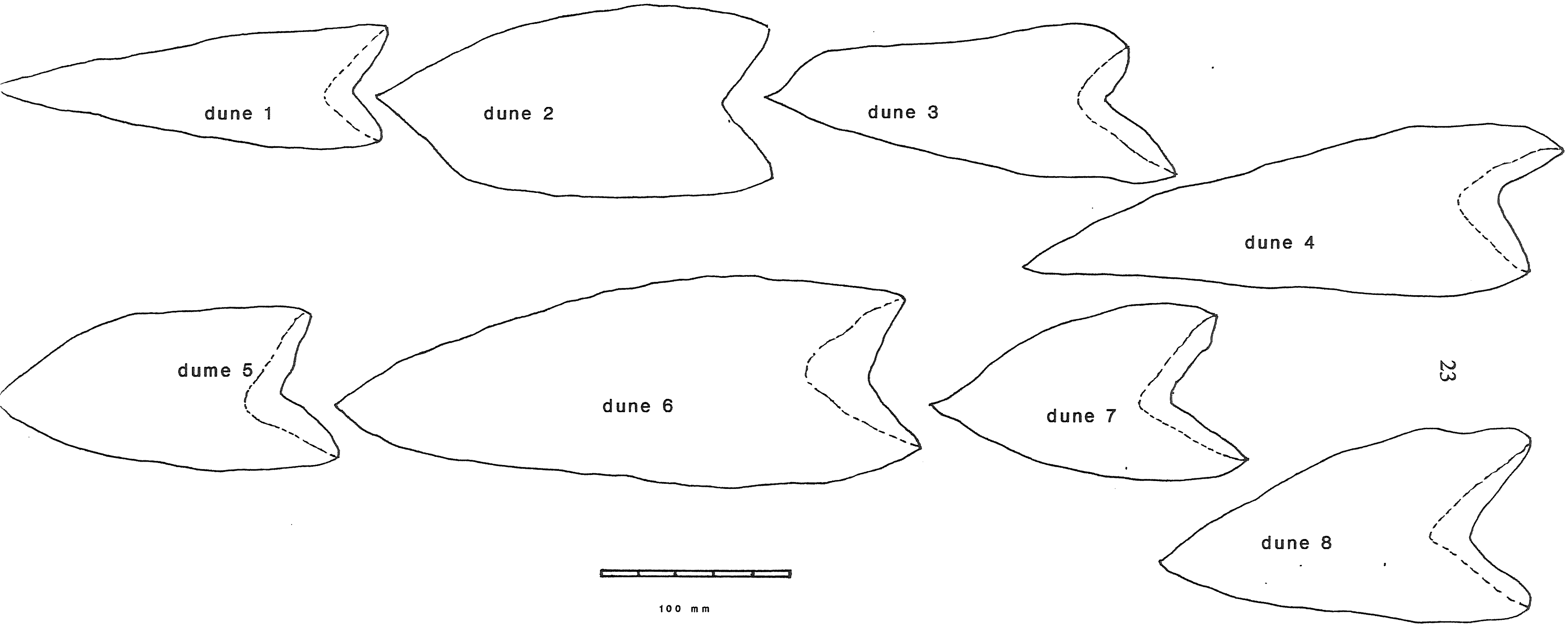


Sand size = 0.9 mm

Run 2 final 1-Oct-1992

PLAN VIEW OF THE ISOLATED DUNES

(See longitudinal bed profile for actual location) S = 0.2% Q = 8.33 l/s



Sand size = 0.9 mm

Run 3 final 12-Oct-1992

APPENDIX IV

Computation Programs

MANNINGS.FOR

```
C**************************************************
C***     THIS PROGRAM CALCULATES THE
C***     HYDRAULIC PARAMETERS OF A
C***     PART-FULL PIPE WITH A SEDIMENT
C***     BED USING THE MANNING FORMULA
C***     AND THE SEPARATION PROCEDURES
C***     OF BOTH EINSTEIN AND HORTON
C**************************************************
      REAL DIAM,S,PIPEN,GR,VI,RDENS
      REAL YWATSED,YSED,D50,DISCHQ
      REAL OPTION
      REAL VEL,FROUDE,REYNOLDS,EQUIVN,EINSTEIN,HORTON
      REAL SEDIMN,HYDRADB,THETAB,GRAINREY,COMPOSN
      CHARACTER*20 TFILE,YFILE
      WRITE(6,*) 'Name of input file'
      READ(5,'(A)') TFILE
      WRITE(6,*) 'Name of output file'
      READ(5,'(A)') YFILE
      OPEN (UNIT=2,FILE=TFILE,MODE='READ')
      OPEN (UNIT=8,FILE=YFILE,MODE='WRITE')
      READ(2,*) DIAM
      READ(2,*) S
      READ(2,*) VI
      READ(2,*) YWATSED
      READ(2,*) YSED
      READ(2,*) D50
      READ(2,*) DISCHQ
      PIPEN=.0103
      GR=9.81
      RDENS=2.65
C  OPTION: ZERO IF THE MANNING COEFFICIENT OF
C        THE BED IS TO BE COMPUTED. ONE IF
C        THE COMPOSITE DISCHARGE IS TO BE
C        COMPUTED
      OPTION=0.
C  TOTAL AREA, WATER WIDTH AND WATER DEPTH
      ANGWAT=2.*ACOS(1.-2.*YWATSED/DIAM)
      AWATSED=DIAM**2.*(ANGWAT-SIN(ANGWAT))/8.
      TWAT=DIAM*SIN(ANGWAT/2.)
