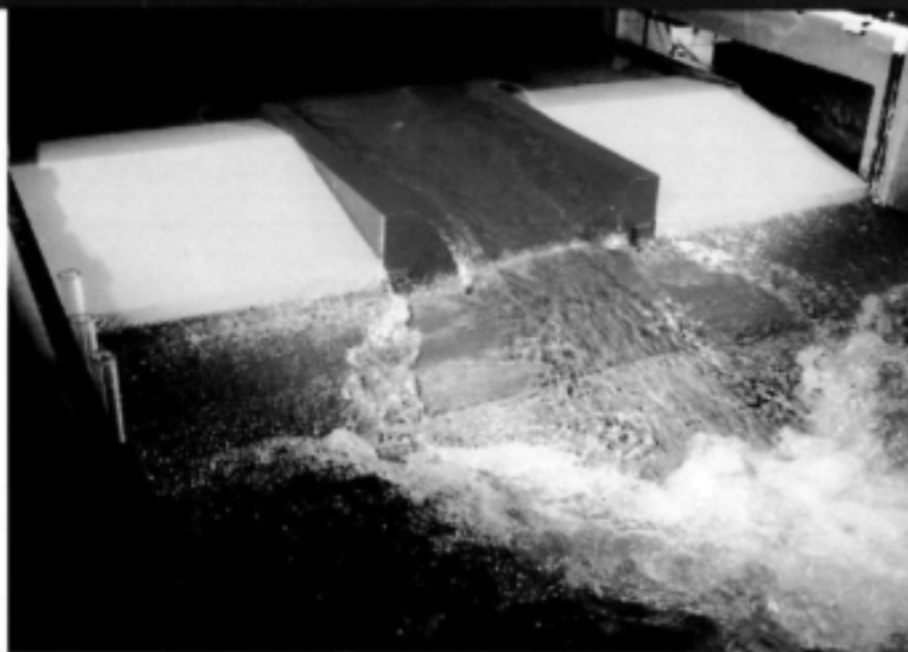
SLUICING FLUMES:

A New Structure for Discharge Measurement in Sediment-Laden Rivers



J Rossouw, C Loubser, A Rooseboom & A Bester

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A New Structure for Discharge Measurement in Sediment-Laden Rivers

by

J Rossouw, C Loubser,

A Rooseboom & A Bester

Σβ SIGMA BETA

CONSULTING CIVIL ENGINEERS

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EXECUTIVE SUMMARY

The main aim of this study was to develop and calibrate sluicing flumes for use as part of compound flow measuring structures in sediment laden South African rivers. Initial studies to develop such a flume were described in a previous report (WRC, 1995). The present study was aimed at increasing the compatibility of the sluicing flume with new and existing compound weir structures by:

- developing a series of flume geometries, concomitant with three different depth to width ratios of the flume,
- calibrating these flumes for use in combination with sharp-crested and Crump weirs of varying length, and
- developing a theoretical basis for calculating the stage - discharge relationship for the flumes as part of compound weir structures.

Ideal flume dimensions for three different depth to width ratios were derived from specifications for flow gauging flumes in the international literature (BSI, 1985). The stage - discharge relationships for such flumes can be determined from basic theory without the need for model testing for cases where all flow is contained within the flume. Once the flow overtops the side walls of a flume, it operates as part of a compound structure and model calibration is required.

Model tests on the three basic flume layouts were conducted in the hydraulics laboratory of the University of Stellenbosch. The results of these tests were used to develop a generally applicable theory for stage - discharge relationships for these flumes when used in combination with sharp-crested and Crump weirs of varying lengths.

While tests were still in progress, the Department of Water Affairs and Forestry constructed the first flume which was based on the initial studies. Although the new structure at Mpambanyoni in Natal was an improvement on previous structures with respect to sedimentation in the pool as well as at the stage recording position, problems with sedimentation in the flume were experienced after a flood. The experience at Mpambanyoni however provided valuable calibration data for simulating the sedimentation process in the model. It also led to proposals to change the flume layout. Various proposals for reducing the sediment deposition in the flume were tested in the model. These tests showed that the reduction of the length of the flume walls was the most effective way of reducing the sedimentation problem. The sedimentation problems led to considerable expansion of the test program.

Once a satisfactory solution to the sedimentation problem was found, the flumes with the shortened walls had to be calibrated. A series of calibration tests showed that the theory which had been developed for the longer flumes could be used for the shorter flumes with minor adjustments to the discharge coefficients being used.

A final series of calibration tests were conducted in which the dimensions of the flumes were optimized. In the tests much higher discharges were used and the stage was recorded in cavities in the flume wall to reduce the risk of sedimentation of the measuring system. The final series of tests were aimed at providing accurate calibration data rather than developing the theory. In these tests the behaviour of the flumes under high flow conditions with high tail water levels was also studied.

