U.S. Department of the Interior
U.S. Geological Survey

VELOCITY AND STAGE DATA COLLECTED IN A LABORATORY FLUME FOR WATER-SURFACE SLOPE DETERMINATION USING A PIPE MANOMETER

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By Jonathan K. Lee, Hannah M. Visser, Harry L. Jenter, and Michael P. Duff

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ABSTRACT

U.S. Geological Survey (USGS) hydrologists and ecologists are conducting studies to quantify vegetative flow resistance in order to improve numerical models of surface-water flow in the Florida Everglades. Water-surface slope is perhaps the most difficult of the flow resistance parameters to measure in the Everglades due to the very low gradients of the topography and flow. In an effort to measure these very small slopes, a unique pipe manometer was developed for the local measurement of water-surface slopes on the order of 1 centimeter per kilometer (cm/km).

According to theory, a very precise measurement of centerline velocity obtained inside the pipe manometer should serve as a unique proxy for water-surface slope in the direction of the pipe axis. In order to confirm this theoretical relationship and calibrate the pipe manometer, water-surface elevation and pipe centerline velocity data were simultaneously measured in a set of experiments carried out in the tilting flume at the USGS Hydraulic Laboratory Facility at Stennis Space Center, Mississippi. A description of the instrumentation and methods used to evaluate this technique for measuring water-surface slope as well as a summary of the entire data set is presented.

INTRODUCTION

Restoration and management decisions about the South Florida ecosystem are based in part on the results of simulations made with numerical surface-water models. Model results are sensitive to the expressions used for vegetative flow resistance and to the values of the coefficients that appear in these expressions. U.S. Geological Survey (USGS) hydrologists and ecologists are conducting studies to quantify vegetative flow resistance in order to improve numerical models of surface-water flow in the Florida Everglades. For use in the models, vegetative flow resistance must be expressed in terms of measurable parameters that describe the flow and the vegetation. These parameters include the flow velocity through the vegetation, the water depth, the water-surface slope, and the type, physical characteristics, and density of the vegetation.

Water-surface slope is perhaps the most difficult of the flow resistance parameters to measure in the Everglades due to the very low gradients of the topography and flow. Conventional surveying methods do not provide the level of precision needed to accurately determine water-surface slopes in such wetland environments. In an effort to measure these very small slopes, a unique pipe manometer (fig. 1) was developed for the local measurement of water-surface slopes on the order of 1 centimeter per kilometer (cm/km).

According to theory (Streeter and Wylie, 1979), for laminar flow conditions, the centerline velocity of fluid in a pipe is a function only of the pipe geometry, the fluid viscosity, and the difference in water-surface elevation over the length of the pipe. Therefore, a very precise measurement of pipe centerline velocity obtained inside the pipe manometer should serve as a

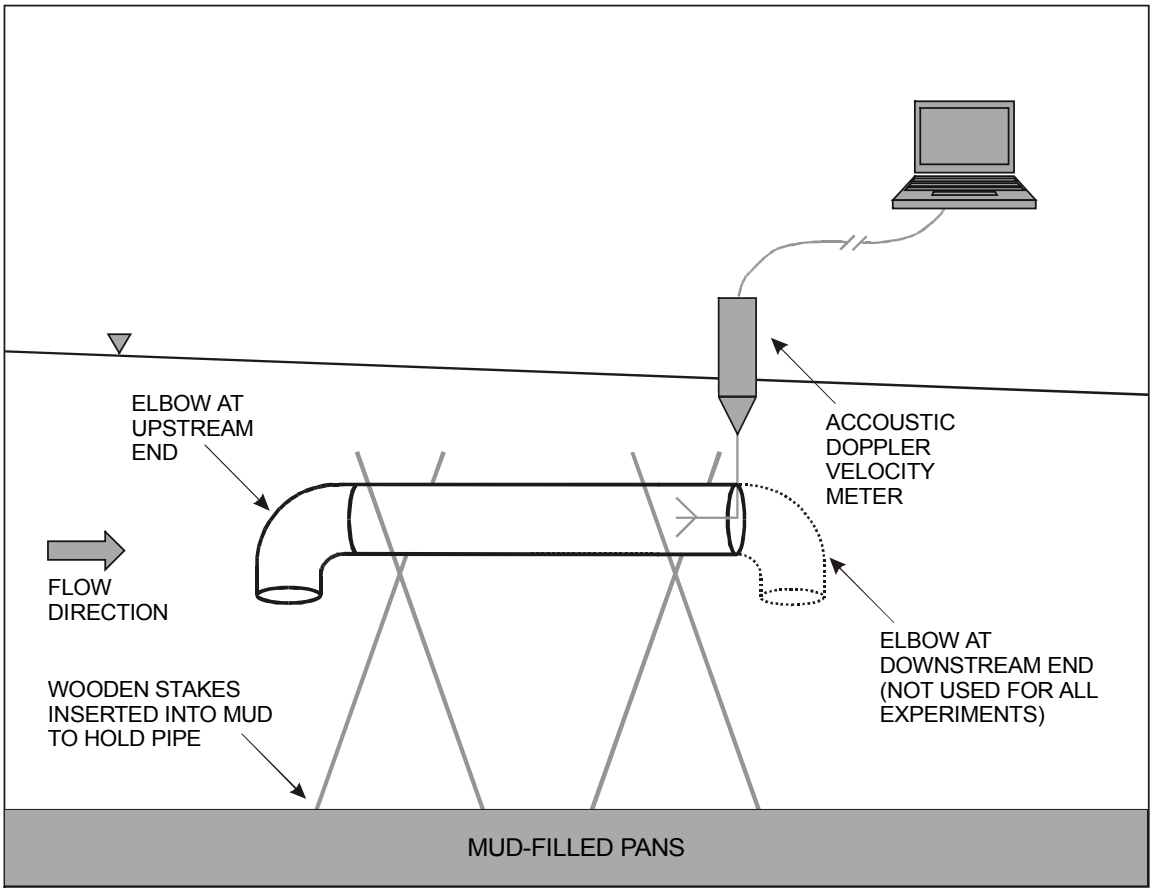

Figure 1. Laboratory configuration of pipe manometer. Not drawn to scale.

unique proxy for water-surface slope in the direction of the pipe axis. In order to confirm this theoretical relationship and calibrate the pipe manometer, water-surface elevation and pipe centerline velocity data were simultaneously measured in a set of experiments carried out in the tilting flume at the USGS Hydraulic Laboratory Facility at Stennis Space Center, Mississippi. The remainder of this document contains a description of the instrumentation and methods used to evaluate this technique for measuring water-surface slope as well as a summary of the entire data set.

The authors thank Kirk Thibodeaux and James Dubuisson for their skill and professionalism in the collection of the data described herein. This work was funded in part through the U.S. Geological Survey's Place-Based Study Program and in part through the Critical Ecosystems Study Initiative administered by the National Park Service.

STUDY METHODS

Flume Description

Pipe calibration experiments were conducted in a 60-m-long, 2-m-wide, 1.2-m-deep tilting flume at the USGS Hydraulic Laboratory Facility at Stennis Space Center, Mississippi (fig. 2). Mud-filled pans were fit tightly into the bottom of the flume and 17,000 sticks (each approximately 1 cm x 2 cm x 120 cm) were inserted into the mud at 8 cm intervals in staggered rows to simulate vegetated conditions. A constant head tank controlled discharge at the upstream end and metal plates, called stop logs, were added or removed at the downstream end to control the depth of water in the flume. Before each set of experiments, the head was raised at the upstream end of the flume to create the desired discharge, and the flow was allowed to reach steady-state. A water depth of approximately 76 cm was maintained for all experiments by installing 2.5 stop logs at the downstream end of the flume (2.5 stop logs equals a nominal depth of 2.5 feet, or 76 cm).

Data Collection

Eleven sets of concurrently measured water-surface slope and pipe centerline velocity data were collected (Table 1 and Table 2). Each set of experiments consisted of two replicate sets of water-surface slope measurements (designated "Pass A" and "Pass B") and approximately twenty pipe centerline velocity measurements, as described below.

Water-Surface Slope Measurement

In order to obtain accurate water-surface elevation measurements, hook gages equipped with digital calipers precise to 0.01 mm (fig. 3) were installed 0.46 m from the flume wall at five locations along the east side of the flume and five corresponding locations along the west side of the flume (fig. 2). Precision to 0.01 mm was necessary because the water-surface slopes in the flume were often very small (on the order of 1 cm/km or roughly 0.5 mm over the 50 m distance between the first and last measurement locations). Six independent stage measurements were collected at each of the ten hook gage locations for each water-surface slope calculation.