      RWATSED=DIAM*(1.-SIN(ANGWAT)/ANGWAT)/4.
      PWATSED=AWATSED/RWATSED
      YWAT=YWATSED-YSED
C  AREA AND WIDTH OF THE SEDIMENT
      ANGSED=2.*ACOS(1.-2.*YSED/DIAM)
      ASED=DIAM**2.*(ANGSED-SIN(ANGSED))/8.
      TSED=DIAM*SIN(ANGSED/2.)
      RSED=DIAM*(1.-SIN(ANGSED)/ANGSED)/4.
```

```
      PSED=ASED/RSED
C   WALLS' AND BED'S WETTED PERIM.
C   HYDRAULIC AREA, TOTAL WETTED PERIM. AND HYD. RADIUS
      PW=PWATSED-PSED
      PB=TSED
      A=AWATSED-ASED
      P=PW+PB
      R=A/P
      AY=A/TWAT
      WRITE(8,*) DIAM,YSED,YWAT,YWATSED
      WRITE(8,*) ANGWAT,AWATSED,TWAT,ANGSED,ASED,TSED
      WRITE(8,*) PW,PB,A,P,R,AY,S
C   CALCULATION OF EITHER THE MANNING COEFFICIENT
C   OF THE BED OR THE COMPOSITE DISCHARGE
      IF(OPTION.EQ.0) THEN
        VEL=DISCHQ/A
        FROUDE=VEL/SQRT(GR*AY)
        REYNOLDS=VEL*R*4./VI
        EQUIVN=(R**(2./3.)*SQRT(S))/VEL
        EINSTEIN=SQRT((EQUIVN**2.*P-PIPEN**2.*PW)/PB)
        HORTON=((A-(PIPEN*VEL/SQRT(S))**1.5*PW)/PB)**
     *  (2./3.)*SQRT(S)/VEL
        HYDRADB=(A-(PW*(PIPEN*VEL/(S**0.5))**1.5))/PB
        THETAB=(HYDRADB*S)/((RDENS-1.)*D50)
        GRAINREY=(SQRT(GR*HYDRADB*S))*D50/VI
        WRITE(8,*) VEL,FROUDE,REYNOLDS,EQUIVN
        WRITE(8,*) EINSTEIN,HORTON,HYDRADB,THETAB,GRAINREY
      ELSEIF(OPTION.EQ.1) THEN
        COMPOSN=SQRT((PIPEN**2.*PW+SEDIMN**2.*PB)/P)
        DISCHQ=A*(R**(2./3.))*SQRT(S)/COMPOSN
        DISCHQ=DISCHQ*1000.
        WRITE(6,1013)COMPOSN,DISCHQ
        WRITE(8,*) COMPOSN,DISCHQ
      ENDIF
      CLOSE (2)
      CLOSE (8)
      STOP
      END
```