The study led to the recommendation that the three flumes shown in Figures 8.1, 8.2 and 8.3 be used. The main characteristics of these flumes are as follows:

- The flumes possess good characteristics with respect to handling heavy sediment loads. Sedimentation in the flume will still occur during the falling stages of a flood if sediment levels in the pool are above the flume invert. These sediment deposits will, however, be removed quickly during the rising stages of the next flood.

- The gauging position remains largely sediment free and the narrow control section of the flume stays totally free of sediment. The flume will therefore be able to provide accurate flow measurements even if some sediment deposits are present in the flume.

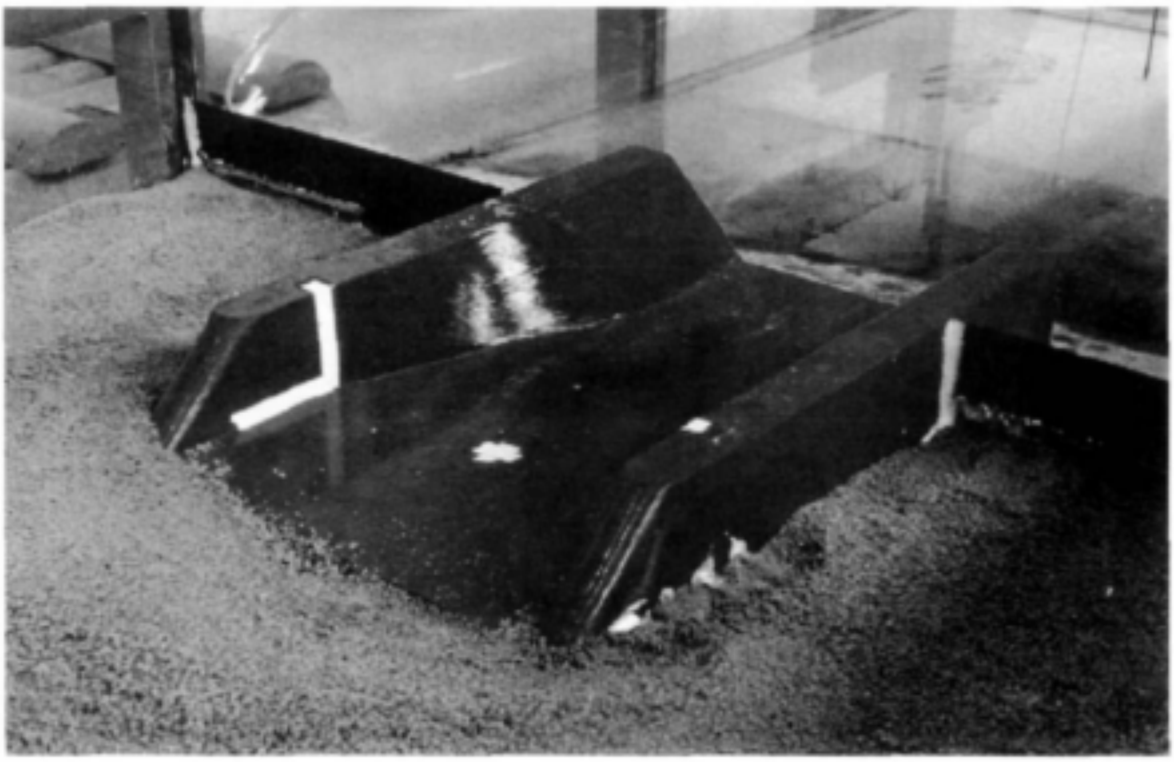
- The flumes possess stable calibration characteristics, insensitive to variations in the adjacent weir structures. This will allow combination of the flumes with a wide variety of adjacent sharp-crested and Crump weir configurations, without the need for model calibration in each case.

- The gauging position is inside the flume. Whilst flows are contained within the flume, this water level can be converted to a rate of flow by using standard theory, and calibration is therefore not affected by sedimentation in the pool upstream of the flume. At higher flows when the abutment walls are overtopped, the recorded water level is converted to a corresponding energy level in the upstream pool. This relationship should not be seriously affected by sediment deposition in the upstream pool and should lead to a more accurate estimate of the energy level in the pool than in the case where water level in the pool is recorded directly, especially where pool depths are unknown due to sedimentation.

- The flume only becomes drowned with high downstream water levels. The modular limit for all three flume configurations tested is 0.8, and flow gauging for the flume as such is possible up to 95% drowning.

- The length of the flume structures in the direction of flow, is relatively short. Although the length is shorter than recommended in the literature, the shortened flumes show stable calibration characteristics. They will be easy to construct and show superior sediment handling characteristics compared to the longer flumes.