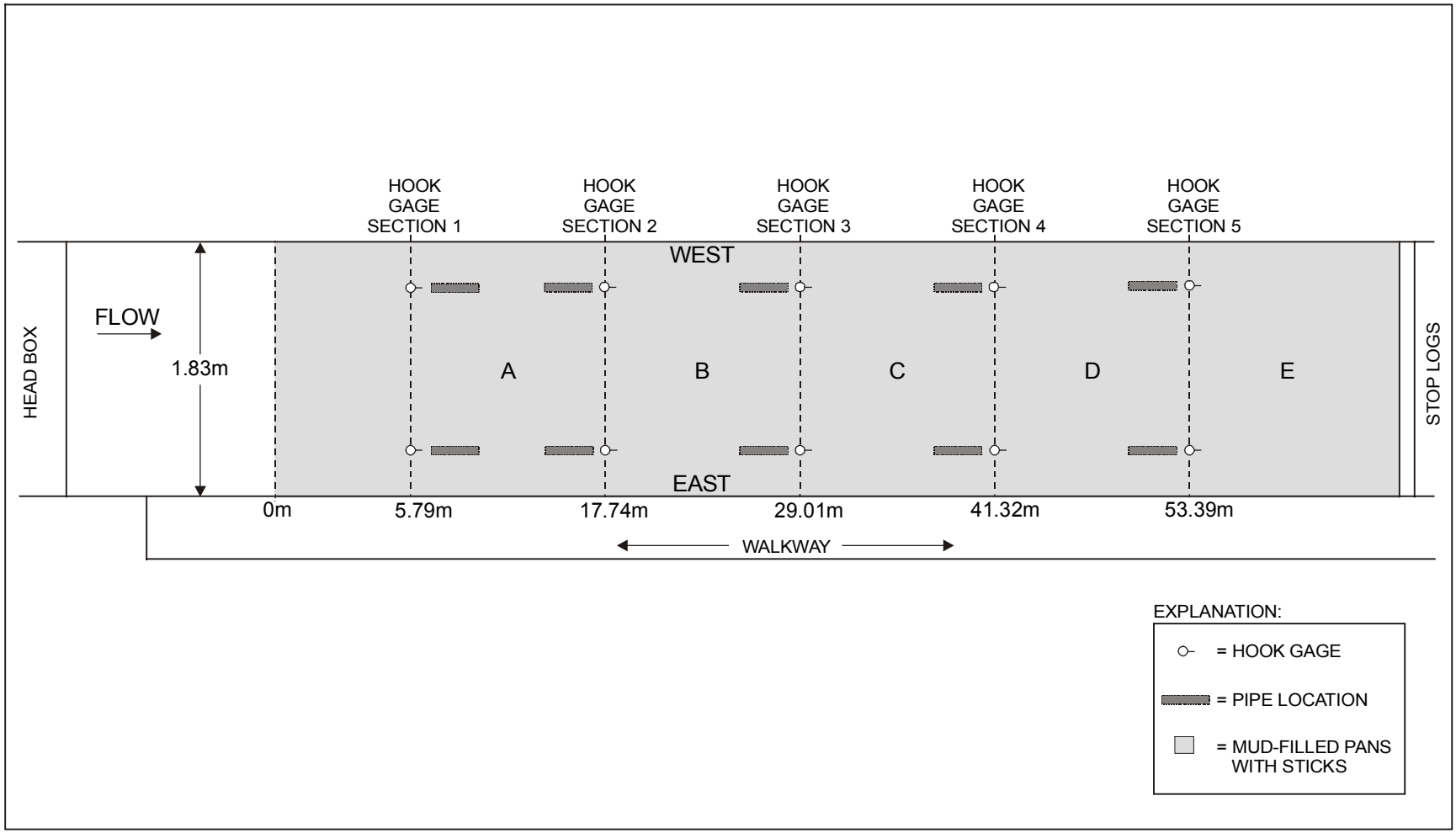

Figure 2. Flume layout in plan view. Not drawn to scale.

Table 1. Water-Surface Slope Data

Experiment Date	Data File Name*	East Slope† x 10^{-3}	West Slope‡ x 10^{-3}	Average Slope x 10^{-3}
02/10/99	021099PA	-0.37172	-0.38714	-0.37943
02/10/99	021099PB	-0.37680	-0.38105	-0.37893
02/11/99	021199PA	-0.30142	-0.30384	-0.30263
02/11/99	021199PB	-0.29686	-0.30900	-0.30293
02/12/99	021299PA	-0.22936	-0.24475	-0.23706
02/12/99	021299PB	-0.23363	-0.24163	-0.23763
02/16/99	021699PA	-0.17454	-0.18588	-0.18021
02/16/99	021699PB	-0.17930	-0.20064	-0.18997
02/17/99	021799PA	-0.13143	-0.14808	-0.13976
02/17/99	021799PB	-0.13754	-0.15013	-0.14384
02/18/99	021899PA	-0.10008	-0.11985	-0.10997
02/18/99	021899PB	-0.10118	-0.12687	-0.11403
02/22/99	022299PA	-0.08589	-0.11321	-0.09955
02/22/99	022299PB	-0.06044	-0.08108	-0.07076
02/23/99	022399PA	-0.04160	-0.05571	-0.04866
02/23/99	022399PB	-0.04252	-0.05478	-0.04865
02/24/99	022499PA	-0.03820	-0.04574	-0.04197
02/24/99	022499PB	-0.03703	-0.04136	-0.03920
02/25/99	022599PA	-0.02795	-0.03791	-0.03293
02/25/99	022599PB	-0.02382	-0.03204	-0.02793
03/15/99	031599PA	-0.01748	-0.02318	-0.02033
03/15/99	031599PB	-0.01515	-0.02121	-0.01818

* PA = Pass A; PB = Pass B

† Water-surface slope measured on east side of flume

‡ Water-surface slope measured on west side of flume

Table 2. Pipe-Centerline Velocity Data

Experiment Date	Data File Name*	Number of Pipe Elbows	Number of Points Passing Average CORR Filter	Number of Points Passing Average SNR Filter	Resultant Mag (x,y,z) CORR Velocity (cm/s)	Resultant Mag (x,y,z) SNR Velocity (cm/s)
02/10/99	021099A1	2	1200	1200	6.61	6.61
02/10/99	021099A2	1	1200	1200	6.84	6.85
02/10/99	021099A3	2	1200	1200	6.45	6.45
02/10/99	021099A4	1	1200	1200	7.10	7.10
02/10/99	021099B1	1	1200	1200	7.37	7.37
02/10/99	021099B2	2	1200	1200	6.63	6.63
02/10/99	021099B3	1	1200	1200	7.58	7.58
02/10/99	021099B4	2	1200	1200	6.55	6.55
02/10/99	021099C1	1	1200	1200	7.10	7.10
02/10/99	021099C2	2	1200	1200	6.50	6.50
02/10/99	021099C3	2	1200	1200	6.81	6.81
02/10/99	021099C4	1	1200	1200	6.82	6.82
02/10/99	021099D1	2	1200	1200	5.86	5.86
02/10/99	021099D2	1	1200	1200	7.07	7.07
02/10/99	021099D3	1	1200	1200	7.06	7.06
02/10/99	021099D3	2	1200	1200	6.19	6.19
02/10/99	021099E1	1	1200	1200	7.12	7.12
02/10/99	021099E2	2	1200	1200	6.13	6.13
02/10/99	021099E3	2	1200	1200	6.31	6.31
02/10/99	021099E4	1	1200	1200	6.95	6.95
02/11/99	021199A1	1	1200	1200	5.92	5.92
02/11/99	021199A2	2	1200	1173	5.33	5.32
02/11/99	021199A3	2	1200	1200	5.54	5.54
02/11/99	021199A4	1	1200	1174	6.01	6.01
02/11/99	021199B1	2	1200	1200	5.59	5.59
02/11/99	021199B2	1	1200	1189	6.48	6.48
02/11/99	021199B3	1	1200	1200	6.49	6.50
02/11/99	021199B4	2	1200	1178	5.79	5.80
02/11/99	021199C1	1	1200	1200	5.94	5.94
02/11/99	021199C2	2	1200	1179	5.88	5.88
02/11/99	021199C3	2	1200	1200	5.65	5.65
02/11/99	021199C4	1	1200	1189	6.16	6.17
02/11/99	021199D1	2	1200	1200	5.49	5.49
02/11/99	021199D2	1	1200	1195	6.23	6.23
02/11/99	021199D3	1	1200	1200	6.43	6.43
02/11/99	021199E1	1	1200	1200	5.97	5.97
02/11/99	021199D4	2	1200	1171	5.48	5.49
02/11/99	021199E2	2	1200	1194	5.45	5.45
02/11/99	021199E3	1	1200	1200	5.71	5.71
02/11/99	021199E4	2	1200	1185	6.26	6.26
02/12/99	021299A1	1	1200	1120	5.18	5.18
02/12/99	021299A2	2	1200	1200	4.91	4.91
02/12/99	021299A3	2	1200	1108	5.02	5.02
02/12/99	021299A4	1	1200	1200	5.37	5.37
02/12/99	021299B1	2	1200	1016	4.81	4.82
02/12/99	021299B2	1	1200	1200	5.60	5.60
02/12/99	021299B3	1	1200	1037	5.21	5.21
02/12/99	021299B4	1	1200	1200	4.99	4.99
02/12/99	021299C1	1	1200	978	5.40	5.41
02/12/99	021299C2	2	1200	1199	4.90	4.90
02/12/99	021299C4	1	1200	1200	5.43	5.43
02/12/99	021299D1	2	1200	849	5.02	5.03
02/12/99	021299D2	1	1200	1198	5.50	5.50
02/12/99	021299D3	1	1199	811	5.61	5.62
02/12/99	021299D4	2	1200	1199	5.16	5.16
02/12/99	021299E1	1	1200	636	5.15	5.17

* Letter designations A through E indicate the flume section where pipe-centerline velocity measurement was collected (Figure 2).