SEDIMENT.FOR

```
C      BERÄKNING AV FRIKTIONSFAKTORER
C      MED COLEBROOK-WHITE & DARCY-WEISBACH
C  1986-08-06 DENNA VERSION ANVÄND FÖR KORNING-KULFORSOK
C FÖR KURVPASSNING TILL ETT KS BASERAT PÅ .15MM+ SAMT
C
C TESTKÖRD MOT KÖRNINGEN 860318 8.56.10 OK
C       OBS  FAKTOR I C-W ÄNDRAD 2-2.18
C       BROOKS  F  K   Q
C       ACKERS  F  K   Q
C
C        GE ERFORDERLIGA DATA: VATTENDJUP(YVUS)
C                              SEDIMENTDJUP(YSED)
C                              K-VÄRDE RÖR(KR)
C                              DIAMETER(DIAM)
C                              LUTNING(S)
      REAL DIAM,YVUS,YSED,S,VI
      REAL YVDJ,YVUSD
      REAL VINKVA,AVUS,TVAT,VINKSE
      REAL ASED,TSED,PR,PS
      REAL P,R,A
      REAL KR,KS,K1,K2
      REAL RR,RS,FR,FS
      REAL F1,Q1,F2,Q2
      CHARACTER*20 SFILE,XFILE
      WRITE(6,*) 'Name of input file'
      READ(5,'(A)') SFILE
      WRITE(6,*) 'Name of output file'
      READ(5,'(A)') XFILE
      OPEN (UNIT=2,FILE=SFILE,MODE='READ')
      OPEN (UNIT=8,FILE=XFILE,MODE='WRITE')
      READ(2,*) DIAM,YVUS,YSED,S,VI
      KR=.00015
      GR=9.81
      EL=.4342945
      YVUS=YVUS-.001
      DO 998 IL=1,2
      YVUS=YVUS+.001
      KS=0.00004
C
C  PERIMETER(PVUS),AREA(AVUS) O. VATTENLINJEBREDD(TVAT) FÖR SEKT.
C  U. SED.
C
      VINKVA=2*ACOS(1.-2.*YVUS/DIAM)
      AVUS=DIAM**2.*(VINKVA-SIN(VINKVA))/8.
      TVAT=DIAM*SIN(VINKVA/2.)
      RVUS=DIAM*(1-SIN(VINKVA)/VINKVA)/4.
      PVUS=AVUS/RVUS
```

```
      YVUSD=YVUS/DIAM
      YVDJ=YVUS-YSED
C
C  PERIMETER(PSED),AREA(ASED) O. SEDIMENTETS BREDD VID YTAN(TSED)
C
      VINKSE=2*ACOS(1.-2.*YSED/DIAM)
      ASED=DIAM**2.*(VINKSE-SIN(VINKSE))/8.
      TSED=DIAM*SIN(VINKSE/2.)
      RSED=DIAM*(1-SIN(VINKSE)/VINKSE)/4.
      PSED=ASED/RSED
C
C  RÖRPERIMETER(PR),SEDIMENTPERIMETER(PS) O.AREA(A)
C