Extensive model tests were performed during the development of the recommended flume configurations. Valued inputs were also obtained from DWAF personnel throughout the study and these inputs were incorporated in the model tests. The end result consists of the three flume configurations recommended in Chapter 8. The calibration curves for any flume and weir combination can be derived analytically by means of the procedures described in Chapter 11. These procedures have a sound theoretical basis and it is expected that flow measurement with errors less than 5% will be possible over a wide range of flow conditions.



Photograph of new flume (d/b=0.5)

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(i) The Water Research Commission for their kind sponsorship and for their full support in the project. A special word of thanks is due to Mr *DS van der Merwe*, Deputy Executive Director of the WRC, for his able leadership on the project.

(ii) The Department of Water Affairs and Forestry for its support. These reports must be seen as direct outcomes of the Department's continued striving towards higher degrees of accuracy. The positive results which have been obtained reflect favourably on the sound basis on which hydrological flow gauging rests in South Africa. Dr *Pieter Wessels* has played an invaluable role in the project not only as the main link between ourselves and the Department, but also as a tenacious advocate of precision.

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(iv) Dr *Hugo Lotriet* was mainly responsible for the initial development of the new type of measuring flume and served as the main author of the relevant report.

(v) Mr *Carlo Loubser* was responsible for the further development of the sluicing flume and made a major contribution to the present report.

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Mr *S van Biljon*
Mr *HC Chapman*
Dr *JM Jordaan*
Dr *MJ Shand*
Mr *JJ van Heerden*
Prof *TW von Backström*
Mr *FP Marais*

A ROOSEBOOM
Project leader

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LIST OF SYMBOLS

Symbol	Meaning of symbol	Unit
A_1	Length by which adjacent weirs are shortened on the right (looking downstream)	m
A_2	Length by which adjacent weirs are shortened on the left (looking downstream)	m
A_c	Critical flow area in the control section	m^2
b	Bottom width of flume	m
B_c	Critical top flow width at the control section	m
C_{d2}	Coefficient of discharge quantifying energy losses between gauge point and flume exit	
C_{d5}	Coefficient of discharge quantifying energy losses between the upstream pool and flume exit	
d	Depth of flume	m
E_s	Specific energy, i.e. energy relative to the channel bed	m
E_{s2}	Specific energy at gauge point 2 in flume	m
E_{s5}	Specific energy in upstream pool (region of gauge point 5)	m
E_{sc}	Specific energy at the control section	m
g	Gravitational acceleration (normally taken as 9,81)	m/s^2
H	Energy level	m
h_0	Unsubmerged flow depth in flume	m
h_{p0}	Unsubmerged flow depth upstream of flume	m
h_{pv}	Submerged flow depth upstream of flume	m
h_v	Submerged flow depth in flume	m
k	Coefficient used to compensate for energy losses between 2 and 5	
L_1	Total width of flume without abutment wall thickness	m
L_2	Length of adjoining weir	m
p	Height of flume bed above channel bed	m
Q	Discharge in general	m^3/s
Q_R	Actual discharge in flume	m^3/s
Q_T	Discharge calculated from theory	m^3/s

Q_{TOT}	Total discharge through flume and over adjacent weirs	m^3/s
Q_W	Discharge over adjacent weirs	m^3/s
s	Abutment wall thickness	m
S	Percentage of submergence	
t	Downstream water level relative to flume bed	m
v	Velocity of flow	m/s
W	Total width of laboratory channel	m
y_2	Water level at gauge point in flume (relative to flume invert)	m
y_5	Water level in upstream pool (relative to flume invert)	m
y_{10}	Water level in downstream pool (relative to flume invert)	m
y_c	Critical water level in the control section	m

CHAPTER

ONE

INTRODUCTION

The development of a new structure for the accurate measurement of discharge in sediment laden South African rivers has been the objective of intensive studies at the University of Stellenbosch from 1992 onwards. A first report dealing with this subject was published in 1995 (WRC, 1995). The background to the study, theoretical concepts and results of the first calibration tests on the newly developed structure were summarized in that report. The proposed new structure consisted of a flume in combination with a pair of Crump weirs which could be fitted into any compound weir structure (see Figure 1.1). The new structure had fixed relative dimensions and the model calibration would be valid only for prototypes scaled up from the model. The calibration of this structure was based entirely on model tests and no effort was made to develop a theoretical basis for its calibration.