Table 2. Pipe-Centerline Velocity Data (continued)

Experiment Date	Data File Name*	Number of Pipe Elbows	Number of Points Passing Average CORR Filter	Number of Points Passing Average SNR Filter	Resultant Mag (x,y,z) CORR Velocity (cm/s)	Resultant Mag (x,y,z) SNR Velocity (cm/s)
02/12/99	021299E2	2	1200	1196	4.61	4.61
02/12/99	021299E3	2	1200	608	4.86	4.88
02/12/99	021299E4	1	1200	1200	5.40	5.40
02/16/99	021699A1	1	1200	1200	4.37	4.37
02/16/99	021699A2	2	1200	1057	4.15	4.15
02/16/99	021699A3	2	1200	1200	4.04	4.04
02/16/99	021699A4	1	1200	1047	4.27	4.27
02/16/99	021699B1	2	1200	1200	4.12	4.12
02/16/99	021699B2	1	1200	1108	4.46	4.47
02/16/99	021699B3	1	1200	1200	4.57	4.58
02/16/99	021699B4	2	1200	1117	4.25	4.25
02/16/99	021699C1	1	1200	1200	4.34	4.34
02/16/99	021699C2	2	1200	1160	4.19	4.20
02/16/99	021699C3	2	1200	1200	4.13	4.13
02/16/99	021699C4	1	1200	1146	4.42	4.42
02/16/99	021699D1	2	1200	1200	4.05	4.05
02/16/99	021699D2	1	1200	1180	4.63	4.63
02/16/99	021699D3	1	1200	1200	4.40	4.40
02/16/99	021699D4	2	1200	1155	4.14	4.14
02/16/99	021699E1	1	1200	1200	4.38	4.37
02/16/99	021699E2	2	1200	1195	4.09	4.09
02/16/99	021699E3	2	1200	1200	3.91	3.91
02/16/99	021699E4	1	1200	1191	4.22	4.22
02/17/99	021799A1	1	1200	863	3.39	3.40
02/17/99	021799A2	2	1200	1198	3.18	3.19
02/17/99	021799A3	2	1200	805	3.10	3.11
02/17/99	021799A4	1	1200	1197	3.43	3.43
02/17/99	021899B1	2	1199	729	3.23	3.24
02/17/99	021799B2	1	1200	1196	3.53	3.53
02/17/99	021799B3	1	1200	713	3.37	3.39
02/17/99	021799B4	2	1200	1188	3.21	3.21
02/17/99	021799C1	1	1200	645	3.65	3.67
02/17/99	021799C2	2	1200	1187	3.11	3.11
02/17/99	021799C3	2	1200	583	3.19	3.20
02/17/99	021799C4	1	1200	1196	3.44	3.44
02/17/99	021799D1	2	1200	566	3.27	3.28
02/17/99	021799D2	1	1200	1190	3.56	3.56
02/17/99	021799D3	1	1200	542	3.51	3.53
02/17/99	021799D4	2	1200	1187	3.18	3.18
02/17/99	021799E1	1	1200	496	3.47	3.50
02/17/99	021799E2	2	1200	1178	3.12	3.12
02/17/99	021799E3	2	1200	518	3.24	3.24
02/17/99	021799E4	1	1200	1177	3.23	3.23
02/18/99	021899A1	2	1200	493	2.39	2.41
02/18/99	021899A2	1	1200	1078	2.43	2.43
02/18/99	021899A3	1	1200	514	2.62	2.64
02/18/99	021899A4	2	1200	1094	2.31	2.31
02/18/99	021899B1	1	1200	467	2.53	2.55
02/18/99	021899B2	2	1200	1171	2.34	2.34
02/18/99	021899B3	2	1200	426	2.34	2.36
02/18/99	021899B4	1	1200	1105	2.44	2.45
02/18/99	021899C1	2	1200	537	2.30	2.32
02/18/99	021899C2	1	1200	1149	2.48	2.48
02/18/99	021899C3	1	1199	384	2.61	2.62
02/18/99	021899C4	2	1200	1119	2.29	2.29
02/18/99	021899D1	1	1200	440	2.62	2.64

* Letter designations A through E indicate the flume section where pipe-centerline velocity measurement was collected (Figure 2).

Table 2. Pipe-Centerline Velocity Data (continued)

Experiment Date	Data File Name*	Number of Pipe Elbows	Number of Points Passing Average CORR Filter	Number of Points Passing Average SNR Filter	Resultant Mag (x,y,z) CORR Velocity (cm/s)	Resultant Mag (x,y,z) SNR Velocity (cm/s)
02/18/99	021899D2	2	1200	1188	2.35	2.35
02/18/99	021899D3	2	1198	455	2.30	2.32
02/18/99	021899D4	1	1200	1173	2.59	2.58
02/18/99	021899E1	2	1200	520	2.29	2.30
02/18/99	021899E2	1	1200	1194	2.35	2.35
02/18/99	021899E3	1	1200	442	2.43	2.45
02/18/99	021899E4	2	1200	1184	2.14	2.14
02/22/99	022299A1	2	1200	874	1.68	1.68
02/22/99	022299A2	1	1199	299	1.90	1.92
02/22/99	022299A3	1	1200	727	1.87	1.87
02/22/99	022299A4	2	1199	261	1.67	1.69
02/22/99	022299B1	1	1200	866	1.77	1.77
02/22/99	022299B2	2	1197	235	1.62	1.65
02/22/99	022299B3	2	1200	695	1.68	1.69
02/22/99	022299B4	1	1198	242	1.75	1.77
02/22/99	022299B5	1	1200	454	1.74	1.76
02/22/99	022299C1	1	1200	934	1.56	1.56
02/22/99	022299C2	2	1198	586	1.76	1.78
02/22/99	022299C3	1	1200	754	1.76	1.76
02/22/99	022299C4	2	1189	150	1.59	1.62
02/22/99	022299D1	1	1200	1200	1.66	1.66
02/22/99	022299D2	2	1189	172	1.55	1.59
02/22/99	022299D3	2	1200	433	1.64	1.64
02/22/99	022294D4	1	1183	152	1.63	1.67
02/22/99	022299E1	2	1200	1192	1.38	1.38
02/22/99	022299E2	1	1199	768	1.65	1.67
02/22/99	022299E3	1	1200	554	1.46	1.47
02/22/99	022299E4	2	1177	122	1.47	1.49
02/23/99	022399A1	1	1194	193	0.85	0.85
02/23/99	022399A2	2	1200	678	0.71	0.71
02/23/99	022399A3	2	1198	207	0.84	0.85
02/23/99	022399A4	1	1200	650	0.77	0.77
02/23/99	022399B1	2	1200	1196	0.76	0.76
02/23/99	022399B2	1	1200	851	0.86	0.87
02/23/99	022399B3	1	1180	115	0.90	0.91
02/23/99	022399B4	2	1200	445	0.80	0.81
02/23/99	022399C1	1	1186	157	0.88	0.91
02/23/99	022399C2	2	1200	485	0.73	0.73
02/23/99	022399C3	2	1168	76	0.82	0.85
02/23/99	022399C4	1	1200	419	0.82	0.82
02/23/99	022399D1	2	1178	189	0.89	0.90
02/23/99	022399D2	1	1200	1143	0.90	0.90
02/23/99	022399D3	1	1144	93	0.96	0.97
02/23/99	022399D4	2	1200	432	0.80	0.80
02/23/99	022399E1	1	1196	328	0.81	0.81
02/23/99	022399E2	2	1200	890	0.69	0.69
02/23/99	022399E3	2	1153	85	0.69	0.69
02/23/99	022399E4	1	1200	364	0.67	0.67
02/24/99	022499A1	1	1200	551	0.56	0.56
02/24/99	022499A2	2	1184	127	0.61	0.61
02/24/99	022499A3	2	1200	373	0.45	0.45
02/24/99	022499A4	1	1167	161	0.54	0.55
02/24/99	022499B1	2	1200	205	0.46	0.47
02/24/99	022499B2	1	1154	70	0.56	0.56
02/24/99	022499B3	1	1200	343	0.41	0.40
02/24/99	022499B4	2	1145	93	0.52	0.53

* Letter designations A through E indicate the flume section where pipe-centerline velocity measurement was collected (Figure 2).

Table 2. Pipe-Centerline Velocity Data (continued)

Experiment Date	Data File Name*	Number of Pipe Elbows	Number of Points Passing Average CORR Filter	Number of Points Passing Average SNR Filter	Resultant Mag (x,y,z) CORR Velocity (cm/s)	Resultant Mag (x,y,z) SNR Velocity (cm/s)
02/24/99	022499C1	1	1200	305	0.37	0.36
02/24/99	022499C2	2	1098	53	0.45	0.46
02/24/99	022499C3	2	1200	280	0.34	0.34
02/24/99	022499C4	1	1051	47	0.50	0.48
02/24/99	022499D1	2	1200	358	0.38	0.37
02/24/99	022499D2	1	1186	99	0.47	0.48
02/24/99	022499D3	1	1200	499	0.31	0.30
02/24/99	022499D4	2	1197	61	0.37	0.37
02/24/99	022499E1	1	1200	201	0.42	0.41
02/24/99	022499E2	2	696	37	0.49	0.51
02/24/99	022499E3	2	1200	190	0.42	0.41
02/24/99	022499E4	1	1184	195	0.50	0.50
02/25/99	022599A1	1	1068	199	0.05	0.05
02/25/99	022599A2	2	1200	309	0.24	0.25
02/25/99	022599A4	1	1200	603	0.22	0.21
02/25/99	022599B2	1	1200	71	0.18	0.19
02/25/99	022599B3	1	1200	1182	0.09	0.09
02/25/99	022599B4	2	1200	1200	0.20	0.20
02/25/99	022599C2	2	1200	179	0.17	0.19
02/25/99	022599C3	2	1200	547	0.15	0.15
02/25/99	022599D3	1	1089	124	0.03	0.03
02/25/99	022599D4	2	1200	1200	0.24	0.24
02/25/99	022599E2	2	1200	206	0.19	0.19
02/25/99	022599E3	2	1200	720	0.13	0.13
02/25/99	022599E4	1	1200	501	0.14	0.15
03/15/99	031599A2	1	1200	100	0.22	0.22
03/15/99	031599A3	1	1198	258	0.14	0.16
03/15/99	031599B3	1	1200	90	0.21	0.20
03/15/99	031599B4	2	1200	1156	0.12	0.12
03/15/99	031599D2	2	1200	84	0.12	0.12
03/15/99	031599E2	1	1200	793	0.18	0.18
03/15/99	031599E3	2	1200	965	0.13	0.13
03/15/99	031599E4	1	1198	187	0.09	0.08

* Letter designations A through E indicate the flume section where pipe-centerline velocity measurement was collected (Figure 2).