      PR=PVUS-PSED
      PS=TSED
      A=AVUS-ASED
      P=PR+PS
      R=A/P
C
      WRITE(8,*) DIAM,YSED,YVDJ,YVUS,YVUSD
      WRITE(8,*) VINKVA,AVUS,TVAT,VINKSE
      WRITE(8,*) ASED,TSED,PR,PS
      WRITE(8,*) P,R,A,S
C
      DO 999 I=1,26
      KS=KS+.00001
      IF(I.EQ.1) KS=0.00005
      IF(I.EQ.2) KS=0.00006
      RRNEW=R
      ITER=0
C   NEWTON-RAPHSON
   10 RR=RRNEW
      RS=(A-PR*RR)/PS
      C11=KR/4./RR/3.71
      C21=KS/4./RS/3.71
      C12=2.51*VI/RR**1.5/SQRT(128*GR*S)
      C22=2.51*VI/RS**1.5/SQRT(128*GR*S)
      C1=C11+C12
      C2=C21+C22
C
      FR=SQRT(RS)*ALOG10(C2)-SQRT(RR)*ALOG10(C1)
C
      DFRDR=.5/SQRT(RS)*ALOG10(C2)*(-PR/PS)+
     *SQRT(RS)*EL/C2*(-C21/RS-1.5*C22/RS)*(-PR/PS)-
     *0.5/SQRT(RR)*ALOG10(C1)-
     *SQRT(RR)*EL/C1*(-C11/RR-1.5*C12/RR)
C
      RRNEW=RR-FR/DFRDR
      IF(RRNEW.GT.A/PR)RRNEW=A/PR-.0001
      IF(RRNEW.LT.0.)RRNEW=.0001
```

```
      DIFF=ABS(RR-RRNEW)/R
      ITER=ITER+1
      IF(DIFF.LT.0.00001) GO TO 100
      IF(ITER.LT.100) GO TO 10
      WRITE(6,*) ITER
  100 CONTINUE
      RS=(A-PR*RRNEW)/PS
      C11=KR/4./RRNEW/3.71
      C21=KS/4./RS/3.71
      C12=2.51*VI/RRNEW**1.5/SQRT(128*GR*S)
      C22=2.51*VI/RS**1.5/SQRT(128*GR*S)
      FR=1/(4.0000*(ALOG10(C11+C12))**2)
      FS=1/(4.0000*(ALOG10(C21+C22))**2)
C BROOKS  F (F1)  K (K1)  Q (Q1)
      F1=(FR*PR+FS*PS)/P
      Q1=A*SQRT(8*GR*R*S/F1)
      C22=2.51*VI/R**1.5/SQRT(128*GR*S)
      C3=-1/SQRT(F1)/2.00
      K1=14.84*R*(10.**C3-C22)
C ACKERS  F (F2)  K (K2)  Q (Q2)
      K2=KR*PR/P+KS*PS/P
      C21=K2/4./R/3.71
      F2=1/(4.0000*(ALOG10(C21+C22))**2)
      Q2=A*SQRT(8*GR*R*S/F2)
C
      WRITE(8,*) KR,KS,RR,RS,FR,FS
      WRITE(8,*) F1,K1,Q1
      WRITE(8,*) F2,K2,Q2
  999 CONTINUE
  998 CONTINUE
      CLOSE (2)
      CLOSE (8)
      STOP
      END
```