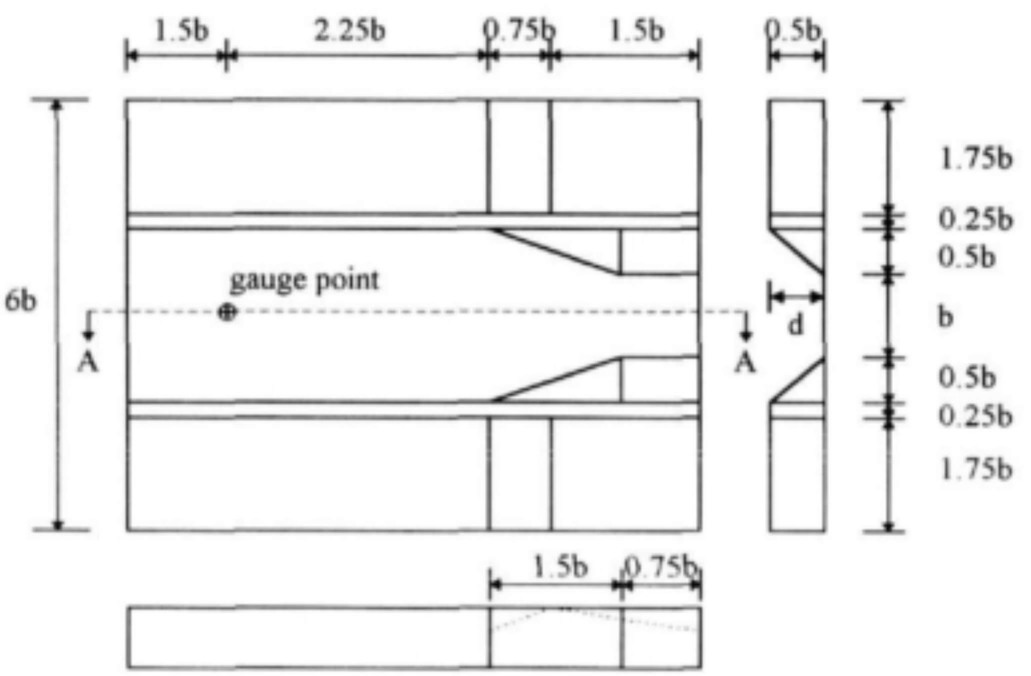

FIGURE 1.1:- Sluicing flume from previous study (WRC,1995)

In order to make the new structure suitable for a wider range of conditions, the original study was extended to include:

- a wider range of depth to width ratios for the flume
- use of the flume in combination with sharp-crested and Crump weirs of varying length
- the development of a theoretical basis which could be used to calculate stage - discharge relationships for a variety of flume - weir combinations

The results of this study would allow the inclusion of the new structure in a large range of existing and new compound flow measuring structures being used in South Africa, without the need for laboratory calibration in each case.

An extensive general background to flow measurement in South African rivers was summarised in the previous report (WRC, 1995). The need for flow measurement, theoretical concepts relating to flow measurements and sediment transport, and the historical evolution of flow measuring structures in South Africa were covered. This material will not be repeated in this report.

This report presents the results of the extended studies. The general approach to the dimensioning of flumes to comply with international standards is described, as well as the basis for theoretical calculation of calibration curves for the flumes which has been developed. This theory has been developed with the aid of the calibration of a large number of flume - weir structures in the Hydraulics Laboratory of the University of Stellenbosch. While these tests were still in progress, the DWAF (Department of Water Affairs and Forestry) constructed the first flume based on the recommendations of the initial study. Although the new structure at Mpambanyoni was an improvement on previous structures with respect to sedimentation in the upstream pool and at the recording position, problems with sedimentation were experienced inside the flume. The experience at Mpambanyoni however provided valuable data for evaluating the sedimentation process in the models. It also led to proposals to change the flume lay-out in an attempt to reduce the sedimentation problem. These changes mainly consisted of shortening of the flume abutment walls. These proposed changes were incorporated in the test program and led to considerable expansion of the test program. The new structures had to be calibrated; their sedimentation characteristics were compared to those of the originally proposed structures and their performance were tested under drowned conditions.

A final series of tests was conducted to provide accurate calibration information for the flumes, using a stage recording position favoured by DWAF and a much higher range of flow conditions than in the earlier tests.

The following lay-out has been used for this report:

- In Chapter 2, dimensioning of the three flumes, to comply with international standards, is described.

- In Chapter 3, the theoretical approach for establishing the stage - discharge relationship for the flume as part of a compound weir structure is described.

- Model tests to calibrate the flume and to test the sensitivity of the calibration to variations in dimensions of the flume walls and adjacent weirs are described in Chapter 4.

- The results of the model calibration tests are analysed in Chapter 5. The coefficients and transfer functions required to make the results more generally applicable as well as accuracies obtained by these methods, are also described.

- Chapter 6 describes the tests that were performed on the model to improve the sedimentation patterns in the flume.

- The modular limit and behaviour of the flume and adjacent weir structures under non-modular flow conditions are covered in Chapter 7.

- The structures being recommended as a result of this study, are described in Chapter 8.

- In Chapter 9 the final calibration tests on the recommended structures are described.

- In Chapter 10 the behaviour of the recommended structures under non-modular flow conditions are described.

- In Chapter 11 the procedures for implementing the results of the structures are summarised.