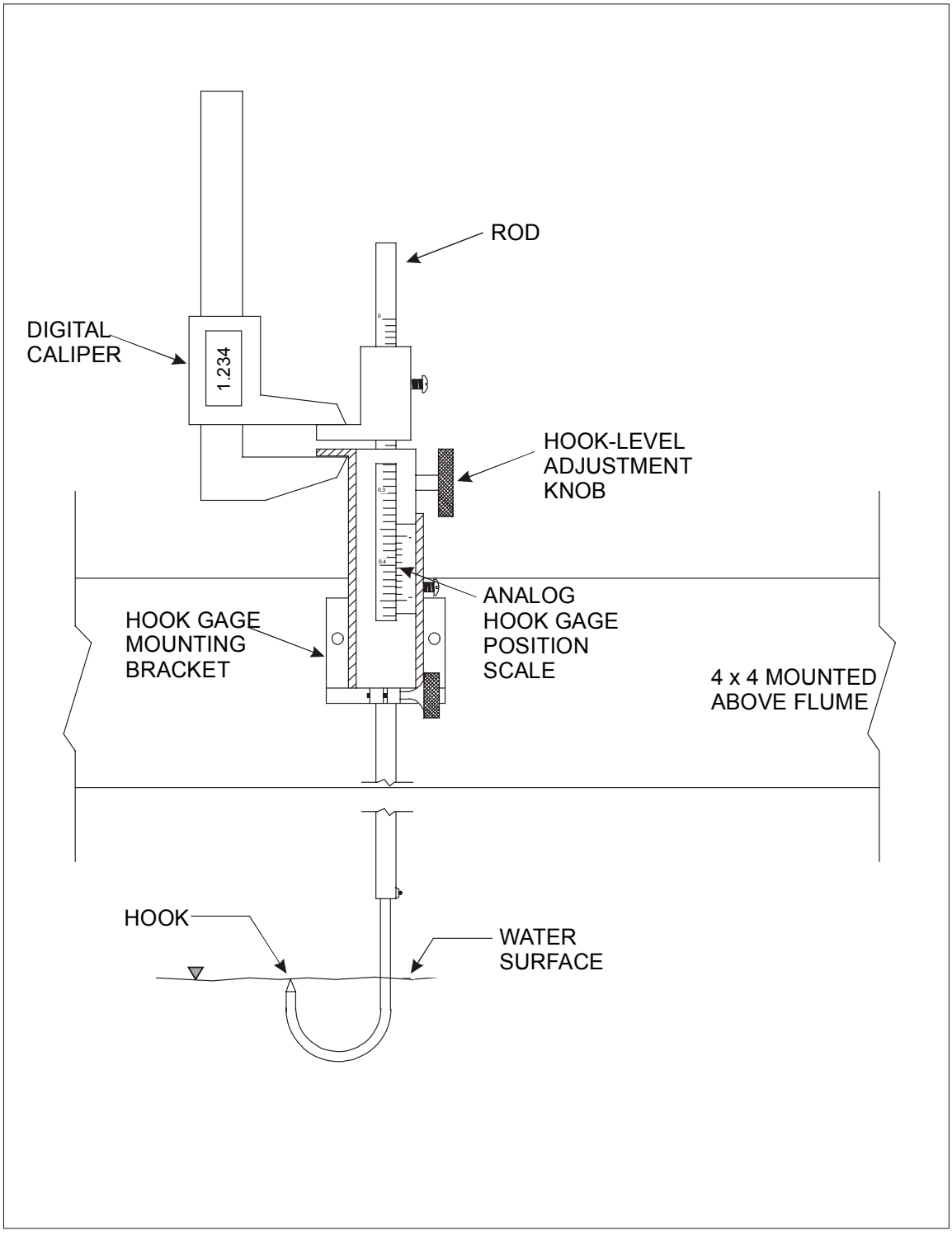

Figure 3. Laboratory configuration of hook gage.

The hook gages provided sufficient resolution at each location but could not provide accurate elevation differences between points until tied to a common vertical datum. Differences in elevation between locations along the length of the flume were so small, however, that conventional surveying techniques could not establish an accurate datum. Efforts to survey a common datum using a laser level referenced to a benchmark on the laboratory wall were unsuccessful.

In order to overcome the surveying difficulties, a level-water surface (attained with no flow in the flume) was used as the common datum. After maintaining no-flow conditions in the flume for a period of 24 hours, the elevation of the level-water surface was determined from six independent stage measurements collected at each of the ten hook gage locations (fig. 2). Hook gage data were time-adjusted (see calculations below) to correct for falling water levels in the flume due to evaporation during the period of data collection. Once the level-water surface was established for a given hook gage configuration, subsequent experiments were referenced to that datum until the gages were moved for any reason. Only one measurement of the level-water surface was required during the collection of the data described herein.

After each set of slope data was collected, the corresponding datum value was subtracted from each measurement to obtain the relative elevation above or below the established level-water surface. Hook gage measurements collected for determining the water-surface slope were not time-adjusted because losses due to evaporation were assumed to be minimal relative to water level differences between locations

Pipe Centerline Velocity Measurement

For each set of experiments, pipe centerline velocity measurements were collected at five locations along the east side of the flume and five corresponding locations along the west side of the flume (fig. 2) using two pipe manometers (fig. 1). Both pipe manometers were constructed from a 2.4-m-long, 7.6-cm-diameter piece of PVC pipe with a short elbow of the same diameter at the upstream end. However, one of the pipe manometers had an additional elbow at the downstream end. For each velocity measurement, the manometer was located approximately 0.46 m from the wall of the flume, aligned parallel to the direction of flow, and positioned horizontally just below the water surface with the elbow(s) pointing down. Each manometer was supported by wooden stakes inserted into the mud in the bottom of the flume in an "X" configuration with the manometer resting in the top part of the "X" (fig. 1).

The pipe centerline velocity was measured by inserting an acoustic Doppler velocity (ADV) meter equipped with a sideward-looking probe into the downstream end of the pipe (fig. 1). The ADV meter has a rated precision of 0.1mm/s in a range of 0 to 10 cm/s (Sontek, 1997). Velocity components in three directions (x, y, and z) were collected at 10 Hz in bursts of two-minute duration producing a 1200-point time series. Along with velocity, two 3-component signal quality statistics, correlation (CORR) and signal-to-noise ratio (SNR), were measured for each data point (Sontek, 1997). These signal quality statistics were used to remove suspect data points from the pipe centerline velocity calculations.

CALCULATION OF WATER LEVELS, WATER-SURFACE SLOPES, AND VELOCITIES

Time-Adjusted Level-Water Datum Calculation

Hook gage measurements used in calculating the level-water surface are presented in Appendix A (Table A-2). Raw hook gage data were time-adjusted to correct for falling water levels in the flume due to evaporation during the period of data collection. Correction of the hook gage data was based on the average rate of water-surface lowering over time, which was calculated from the individual rates of change of the water-surface elevation at each gage location.

The rate of change (m_i) of the water-surface elevation at the i^{th} location along the length of the flume was determined from the slope of the regression line through the six independent measurements ($h_{ij}, t_{ij}, j = 1...6$) taken at that location. The rate of water-surface lowering at an individual location was calculated as:

$$m_i = \frac{\Delta h_i}{\Delta t_i} = \frac{6\sum_{j=1}^{6}(t_{ij} - t_0)h_{ij} - \sum_{j=1}^{6}h_{ij}\sum_{j=1}^{6}(t_{ij} - t_0)}{6\sum_{j=1}^{6}(t_{ij} - t_0)^2 - [\sum_{j=1}^{6}(t_{ij} - t_0)]^2}, \quad (1)$$

where h_{ij} = unadjusted water-surface elevation and $(t_{ij} - t_0)$ = total time elapsed between the time (t_{ij}) that each measurement (h_{ij}) was collected and an arbitrary reference time (t_0) chosen as the time that the first measurement of the day (h_{11}) was collected.

The slope values from each of the ten hook gage locations (Table A-3) were then averaged to estimate the rate of change of the level-water surface for the entire flume (M) using:

$$M = \frac{1}{10}\sum_{i=1}^{10} m_i \ . \quad (2)$$

Individual time-adjusted datum values (H_{ij}) shown in Table A-4 were obtained by subtracting the average rate of change of the level-water surface (M) multiplied by the total elapsed time $(t_{ij} - t_0)$ from the unadjusted hook gage measurement (h_{ij}) as shown in equation (3).

$$H_{ij} = h_{ij} - M(t_{ij} - t_0) \quad (3)$$

The individual time adjusted data (H_{ij}) were then averaged to determine a final level-water datum value (η_i) at each of the ten hook gage locations (Table A-5) using equation (4).

$$\eta_i = \frac{1}{6}\sum_{j=1}^{6} H_{ij} \tag{4}$$

Figure A-1 shows the variation in the level-water surface data shown as a plot of $H_{ij} - \eta_i$ vs. distance along the flume.

Water-Surface Slope Calculation

Hook gage measurements used in calculating water-surface slopes are presented in Appendix B (Tables B-1 through B-22). For each set of hook gage measurements, the water-surface slope (b) was first determined separately for the east and west sides of the flume by calculating the slope of the regression line through all of the independent stage measurements collected at each of the five hook gage locations along one side of the flume ($h_k, x_k, k = 1...30$) using:

$$b = \frac{\Delta h}{\Delta x} = \frac{30\sum_{k=1}^{30} x_k h_k - \sum_{k=1}^{30} x_k \sum_{k=1}^{30} h_k}{30\sum_{k=1}^{30} x_k^2 - (\sum_{k=1}^{30} x_k)^2}, \tag{5}$$

where h_k = the difference in elevation between the raw hook gage measurement and the established level-water reference datum at the hook gage and x_k = the hook gage's location along the length of the flume. The slope values from the east and west sides of the flume were then averaged to obtain the average water-surface slope for each experiment (Table 1).