FREDSØES.FOR

```
C*********************************************************************
C*** THIS PROGRAM CALCULATES THE GEOMETRY OF DUNES USING
C*** THE FREDSØE METHOD BASED ON THE RELATIONSHIP BETWEEN
C*** DUNE HEIGHT AND WATER DEPTH:
C***
C***  (H/D)/(1-H/2D)=(THETA'-THETA CRITICAL)/(3*THETA')
C***
C*** AND THE RELATIONSHIP BETWEEN DUNE HEIGHT AND DUNE
C*** LENGTH:
C***
C***  L=H/(0.06-146(0.15+THETA CRITICAL-THETA)**4.26)
C***  FOR THETA LESS THAN 0.15+THETA CRITICAL
C***
C***  L=H/0.06 FOR THETA GREATER THAN 0.15+THETA CRITICAL
C***
C***   REFERENCE: ASCE HYD, VOL. 108, NO. 8, AUG. 1982
C***
C***   INPUT DATA:     WATER DEPTH (YDEPTH)
C***                 SAND DIAMETER (SDIAM)
C***        ACCELERATION OF GRAVITY (G)
C***                      SLOPE (S)
C***               RELATIVE DENSITY (RDENS)
C***                 CRITICAL THETA (THETAC)
C***                  FLOW VELOCITY (VEL)
C***            BED HYDRAULIC RADIUS (RADB)
C*********************************************************************
C
      REAL YDEPTH,SDIAM,S,THETAC,VEL,RADB
      REAL THETAT,THETAE,BLTHK,UFMK,DUNH,DUNL
      CHARACTER*20 RFILE,WFILE
      WRITE(6,*) 'Name of input file'
      READ(5,'(A)') RFILE
      WRITE(6,*) 'Name of output file'
      READ(5,'(A)') WFILE
      OPEN (UNIT=2,FILE=RFILE,MODE='READ')
      OPEN (UNIT=8,FILE=WFILE,MODE='WRITE')
      READ(2,*) YDEPTH,SDIAM
      READ(2,*) S,THETAC
      READ(2,*) VEL,RADB
      G=9.81
      RDENS=2.65
C
C------------------------------------------------------------
C---    VARIABLES:     TOTAL THETA (THETA)
C---      BOUNDARY LAYER THICKNESS (BLTHK)
C---         SHEAR STRESS VELOCITY (UFMK)
C---               EFFECTIVE THETA (THETAE)
```

```
C---               DUNE HEIGHT (DUNH)
C---               DUNE LENGTH (DUNL)
C---------------------------------------------------------
C
      THETAT=(RADB*S)/((RDENS-1.0)*SDIAM)
      THETAE=0.4*THETAT**2+0.06
      BLTHK=YDEPTH*(0.4*THETAT+0.06/THETAT)
      UFMK=VEL/(2.5*(ALOG((12.*BLTHK)/(SDIAM))-1.0))
      AUX=THETAE
      THETAE=UFMK**2/((RDENS-1.0)*G*SDIAM)
      ATEST=ABS(AUX-THETAE)
      IF(ATEST.LT..0001)GO TO 100
      GO TO 10
   10 BLTHK=YDEPTH*THETAE/THETAT
      UFMK=VEL/(2.5*(ALOG((12.*BLTHK)/(SDIAM))-1.0))
      AUX=THETAE
      THETAE=UFMK**2/((RDENS-1.0)*G*SDIAM)
      ATEST=ABS(AUX-THETAE)
      IF(ATEST.LT..0001)GO TO 100
      GO TO 10
  100 CONTINUE
      DIFF=THETAE-THETAC
      DUNH=2.0*YDEPTH*DIFF/(7.0*THETAE-THETAC)
      CONTINUE
      IF(THETAT.LT.0.15+THETAC)GO TO 200
      GO TO 20
   20 DUNL=DUNH/0.06
      GO TO 300
  200 DUNL=DUNH/(0.06-146.0*(0.15+THETAC-THETAT)**4.26)
      GO TO 300
      WRITE(8,*) THETAT,THETAE
      WRITE(8,*) UFMK,BLTHK
      WRITE(8,*) DUNH,DUNL
      CLOSE (2)
      CLOSE (8)
      STOP
      END
```