- Conclusions and recommendations are contained in Chapters 12 & 13.

The numbers used for figures, tables and appendices in the report follow sequentially in each chapter. The first figure, table and appendix in Chapter 3 for example, will be numbered Figure 3.1, Table 3.1 and Appendix 3.1, respectively.

CHAPTER

TWO

SELECTION OF FLUME DIMENSIONS

The reasoning and tests which led to the measuring structure recommended in the initial study (see Figure 1.1), were described in WRC, 1995. This structure consisted of two components:

(i) A flume structure which complies with international standards regarding lay-out and measurement position.

(ii) Two adjoining Crump weirs, which are not separated from the flume by dividing walls, and with the crests of these weirs at the same level as the top of the flume walls.

When it was decided to extend the applicability of this structure to a wider range of conditions, two additional depth-to-width ratios of the flume were considered at the request of the DWAF. These three flumes need to be used in combination with sharp-crested and Crump weirs of different crest lengths. To limit the number of combinations of structure components that had to be tested, it was decided to adhere as closely as possible to international standards for the flume lay-out. This would ensure that the calibration curve for the flume as such could be derived from theory, thereby eliminating the need for extensive calibration tests on the flume.

The detailed analysis which led to the selected flume lay-outs shown in Figure 2.1, is given in Lotriet (1996). In principle, three different depth-to-width ratios were considered at the request of DWAF, i.e. 0.25, 0.5 and 1.0. For each of these flumes the length of the throat, the transition and the head measuring position, were determined to ensure that the flume would comply with international standards.

A feature of all three these flumes was the relatively long length of the flume abutment walls, providing the required distance between the control section of the flume at the flume outlet and the stage recording position. These long flumes often present construction difficulties since the rock on which the flow gauging structures are normally founded, often does not extend sufficiently far upstream to support the walls. Sedimentation tests also showed that shorter flumes have better self cleansing characteristics. For these reasons, much shorter flumes were also tested at a later stage in this study. The reduction in flume length was obtained by reducing the length of the parallel section of the flume. The upstream ends of the flume walls were also sloped at an angle of 45 degrees when the shorter flume walls were tested, as experience of the DWAF indicated a lesser tendency for trees an other debris to become entangled when sloped ends were used.