Pipe Centerline Velocity Calculation

For each 1200-point time series of velocity measurements, signal quality values for the three velocity components were averaged to obtain a corresponding 1200-point time series of average CORR and average SNR values. Points with average CORR values below a selected signal quality threshold (CORR < 70; Sontek, 1997) were identified and removed from the unfiltered time series to create a separate CORR-filtered time series. The three velocity components of the data points in the CORR-filtered time series were then averaged separately and a resultant magnitude, called the CORR-velocity, was calculated. Similarly, data points with average SNR values below a selected signal quality threshold (SNR < 5; Sontek, 1997) were removed from the unfiltered time series to create an SNR-filtered time series. The velocity components of the data points in the SNR-filtered time series were averaged separately and used to calculate the resultant SNR-velocity. If the resultant CORR- and SNR-velocities agreed within 15%, the CORR-velocity was used as the pipe centerline velocity. If the difference was greater than 15%, the data from that experiment were not used. In total, 316 out of the 332 velocity measurements (95%) passed this signal quality test. Pipe centerline velocity data are summarized in Table 2. Figure 4 shows pipe centerline velocity data plotted against the square root of the water-surface slope. The two parameters display a distinct linear relationship.

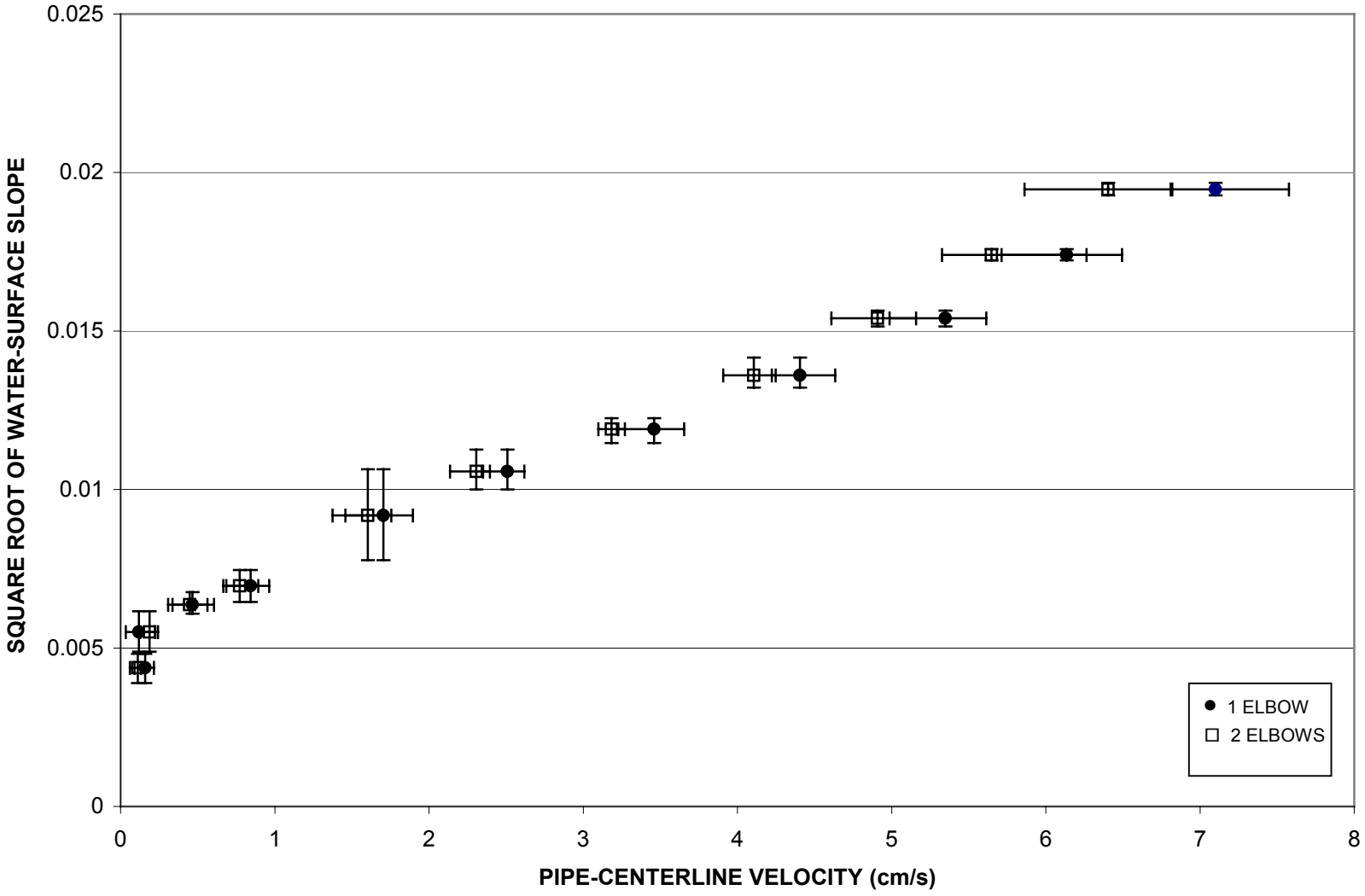

Figure 4. Relation of pipe-centerline velocity to the square root of the water-surface slope for one- and two-elbow pipe manometer configurations. (Error bars indicate the spread of the velocity and slope data.)

REFERENCES

Streeter, V.L., and Wylie, E.B., 1979, Fluid Mechanics, Seventh Edition: McGraw-Hill Book Co., New York, NY, 562p.

_____, 1997, Sontek ADV acoustic Doppler velocimeter technical documentation: Sontek, San Diego, CA, 164

Appendix A. Level-Water Surface Data

LEVEL-WATER SURFACE DATA

Experiment Date: **01/22/99** Hook Gages: FIXED
Experiment Name: **012299Z0** Calipers: Yes
Filename: 012299Z0PRO Q (cfs): 0

TABLE A-1

Distance along flume from upstream end (m)

1W	1E	2W	2E	3W	3E	4W	4E	5W	5E
5.73	5.73	17.61	17.61	28.87	28.87	41.14	41.14	53.28	53.28

TABLE A-2

Raw hook gage measurements (mm) and times (HR:MIN:SEC)

1W		1E		2W		2E		3W		3E		4W		4E		5W		5E	
22.28	7:14:00	19.96	7:15:00	17.75	7:16:00	28.28	7:17:00	20.47	7:18:00	27.77	7:19:00	34.10	7:20:00	27.06	7:21:00	25.79	7:23:00	25.53	7:22:00
21.81	7:32:00	19.46	7:31:00	17.31	7:31:00	27.95	7:30:00	20.32	7:29:00	27.30	7:28:00	33.97	7:26:00	27.21	7:27:00	25.85	7:25:00	25.48	7:24:00
21.85	7:34:00	19.45	7:33:00	17.13	7:35:00	27.96	7:34:00	20.05	7:36:00	27.39	7:36:00	33.50	7:42:00	26.66	7:41:00	25.18	7:44:00	24.99	7:43:00
21.29	7:51:00	19.21	7:50:00	16.33	7:49:00	27.44	7:48:00	19.75	7:47:00	26.86	7:46:00	33.30	7:46:00	26.57	7:45:00	25.39	7:44:00	24.95	7:43:00
21.39	7:51:00	19.19	7:50:00	16.14	7:53:00	27.18	7:52:00	19.38	7:54:00	26.69	7:53:00	32.87	7:56:00	26.09	7:55:00	24.82	7:58:00	24.46	7:57:00
20.99	8:05:00	18.49	8:04:00	15.91	8:03:00	26.99	8:03:00	19.18	8:02:00	26.23	8:01:00	32.84	8:00:00	26.03	7:59:00	24.86	7:58:00	24.44	7:57:00

TABLE A-3

Rate of change of water-surface elevation at each hook gage location (mm/min)

1W	1E	2W	2E	3W	3E	4W	4E	5W	5E
-0.02559	-0.02642	-0.04271	-0.02986	-0.03101	-0.03411	-0.03321	-0.03117	-0.02858	-0.03073

Average rate of change of level-water surface for all locations(mm/min) = -0.03198

TABLE A-4

Time-adjusted datum (mm)

1W	1E	2W	2E	3W	3E	4W	4E	5W	5E
22.27	19.98	17.80	28.36	20.59	27.92	34.28	27.27	26.06	25.77
22.36	19.98	17.83	28.44	20.78	27.73	34.34	27.61	26.19	25.78
22.47	20.04	17.78	28.58	20.73	28.07	34.37	27.50	26.11	25.89
22.44	20.33	17.42	28.50	20.77	27.85	34.29	27.53	26.32	25.85
22.54	20.31	17.35	28.36	20.62	27.90	34.18	27.37	26.19	25.80
22.58	20.05	17.44	28.52	20.67	27.69	34.27	27.43	26.23	25.78

TABLE A-5

Average level-water datum (mm)