WORKSHEET PROGRAM "LOTUSEDIM"

Pipe slope, S	given value
Sand size, D50 (m)	given value
Sediment thickness, t (m)	given value
Sediment width, Pb (m)	given value
Flow discharge, Q (m3/s)	given value
Flow depth, Y (m)	(D11-D7)
Total depth, y+t (m)	given value
Mean transport rate, mtr (g/min)	given value
Area water+sediment, At (m2)	($R$22^2/8)*((2*@ACOS(1-2*D11/$R$22))-@SIN(2*(@ACOS(1-2*D11/$R$22))))
Area sediment, As (m2)	($R$22^2/8)*(2*@ACOS(1-2*D7/$R$22)-@SIN(2*(@ACOS(1-2*D7/$R$22))))
Hydraulic area, A (m2)	(D13-D14)
Walls wetted perimeter, Pw (m)	(2*($R$22/2)*(@ACOS(1-2*D11/$R$22)-@ACOS(1-2*D7/$R$22)))
Bed wetted perimeter,Pb (m)	($R$22*@SIN(2*@ACOS(1-2*D7/$R$22)/2))
Total wetted perimeter, P (m)	(D16+D17)
Water width, B (m)	($R$22*@SIN(2*@ACOS(1-2*D11/$R$22)/2))
Hydraulic radius, R (m)	(D15/D18)
Mean depth, M (m)	(D15/D19)
Flow velocity, V (m/s)	(D9/D15)
Froude Number, Fr	(D22/@SQRT(9.81*D21))
Kinematic viscosity, v (m2/s)	given value
Reynolds number, Re	(D22*D20*4/D24)
Equiv. Manning's coeff., ne	(D20^(2/3)*@SQRT(D5)/D22)
Einstein's Bed Manning's coeff., nbE	(@SQRT((D26^2*D18-$U$22^2*D16)/D17))
Horton's Bed Manning's coeff., nbH	(((D15-($U$22*D22/@SQRT(D5))^1.5*D16)/D17)^(2/3)*@SQRT(D5)/D22)
Bed hydraulic radius, Rb (m)	((D15-(D16*($U$22*D22/(D5^0.5))^1.5))/D17)
Mobility number, Ob	((D29*D5)/(1.65*D6))
Particle Reynolds number, Re*	((@SQRT(9.81*D29*D5))*D6/D24)
Sediment transport rate, Tb (kg/s)	(D12/60000)
Volumetric sedim. conc., Cv (ppm)	((D12/D9)*(1/159))
Unit sed. tran. rate, tb (g/min m)	(D12/D8)
Sediment transport rate, Qb (m3/s)	(D36*D8)
Unit sed. tran. rate, qb (m3/s m)	(D34/159000000)
Transport parameter, Ob	(D34/(159000000*@SQRT(1.65*9.81*D6^3)))
Dune height, H (mm)	given value
Dune length, L (mm)	given value

Grain friction coeff., fb′	(8*(5.75*@LOG((12*D29)/(2.5*D6)))^-2)
Dune friction coeff., fb′′	(D42-D40)
Bed friction coeff., fb	computed from program "SEDIMENT.FOR"
Grain roughness, kb′ (m)	(D6*2.5)
Dune roughness, kb′′ (m)	(D45-D43)
Bed roughness, kb (m)	computed from program "SEDIMENT.FOR"
Grain shear stress, Thaub′ (N/m2)	(D57*1.65*9.81*D6*1000)
Dune shear stress, Thaub′′ (N/m2)	(D48-D46)
Bed shear stress, Thaub (N/m2)	(1000*9.81*D29*D5)
Grain shear veloc. 1, u*1 (m/s)	(D22/(5.75*@LOG(((10^($BJ$22/5.75))*D29)/(2.5*D50))))
Auxiliary roughness, k′ (mm)	(D6*2)
Log. factor 1	(@LOG((D49*D50)/D24))
Roughness function 1, Bs1	((5.5+(2.5*D51))*(@EXP(-0.217*(D51^2)))+8.5*(1-(@EXP(-0.217*(D51^2)))))
Grain shear veloc. 2, u*2 (m/s)	(D22/(5.75*@LOG(((10^(D52/5.75))*D29)/(2.5*D50))))
Log. factor 2	(@LOG((D53*D50)/D24))
Roughness function 2, Bs2	((5.5+(2.5*D54))*(@EXP(-0.217*(D54^2)))+8.5*(1-(@EXP(-0.217*(D54^2)))))
Grain shear veloc. 3, u*3 (m/s)	(D22/(5.75*@LOG(((10^(D55/5.75))*D29)/(2.5*D50))))
Grain mobility number, Ob′ (Lau′s method)	((D56^2)/(1.65*9.81*D6))

CHALMERS TEKNISKA HÖGSKOLA
Institutionen för vattenbyggnad

Report Series B

B:1 Bergdahl, L.: Beräkning av vågkrafter. (Ersatts med 1979:07) 1977.