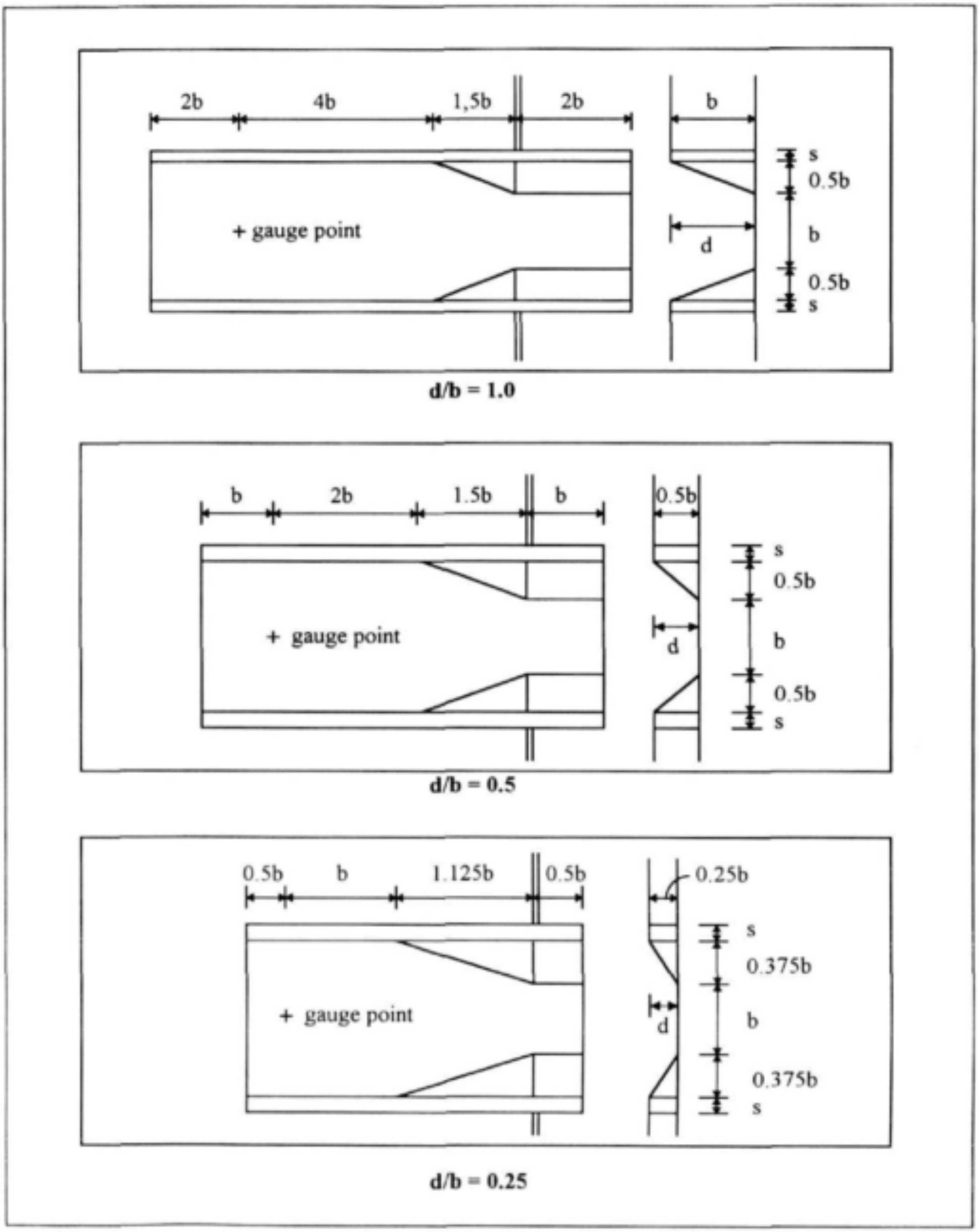

FIGURE 2.1 - Sluicing flumes based on international standards

CHAPTER

THREE

THEORETICAL STAGE - DISCHARGE RELATIONSHIP

3.1 General

The main reason for selecting flume structures that comply with international standards, is that the stage - discharge relationship for such flumes can be calculated from known and accepted theory and known coefficients. As long as the flume abutment walls are not overtopped, and flow takes place through the flume only, standard theory can be used in calculating the stage - discharge relationship.

Once the abutment walls are overtopped, the flow pattern becomes more complicated and certain assumptions are needed to calculate the stage - discharge relationship. In this study these assumptions were tested and the results for the various assumptions compared to those obtained from laboratory calibration of the structures. The aim was to find a rational approach whereby the theoretical stage - discharge relationship of the flume, in conjunction with adjacent weir structures, could be determined. If this could be achieved, the flume could be combined with a wide range of existing measurement structures without the need for laboratory calibration of each flume - weir combination.

Three distinct flow conditions were considered i.e.:

- Condition 1: Flow in the flume only, before the abutment walls overtopped (The energy level in the pool upstream of the flume is lower than the walls of the flume).
- Condition 2: The abutment walls of the flume overtopped (and therefore the adjacent weirs as well), but the flow depth at the flume outlet was lower than the flume height.
- Condition 3: The flume abutment walls overtopped and the flow depth at the flume outlet exceeded the flume height.

3.2 Flow within the flume only

Before the abutment walls are overtopped, all flow enters the rectangular section of the flume between the walls, and leaves the trapezium shaped control section of the flume under critical conditions. This situation is illustrated in Figure 3.1