1W	1E	2W	2E	3W	3E	4W	4E	5W	5E
22.44	20.11	17.60	28.46	20.70	27.86	34.29	27.45	26.18	25.81

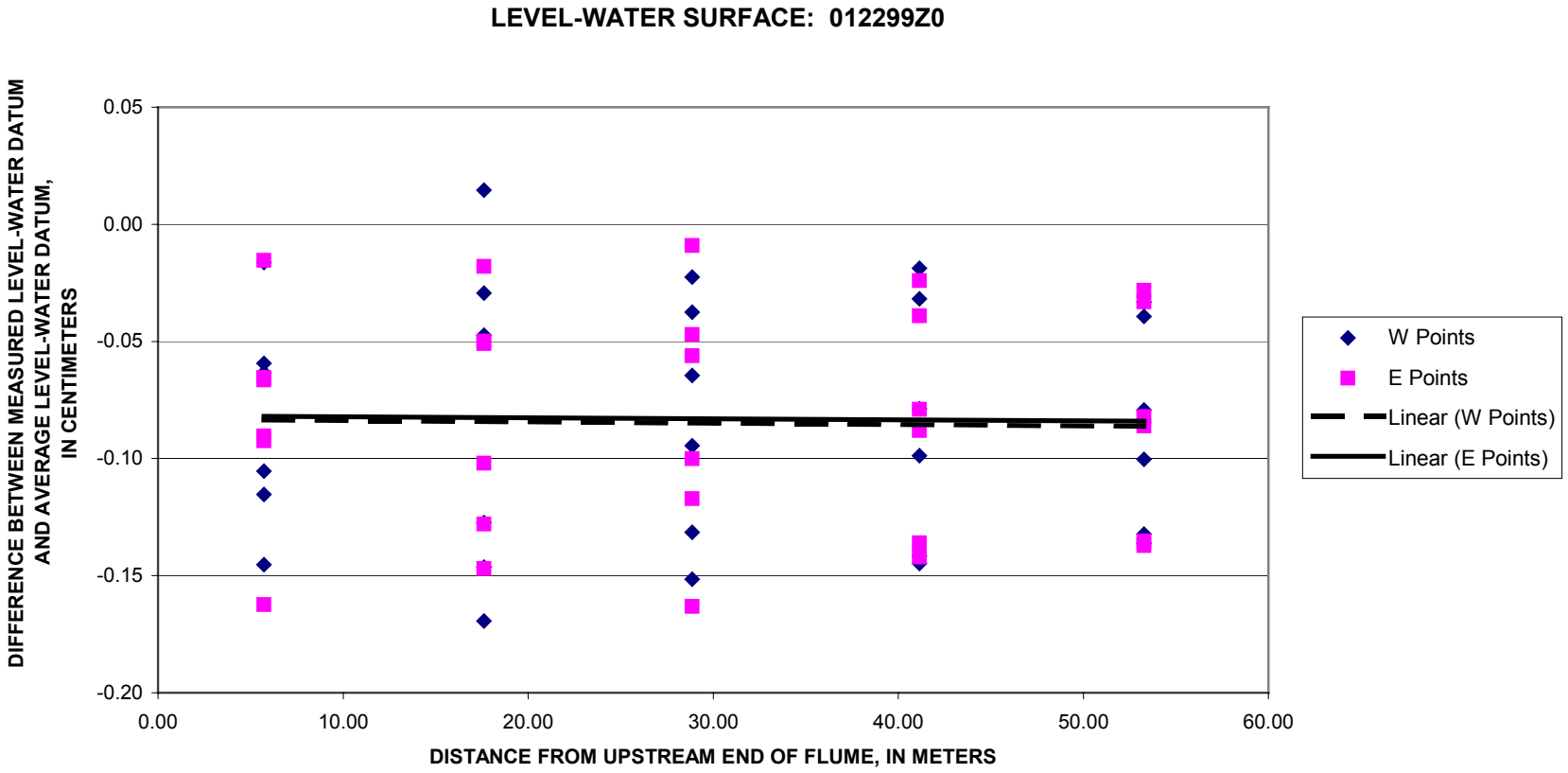

Figure A-1. Plot showing variability associated with level-water surface data, experiment 012299Z0

Appendix B. Water-Surface Slope Data

WATER-SURFACE SLOPE DATA

LEVEL-WATER SURFACE REFERENCE DATA: 012299Z0

TABLE A-1

Distance along flume from upstream end (m)									
1W	1E	2W	2E	3W	3E	4W	4E	5W	5E
5.73	5.73	17.61	17.61	28.87	28.87	41.14	41.14	53.28	53.28

TABLE A-5

Average level-water datum (mm)									
1W	1E	2W	2E	3W	3E	4W	4E	5W	5E
22.44	20.11	17.60	28.46	20.70	27.86	34.29	27.45	26.18	25.81

HOOK GAGE MEASUREMENTS REFERENCED TO LEVEL-WATER SURFACE 012299Z0

TABLE B-1

Experiment Date:	**02/10/99**	Fixed Hook Gages:	Yes	Stop Logs:	2.5
Experiment Name:	**021099PA**	Calipers:	Yes		
Filename:	021099PA PRO 3	Level-Water Reference:	012299Z0		

Hook gage measurements (mm)									
1W	1E	2W	2E	3W	3E	4W	4E	5W	5E
124.80	122.82	115.91	126.74	114.02	121.55	123.40	116.89	110.28	111.27
124.93	123.00	115.54	126.96	114.42	121.72	123.38	116.78	110.33	111.19
124.84	123.03	115.81	126.89	114.09	121.71	123.58	116.70	110.00	111.02
124.85	123.18	115.70	126.78	114.37	121.64	123.38	116.87	110.20	110.94
124.74	123.09	115.76	126.91	114.01	121.52	123.64	116.91	109.86	111.64
124.71	123.34	115.89	126.84	114.24	121.81	123.29	117.19	109.89	111.09

TABLE B-2

Experiment Date:	**02/10/99**	Fixed Hook Gages:	Yes	Stop Logs:	2.5
Experiment Name:	**021099PB**	Calipers:	Yes		
Filename:	021099PB PRO 4	Level-Water Reference:	012299Z0		

Hook gage measurements (mm)									
1W	1E	2W	2E	3W	3E	4W	4E	5W	5E
124.96	123.10	115.60	127.23	114.01	121.65	123.56	117.29	110.34	111.06
124.82	123.27	115.61	127.18	113.92	121.89	123.62	117.45	110.45	110.99
124.85	123.20	115.67	127.30	114.15	121.50	123.81	117.40	110.68	111.03
124.95	123.60	115.56	126.85	114.22	121.91	123.34	117.30	110.36	111.05
124.84	123.42	115.74	126.91	114.10	121.77	123.44	117.39	110.49	111.16
125.30	123.55	115.69	127.13	114.26	121.80	123.70	117.35	110.46	111.06

TABLE B-3

Experiment Date:	**02/11/99**	Fixed Hook Gages:	Yes	Stop Logs:	2.5
Experiment Name:	**021199PA**	Calipers:	Yes		
Filename:	021199PA PRO 5	Level-Water Reference:	012299Z0		

Hook gage measurements (mm)									
1W	1E	2W	2E	3W	3E	4W	4E	5W	5E
115.47	113.34	106.55	118.01	105.79	113.65	116.87	110.06	104.39	104.80
115.30	113.58	106.69	118.11	105.88	113.77	116.77	110.17	104.48	104.88
115.29	113.55	106.68	118.01	106.05	113.41	116.36	109.96	104.36	104.84
115.18	113.77	106.49	117.96	106.01	113.35	116.48	110.16	104.54	104.73
115.26	113.38	106.82	118.29	106.16	113.53	116.15	110.01	104.22	104.97
115.08	113.49	106.69	118.18	106.09	113.61	116.39	109.82	104.36	104.89

TABLE B-4

Experiment Date:	**02/11/99**	Fixed Hook Gages:	Yes	Stop Logs:	2.5
Experiment Name:	**021199PB**	Calipers:	Yes		
Filename:	021199PB PRO 6	Level-Water Reference:	012299Z0		

Hook gage measurements (mm)									
1W	1E	2W	2E	3W	3E	4W	4E	5W	5E
115.05	113.58	107.12	118.16	106.26	113.66	116.39	110.07	104.18	104.70
114.96	113.28	106.96	118.25	106.43	113.69	116.31	110.48	104.50	105.15
115.49	113.30	107.14	118.27	106.22	113.77	116.16	109.89	104.35	104.96
115.25	113.35	107.06	118.20	106.15	113.69	116.29	110.11	104.17	104.83
115.40	113.16	106.91	118.21	106.07	113.82	116.48	110.48	104.46	104.95
115.28	113.30	106.77	118.12	106.15	113.75	116.31	110.15	104.28	104.85

TABLE B-5

Experiment Date:	**02/12/99**	Fixed Hook Gages:	Yes	Stop Logs:	2.5
Experiment Name:	**021299PA**	Calipers:	Yes		
Filename:	021299PA PRO 7	Level-Water Reference:	012299Z0		

Hook gage measurements (mm)									
1W	1E	2W	2E	3W	3E	4W	4E	5W	5E
107.00	105.42	99.47	110.53	99.59	107.02	110.36	104.41	98.92	99.99
106.94	105.56	99.35	110.50	99.48	106.99	110.24	103.96	98.84	100.10
107.04	104.90	99.10	110.59	99.44	106.97	110.81	104.23	99.28	99.91
107.10	105.00	99.21	110.44	99.39	107.00	110.43	104.20	99.19	99.97
106.92	104.86	99.63	110.61	99.81	107.25	110.72	104.07	98.90	99.68
107.07	104.97	99.37	110.49	99.61	107.14	110.61	104.18	98.81	99.60

TABLE B-6

Experiment Date:	**02/12/99**	Fixed Hook Gages:	Yes	Stop Logs:	2.5
Experiment Name:	**021299PB**	Calipers:	Yes		
Filename:	021299PB PRO 8	Level-Water Reference:	012299Z0		

Hook gage measurements (mm)									
1W	1E	2W	2E	3W	3E	4W	4E	5W	5E
107.50	105.21	99.19	110.65	99.60	107.12	110.78	104.23	99.32	99.65
107.34	105.18	99.32	110.76	99.75	106.96	110.57	104.04	99.21	99.70
107.32	105.28	99.25	110.65	99.39	107.15	110.62	104.05	99.22	99.74
107.41	105.25	99.16	110.62	99.52	107.04	110.50	104.29	99.36	99.65
106.96	105.06	99.48	110.58	99.52	106.80	110.61	104.43	99.29	99.78
106.89	104.99	99.08	110.52	99.43	106.87	110.54	104.24	99.43	99.66