B:2 Arnell, V.: Studier av amerikansk dagvattenteknik. 1977.

B:3 Sellgren, A.: Hydraulic Hoisting of Crushed Ores. A feasibility study and pilot-- plant investigation on coarse iron ore transportation by centrifugal pumps. 1977.

B:4 Ringesten, B.: Energi ur havsströmmar. 1977.

B:5 Sjöberg, A., Asp, T.: Brukar-anvisning för ROUTE-S. En matematisk modell för beräkning av icke-stationära flöden i floder och kanaler vid strömmande tillstånd. 1977.

B:6 Annual Report 1976/77. 1977.

B:7 Bergdahl, L., Wernersson, L.: Calculated and Expected Thermal Ice Pressures in Five Swedish Lakes. 1977.

B:8 Göransson, C-G., Svensson, T.: Drogue Tracking - Measuring Principles and Data Handling. 1977.

B:9 Göransson, C-G.: Mathematical Model of Sewage Discharge into confined, stratified Basins - Especially Fjords. 1977.

B:10 Arnell, V., Lyngfelt, S.: Beräkning av dagvattenavrinning från urbana områden. 1978.

B:11 Arnell, V.: Analysis of Rainfall Data for Use in Design of Storm Sewer Systems. 1978.

B:12 Sjöberg, A.: On Models to be used in Sweden for Detailed Design and Analysis of Storm Drainage Systems. 1978.

B:13 Lyngfelt, S.: An Analysis of Parameters in a Kinematic Wave Model of Overland Flow in Urban Areas. 1978.

B:14 Sjöberg, A., Lundgren, J., Asp, T., Melin, H.: Manual för ILLUDAS (Version S2). Ett datorprogram för dimensionering och analys av dagvattensystem. 1979.

B:15 Annual Report 1978/79. 1979.

B:16 Nilsdal, J-A., Sjöberg, A.: Dimensionerande regn vid höga vattenstånd i Göta älv. 1979.

B:17 Stöllman, L-E.: Närkes Svartå. Hydrologisk inventering. 1979.

B:18 Svensson, T.: Tracer Measurements of Mixing in the Deep Water of a Small, Stratified Sill Fjord. 1979.

B:19 Svensson, T., Degerman, E., Jansson, B.,Westerlund, S.: Energiutvinning ur sjö- och havssediment. En förstudie. R76:1980. 1979.

B:20 Annual Report 1979. 1980.

B:21 Stöllman, L-E.: Närkes Svartå. Inventering av vattentillgång och vattenanvändning. 1980.

Report Series B

B:22 Häggström, S., Sjöberg, A.: Effects of Distortion in Physical Models of Cooling Water Discharge. 1979.

B:23 Sellgren, A.: A Model for Calculating the Pumping Cost of Industrial Slurries. 1981.

B:24 Lindahl, J.: Rörelseekvationen för en kabel. 1981.

B:25 Bergdahl, L., Olsson, G.: Konstruktioner i havet. Vågkrafter-rörelser. En inventering av datorprogram. 1981.

B:26 Annual Report 1980. 1981.

B:27 Nilsdal, J-A.: Teknisk-ekonomisk dimensionering av avloppsledningar. En litteraturstudie om datormodeller. 1981.

B:28 Sjöberg, A.: The Sewer Network Models DAGVL-A and DAGVL-DIFF. 1981.

B:29 Moberg, G.: Anläggningar för oljeutvinning till havs. Konstruktionstyper, dimensioneringskriterier och positioneringssystem. 1981.