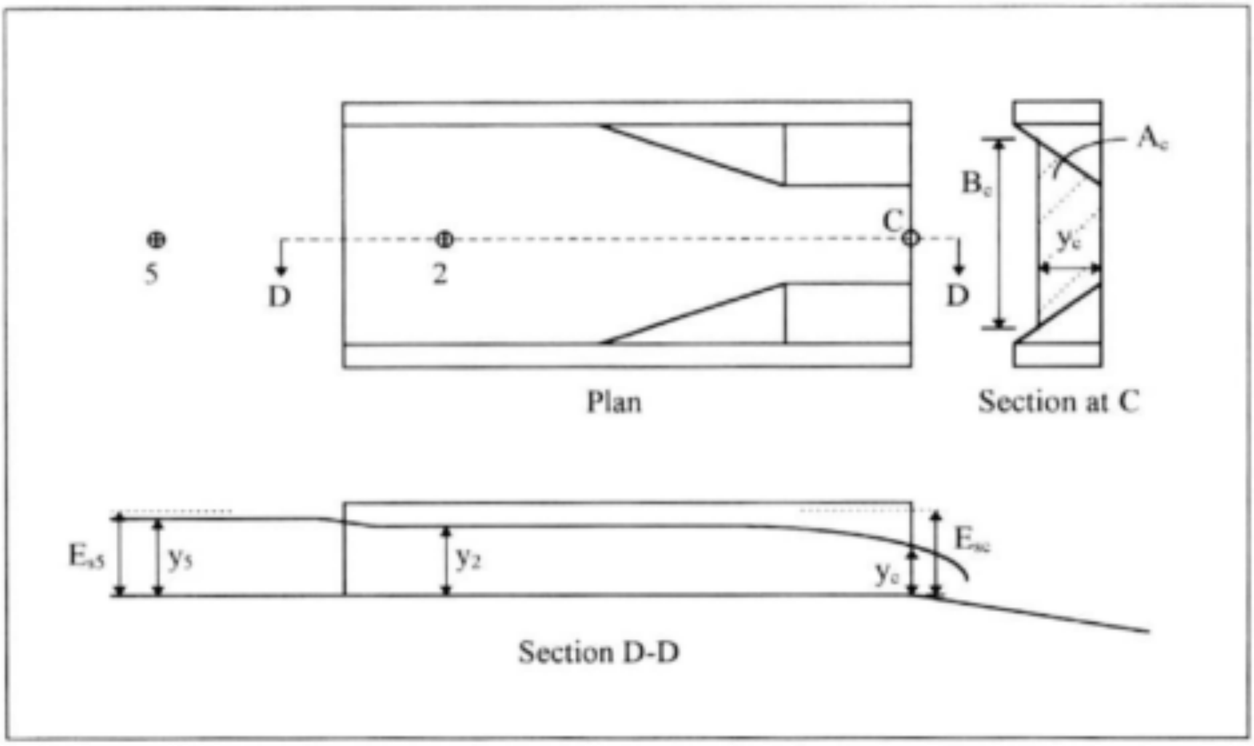

FIGURE 3.1: Definition sketch - flow in flume only

For this case the calculation of the discharge from a known water level at the recording position in the flume, is simple. The procedure is as follows:

- Select a value for the critical depth (y_c) at the control section of the flume.
- Calculate the flow area (A_c) and the top width (B_c) at the control section corresponding to the selected critical depth (y_c).
- Calculate the discharge from $Q_T^2 B_c / g A_c^3 = 1$.
- Calculate the specific energy E_{sc} at the control section as $E_{sc} = y_c + v_c^2/2g$ with $v_c = Q_T / A_c$.
- Assume no energy losses between the control section (c) and the measurement position (2), i.e. $E_{sc} = E_{s2} = y_2 + v_2^2/2g$ with $v_2 = Q_T / A_2$. Solve for y_2.
- The theoretical discharge value (Q_T) calculated above, can be converted to an actual discharge (Q_R) by the use of a discharge coefficient (C_{d2}), which must be determined experimentally or from published data, i.e. $Q_R = C_{d2} \times Q_T$.

These calculations are valid until the energy upstream of the flume, E_{s5}, reaches a value equal to the flume height. At this stage the abutment walls will be overtopped and flow over the adjacent structures must therefore be taken into account.

3.3 Abutment walls overtopped, with y_c in the flume less than the flume height

When the abutment walls of the flume are overtopped, the flow passing through the flume control section at the flume exit, enters through the rectangular entrance, as well as across the abutment walls. Under these conditions it is necessary to convert the recorded water level in the flume, y_2, to an energy level in the pool upstream of the flume, E_{s5}. Results from laboratory tests will be needed to establish the procedure for this conversion. With a known energy level in the pool upstream of the flume, E_{s5}, the theoretical discharge through the flume can be calculated by assuming the critical (minimum) energy height at the flume exit, E_{sc}, to be the same as the upstream energy head, E_{s5}. The true discharge can be obtained by allowing for the losses between the pool and the flume exit by means of a discharge coefficient, C_{d5}. It is further assumed that the flow perpendicular to the ends of the flume walls can be neglected. The discharge over the weirs adjacent to the flume can be calculated from E_{s5} using the internationally accepted formulas for sharp-crested or Crump weirs. A total discharge for the compound structure as a function of the energy level in the pool upstream of the flume, E_{s5}, can therefore be determined for any combination of flumes and weirs.

3.4 Abutment walls overtopped, with y_c at the flume outlet greater than the flume height

This case is similar to the one described in section 3.3 above. The only difference now is that the flow over the end sections of the flume abutment walls increases. This is illustrated in Figure 3.2.