TABLE B-7

Experiment Date:	**02/16/99**	Fixed Hook Gages:	Yes	Stop Logs:	2.5
Experiment Name:	**021699PA**	Calipers:	Yes		
Filename:	021699PA PRO 9	Level-Water Reference:	012299Z0		

Hook gage measurements (mm)									
1W	1E	2W	2E	3W	3E	4W	4E	5W	5E
95.91	94.53	88.99	100.54	89.78	97.07	101.55	95.35	90.61	91.72
95.97	94.16	89.06	100.46	89.67	96.91	101.51	95.27	90.70	91.92
96.06	94.20	89.00	100.38	89.70	96.92	101.65	95.29	90.75	91.75
95.95	94.46	89.14	100.41	89.72	97.10	101.58	95.20	90.64	91.76
95.83	94.38	88.96	100.32	89.58	97.18	101.76	95.41	90.80	91.60
95.90	94.43	88.91	100.40	89.70	97.28	101.52	95.26	90.69	91.71

TABLE B-8

Experiment Date:	**02/16/99**	Fixed Hook Gages:	Yes	Stop Logs:	2.5
Experiment Name:	**021699PB**	Calipers:	Yes		
Filename:	021699PB PRO 10	Level-Water Reference:	012299Z0		

Hook gage measurements (mm)									
1W	1E	2W	2E	3W	3E	4W	4E	5W	5E
96.31	94.24	89.26	100.42	89.69	97.11	101.53	95.38	90.38	91.54
96.44	94.67	89.34	100.35	89.62	97.13	101.41	95.45	90.28	91.46
96.22	94.75	89.41	100.30	89.53	97.31	101.33	95.55	90.49	91.58
96.28	94.30	89.05	100.41	89.73	97.02	101.52	95.28	90.27	91.37
96.43	94.44	89.11	100.39	89.60	97.21	101.58	95.46	90.53	91.46
96.38	94.34	88.99	100.35	89.67	97.13	101.33	95.63	90.40	91.33

TABLE B-9

Experiment Date: **02/17/99** Fixed Hook Gages: Yes Stop Logs: 2.5
Experiment Name: **021799PA** Calipers: Yes
Filename: 021799PA PRO 11 Level-Water Reference: 012299Z0

Hook gage measurements (mm)									
1W	1E	2W	2E	3W	3E	4W	4E	5W	5E
86.38	84.26	79.38	90.83	80.77	88.13	93.03	86.82	82.55	83.46
86.45	84.48	79.31	90.80	80.65	88.08	93.25	87.05	82.63	83.66
86.35	84.25	79.44	90.94	80.85	88.22	93.44	86.71	82.81	83.69
86.30	84.16	79.40	90.84	80.73	88.26	93.27	86.64	82.76	83.64
86.31	84.13	79.37	90.98	80.75	88.14	93.49	86.82	82.65	83.77
86.23	84.35	79.53	90.94	80.67	88.31	93.33	86.91	82.71	83.90

TABLE B-10
Experiment Date: **02/17/99** Fixed Hook Gages: Yes Stop Logs: 2.5
Experiment Name: **021799PB** Calipers: Yes
Filename: 021799PB PRO 12 Level-Water Reference: 012299Z0

Hook gage measurements (mm)									
1W	1E	2W	2E	3W	3E	4W	4E	5W	5E
86.32	84.64	79.69	90.96	80.77	88.44	93.35	86.72	82.95	83.72
86.49	84.34	79.57	90.98	80.71	88.20	93.43	86.84	82.91	83.65
86.44	84.52	79.64	91.01	80.69	88.12	93.13	86.91	82.77	83.54
86.39	84.33	79.62	90.95	80.72	88.26	93.24	86.90	82.64	83.48
86.52	84.41	79.50	91.14	80.92	88.10	93.35	86.81	82.66	83.53
86.47	84.49	79.44	91.07	80.84	88.16	93.30	86.94	82.57	83.43

TABLE B-11
Experiment Date: **02/18/99** Fixed Hook Gages: Yes Stop Logs: 2.5
Experiment Name: **021899PA** Calipers: Yes
Filename: 021899PA PRO 13 Level-Water Reference: 012299Z0

Hook gage measurements (mm)									
1W	1E	2W	2E	3W	3E	4W	4E	5W	5E
76.93	75.00	70.46	81.92	72.01	79.77	84.94	78.61	74.36	75.91
76.89	74.95	70.59	81.88	72.13	79.69	84.97	78.66	74.45	75.88
76.97	75.07	70.43	82.00	71.94	79.50	84.80	78.76	74.82	75.74
76.90	74.99	70.32	81.90	72.02	79.60	84.83	78.68	74.77	75.84
76.94	75.01	70.41	82.07	71.98	79.48	84.97	78.62	74.66	76.02
76.82	75.00	70.39	81.99	72.03	79.53	84.98	78.80	74.77	75.90

TABLE B-12
Experiment Date: **02/18/99** Fixed Hook Gages: Yes Stop Logs: 2.5
Experiment Name: **021899PB** Calipers: Yes
Filename: 021899PB PRO 14 Level-Water Reference: 012299Z0

Hook gage measurements (mm)									
1W	1E	2W	2E	3W	3E	4W	4E	5W	5E
77.30	74.88	70.44	81.89	71.91	79.22	84.79	78.42	74.51	75.76
77.23	74.90	70.51	81.80	72.03	79.13	84.83	78.63	74.38	75.52
77.14	74.83	70.50	81.84	71.89	79.45	84.97	78.58	74.63	75.69
77.22	74.92	70.41	81.87	71.81	79.32	85.03	78.61	74.80	75.56
77.22	74.77	70.45	81.91	71.84	79.30	84.86	78.74	74.40	75.67
77.17	74.65	70.36	81.85	72.03	79.35	84.93	78.64	74.50	75.57

TABLE B-13
Experiment Date: **02/22/99** Fixed Hook Gages: Yes Stop Logs: 2.5
Experiment Name: **022299PA** Calipers: Yes
Filename: 022299PA PRO 15 Level-Water Reference: 012299Z0

Hook gage measurements (mm)									
1W	1E	2W	2E	3W	3E	4W	4E	5W	5E
69.97	67.54	63.29	74.83	65.23	72.76	78.14	71.61	67.84	69.17
70.01	67.77	63.37	74.80	65.27	72.69	78.25	71.70	67.76	69.21
69.93	67.59	63.40	74.89	65.17	72.56	77.84	72.15	68.04	69.29
69.82	67.76	63.17	74.84	65.25	72.45	77.97	71.81	67.97	69.26
69.84	67.63	63.15	74.90	65.07	72.71	78.14	71.80	67.85	69.22
69.79	67.54	63.18	74.84	65.04	72.67	78.03	72.07	67.70	69.17

TABLE B-14

Experiment Date:	**02/22/99**	Fixed Hook Gages:	Yes	Stop Logs:	2.5
Experiment Name:	**022299PB**	Calipers:	Yes		
Filename:	022299PB PRO 16	Level-Water Reference:	012299Z0		

Hook gage measurements (mm)									
1W	1E	2W	2E	3W	3E	4W	4E	5W	5E
68.95	66.79	62.78	74.62	66.05	73.36	78.33	72.31	68.56	69.51
68.84	66.70	62.79	74.55	66.11	73.29	78.47	72.29	68.38	69.43
68.92	66.62	62.81	74.56	66.08	73.40	78.41	72.09	68.28	69.52
68.89	66.69	62.74	74.53	65.91	73.32	78.49	72.05	68.47	69.47
68.93	66.41	62.96	74.66	66.10	73.25	78.23	71.96	68.48	69.45
68.86	66.47	62.99	74.59	66.05	73.37	78.38	72.03	68.36	69.37

TABLE B-15

Experiment Date:	**02/23/99**	Fixed Hook Gages:	Yes	Stop Logs:	2.5
Experiment Name:	**022399PA**	Calipers:	Yes		
Filename:	022399PA PRO 17	Level-Water Reference:	012299Z0		

Hook gage measurements (mm)									
1W	1E	2W	2E	3W	3E	4W	4E	5W	5E
61.47	58.96	55.54	66.98	58.80	66.20	71.80	65.36	62.14	62.72
61.41	59.16	55.41	67.02	58.82	66.17	71.77	65.38	62.12	62.69
61.56	58.98	55.40	67.21	58.76	66.29	71.62	65.25	62.00	62.61
61.49	58.93	55.34	67.15	58.91	66.21	71.79	65.45	62.18	62.57
61.44	59.05	55.47	67.21	58.75	66.08	71.87	65.15	62.01	62.69
61.48	59.00	55.42	67.14	58.75	66.12	71.85	65.21	62.10	62.65

TABLE B-16

Experiment Date:	**02/23/99**	Fixed Hook Gages:	Yes	Stop Logs:	2.5
Experiment Name:	**022399PB**	Calipers:	Yes		
Filename:	022399PB PRO 18	Level-Water Reference:	012299Z0		

Hook gage measurements (mm)									
1W	1E	2W	2E	3W	3E	4W	4E	5W	5E
61.45	59.00	55.40	67.10	58.80	66.17	71.80	65.30	62.08	62.65
61.35	58.99	55.46	67.17	58.63	66.16	71.56	65.14	62.18	62.66
61.43	59.04	55.38	67.11	58.71	66.23	71.70	65.42	61.95	62.60
61.32	59.14	55.42	67.12	58.88	66.18	71.61	65.16	62.12	62.74
61.42	59.09	55.34	67.17	58.62	66.10	71.79	65.20	62.04	62.69
61.31	59.06	55.47	67.14	58.59	66.05	71.65	65.07	62.17	62.80