B:30 Sjöberg, A., Bergdahl, L.: Förankringar och förankringskrafter. 1981.

B:31 Häggström, S., Melin, H.: Användning av simuleringsmodellen MITSIM vid vattenresursplanering för Svartån. 1982.

B:32 Bydén, S., Nielsen, B.: Närkes Svartå. Vattenöversikt för Laxå kommun. 1982.

B:33 Sjöberg, A.: On the stability of gradually varied flow in sewers. 1982.

B:34 Bydén, S., Nyberg, E.: Närkes Svartå. Undersökning av grundvattenkvalitet i Laxå kommun. 1982.

B:35 Sjöberg, A., Mårtensson, N.: Regnenveloppmetoden. En analys av metodens tillämplighet för dimensionering av ett 2-års perkolationsmagasin. 1982.

B:36 Svensson, T., Sörman, L-O.: Värmeupptagning med bottenförlagda kylslangar i stillastående vatten. Laboratorieförsök. 1982.

B:37 Mattsson, A.: Koltransporter och kolhantering. Lagring i terminaler och hos storförbrukare. (Delrapport). 1983.

B:38 Strandner, H.: Ett datorprogram för sammankoppling av ILLUDAS och DAGVL-DIFF. 1983.

B:39 Svensson, T., Sörman, L-O.: Värmeupptagning med bottenförlagda slangar i rinnande vatten. Laboratorieförsök. 1983.

B:40 Mattsson, A.: Koltransporter och kolhantering. Lagring i terminaler och hos storförbrukare. Kostnader. Delrapport 2. 1983.

B:41 Häggström, S., Melin, H.: Närkes Svartå. Simuleringsmodellen MITSIM för kvantitativ analys i vattenresursplanering. 1983.

B:42 Hård, S.: Seminarium om miljöeffekter vid naturvärmesystem. Dokumentation sammanställd av S. Hård, VIAK AB. BFR-R60:1984. 1983.

B:43 Lindahl, J.: Manual för MODEX-MODIM. Ett datorprogram för simulering av dynamiska förlopp i förankringskablar. 1983.

Report Series B

B:44 Activity Report. 1984.

B:45 Sjöberg, A.: DAGVL-DIFF. Beräkning av icke-stationära flödesförlopp i helt eller delvis fyllda avloppssystem, tunnlar och kanaler. 1984.

B:46 Bergdahl, L., Melin, H.: WAVE FIELD. Manual till ett program för beräkning av ytvattenvågor. 1985.

B:47 Lyngfelt, S.: Manual för dagvattenmodellen CURE. 1985.

B:48 Perrusquía, G., Lyngfelt, S., Sjöberg, A.: Flödeskapacitet hos avloppsledningar delvis fyllda med sediment. En inledande experimentell och teoretisk studie. 1986.

B:49 Lindahl, J., Bergdahl, L.: MODEX-MODIM. User's Manual. 1987.

B:50 Mårtensson, N.: Dynamic Analysis of a Moored Wave Energy Buoy. 1988.

B:51 Lyngfelt, S.: Styrning av flöden i avloppssystem. Begrepp - Funktion - FoU-Behov. 1989.

B:52 Perrusquía, G.: Sediment in Sewers. Research Leaves in England. 1990.

B:53 Lyngfelt, S.: Simulering av ytavrinning i dagvattensystem. 1991.

B:54 Lyngfelt, S.: Two papers on urban runoff modelling: Base catchment modelling in urban runoff simulation and An improved rational method for urban runoff application. 1991

B:55 Perrusquía, G.: Sediment transport in pipe channels. Postdoctoral experimental studies. December 1991 - April 1992.

B:56 Nordisk möte om bölgeenergi. Hanstholm 8-9 maj 1992.

B:57 Gustavo Perrusquía: An experimental study from flume to stream traction in pipe channels. 1993.

B:58 Activity report 1992.