TABLE B-17

Experiment Date:	**02/24/99**	Fixed Hook Gages:	Yes	Stop Logs:	2.5
Experiment Name:	**022499PA**	Calipers:	Yes		
Filename:	022499PA PRO 19	Level-Water Reference:	012299Z0		

Hook gage measurements (mm)									
1W	1E	2W	2E	3W	3E	4W	4E	5W	5E
58.73	56.47	52.80	64.55	56.26	63.46	69.36	62.65	60.01	60.21
58.67	56.49	52.88	64.51	56.20	63.40	69.35	62.66	59.87	60.23
58.73	56.31	52.75	64.56	56.28	63.43	69.26	62.71	59.75	60.24
58.82	56.38	52.71	64.52	56.17	63.46	69.46	62.83	59.80	60.17
58.77	56.28	52.77	64.43	56.11	63.51	69.18	62.43	59.81	60.33
58.68	56.32	52.70	64.50	56.10	63.53	69.23	62.60	59.84	60.25

TABLE B-18

Experiment Date:	**02/24/99**	Fixed Hook Gages:	Yes	Stop Logs:	2.5
Experiment Name:	**022499PB**	Calipers:	Yes		
Filename:	022499PB PRO 20	Level-Water Reference:	012299Z0		

Hook gage measurements (mm)									
1W	1E	2W	2E	3W	3E	4W	4E	5W	5E
58.74	56.46	52.73	64.53	55.75	63.74	69.20	62.48	60.07	60.38
58.66	56.41	52.65	64.43	55.61	63.60	69.00	62.55	59.99	60.31
58.62	56.55	52.88	64.54	55.64	63.61	69.38	62.78	60.18	60.26
58.69	56.30	52.69	64.53	55.64	63.68	69.16	62.67	60.14	60.30
58.63	56.28	52.68	64.60	55.67	63.60	68.93	62.66	60.13	60.24
58.66	56.22	52.81	64.53	55.56	63.77	69.00	62.70	60.15	60.41

TABLE B-19

Experiment Date: **02/25/99** Fixed Hook Gages: Yes Stop Logs: 2.5
Experiment Name: **022599PA** Calipers: Yes
Filename: 022599PA PRO 21 Level-Water Reference: 012299Z0

Hook gage measurements (mm)									
1W	1E	2W	2E	3W	3E	4W	4E	5W	5E
55.16	52.84	49.30	60.88	52.42	60.37	65.43	59.54	56.76	57.09
55.19	52.75	49.33	60.91	52.33	60.32	65.60	59.60	56.69	57.21
55.18	52.68	49.25	61.04	52.42	60.27	65.86	59.35	56.82	57.09
55.01	52.83	49.40	61.02	52.29	60.22	65.91	59.56	56.75	57.05
55.10	52.73	49.37	61.15	52.34	60.25	65.82	59.44	56.81	57.18
55.05	52.85	49.39	61.18	52.32	60.36	65.76	59.24	56.71	57.04

TABLE B-20
Experiment Date: **02/25/99** Fixed Hook Gages: Yes Stop Logs: 2.5
Experiment Name: **022599PB** Calipers: Yes
Filename: 022599PB PRO 22 Level-Water Reference: 012299Z0

Hook gage measurements (mm)									
1W	1E	2W	2E	3W	3E	4W	4E	5W	5E
55.14	52.70	49.52	61.24	52.65	60.51	65.91	59.42	57.03	57.24
55.08	52.90	49.41	61.27	52.58	60.37	65.76	59.52	56.92	57.33
55.07	52.65	49.30	61.29	52.67	60.49	65.83	59.50	57.12	57.23
55.17	52.70	49.22	61.11	52.56	60.42	66.00	59.70	56.85	57.43
54.85	52.77	49.47	61.03	52.73	60.64	65.83	59.53	56.95	57.34
54.81	52.69	49.38	61.11	52.57	60.59	65.73	59.61	57.00	57.46

TABLE B-21
Experiment Date: **03/15/99** Fixed Hook Gages: Yes Stop Logs: 2.5
Experiment Name: **031599PA** Calipers: Yes
Filename: 031599PA PRO 23 Level-Water Reference: 012299Z0

Hook gage measurements (mm)									
1W	1E	2W	2E	3W	3E	4W	4E	5W	5E
51.64	49.12	46.05	57.21	49.25	57.05	62.80	56.18	54.13	53.95
51.63	49.24	46.19	57.30	49.16	57.03	62.70	56.24	54.08	53.98
51.74	49.36	45.98	57.36	49.15	56.92	62.84	56.54	54.05	53.87
51.69	49.29	45.89	57.32	49.08	56.89	62.78	56.50	54.10	53.76
51.73	49.21	46.13	57.32	49.07	56.90	62.66	56.39	53.90	53.81
51.70	49.15	45.94	57.28	49.09	56.85	62.63	56.36	54.00	53.79

TABLE B-22
Experiment Date: **03/15/99** Fixed Hook Gages: Yes Stop Logs: 2.5
Experiment Name: **031599PB** Calipers: Yes
Filename: 031599PB PRO 24 Level-Water Reference: 012299Z0

Hook gage measurements (mm)									
1W	1E	2W	2E	3W	3E	4W	4E	5W	5E
51.62	49.14	46.19	57.40	49.17	56.88	62.84	56.41	54.31	53.88
51.65	48.88	46.07	57.32	49.41	56.87	63.01	56.13	54.04	53.76
51.71	48.99	46.01	57.75	49.23	57.11	62.84	56.52	53.94	53.85
51.60	48.95	45.98	57.69	49.30	57.20	63.05	56.51	53.89	53.91
51.70	48.93	46.18	57.49	49.25	57.00	62.88	56.34	54.20	53.80
51.67	48.81	45.99	57.50	49.40	56.91	62.83	56.46	54.02	53.73

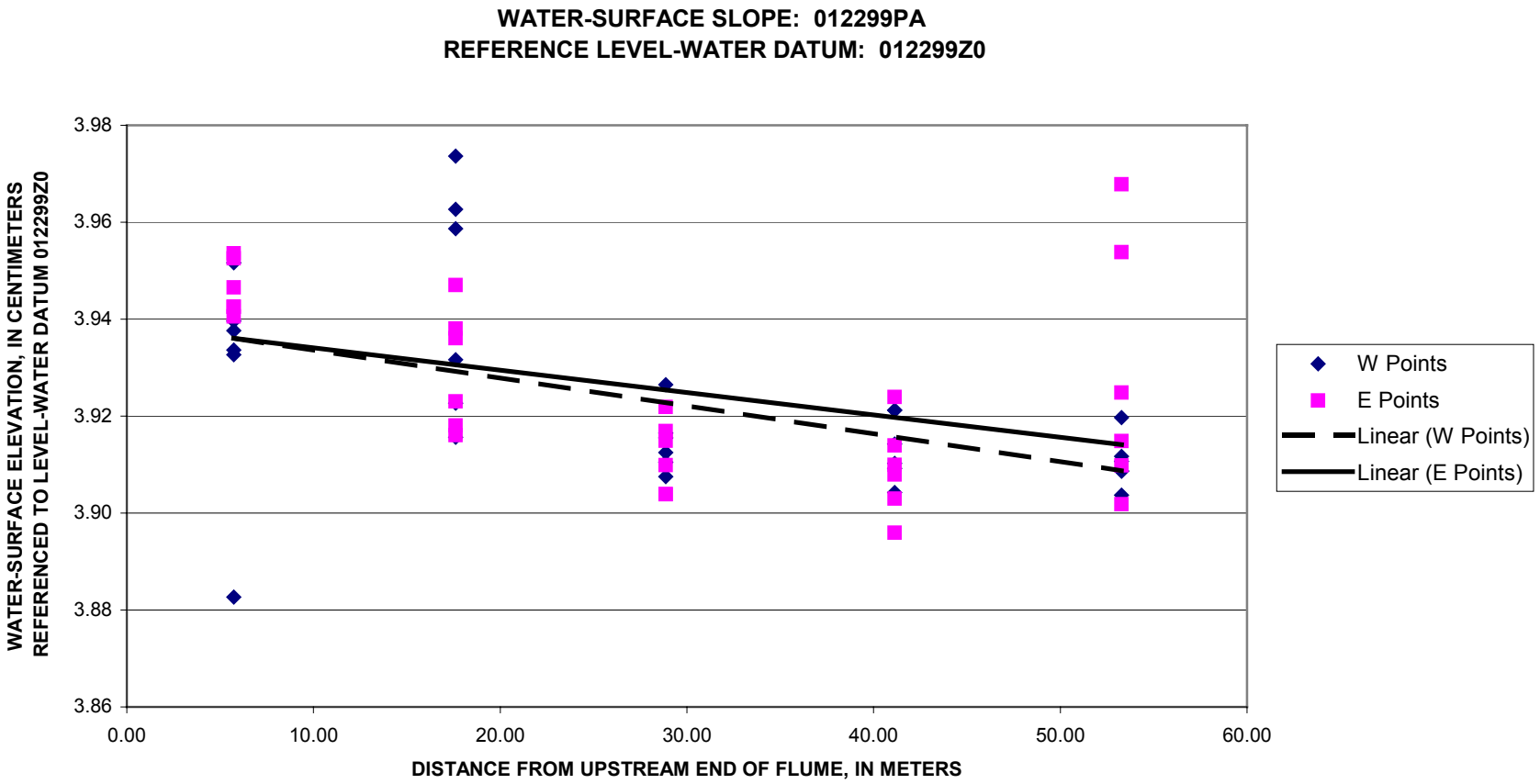

Figure B-1. Water-surface elevation as a function of distance along flume, experiment 012299PA.