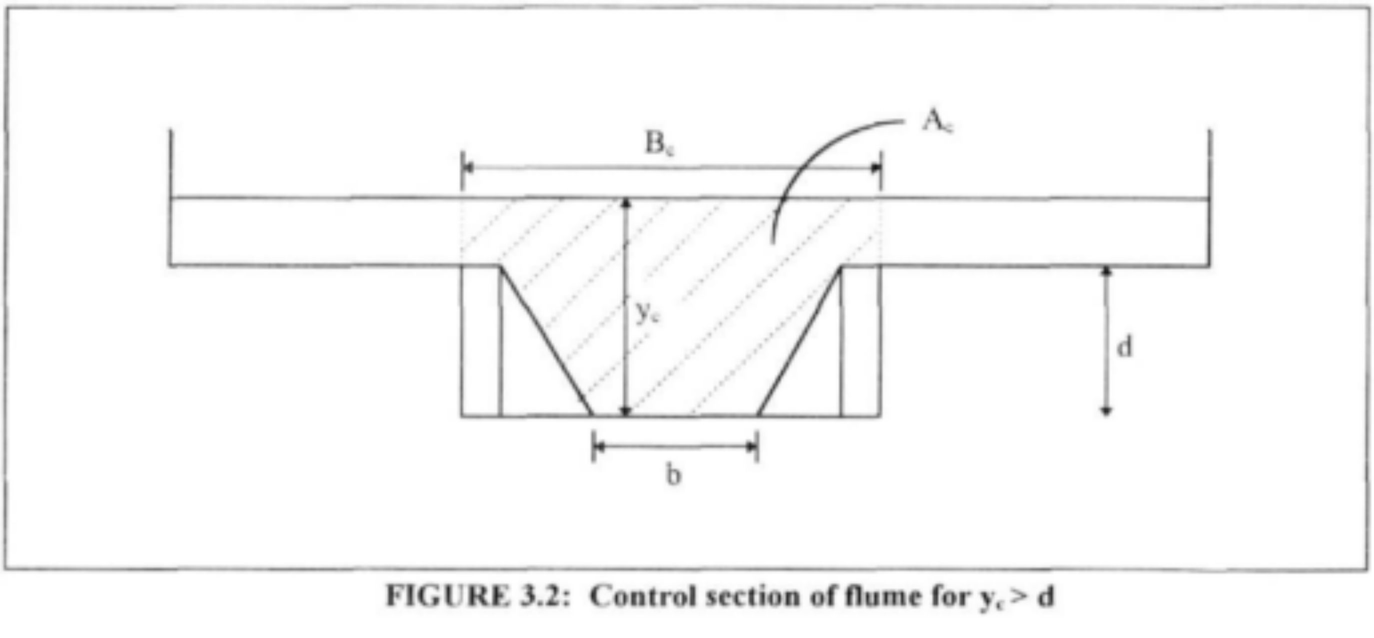

FIGURE 3.2: Control section of flume for $y_c > d$

The assumption is therefore made that the control section of the flume is now a combination of a trapezium flowing full with a rectangular section on top as illustrated in Figure 3.2. For a given critical depth y_c, the expression for A_c is changed and B_c becomes the top width of the full flume plus the width of the two abutment walls.

3.5 Conclusions

Based on the procedures described in the above sections it is thus possible to establish a theoretical relationship between the stage recorded inside the flume (y_2) and the discharge (Q) directly, for cases where all the flow is contained within the flume. When the flume abutment walls and the weirs adjacent to the flume are overtopped, the relationship between the energy upstream of the flume, E_{s5}, and the discharge can also be derived theoretically for any combination of flume and weir structures. The relationship between the recorded stage, y_2, and the energy level in the pool, E_{s5}, as well as discharge coefficients C_{d2} and C_{d5}, to compensate for energy losses, must be based on model tests.

CHAPTER

FOUR

CALIBRATION TESTS

4.1 Introduction

The aim of calibration tests on flow measuring structures is to establish the relationship between the water level (stage) at a point in the flume and the discharge. In the case of the sluicing flumes being considered here, an additional aim is to establish the discharge coefficients for the flume when used in combination with sharp-crested and Crump weirs of various lengths. Similarly, the relationship between stage as measured in the flume and the energy upstream of the flume needs to be established. In order to achieve these objectives it is necessary to accurately record the discharge and the water levels inside as well as upstream of the flume for a variety of flume configurations and discharges.

To limit the number of calibration tests that had to be performed, model tests in this study were used mainly as an aid to develop a sound theory for the calculation of the stage - discharge relationship. To assist in the development of the theory, water levels were recorded at a number of positions in the model. These water levels, combined with the recorded discharges, could be used to define energy losses across the structure and to establish the relationship between recorded water level and energy upstream of the structure. The discharge coefficients required to convert from theoretical to actual discharges, could also be determined from these observations.

4.2 Laboratory facilities

4.2.1 Laboratory set-up

All the model tests were done in the hydraulics laboratory of the University of Stellenbosch. Water was supplied to the model from a constant head tank to ensure a constant rate of flow for the duration of each experiment. The rate of flow was adjusted by a valve in the supply line to the model. The discharge to the model was measured in the supply line by using an orifice plate connected to a manometer. The rate of flow in the return channel from the model was recorded by means of sharp-crested rectangular and V-notch weirs.

In a calibration study, accurate measurement of discharge is of obvious importance. Where possible, discharges were measured upstream and downstream of the flume, using different flow measuring devices. This ensured stabilization of flow and especially low discharges and minimized chances of mistakes.

4.2.2 Orifice and manometer

A pressure differential is created along the flow by providing a sudden constriction in the pipeline, in the form of a circular ring with an inside diameter less than that of the pipe. This pressure differential is measured by means of a manometer. For measuring low flows accurately, a water manometer was used, while the higher flows were measured by means of a mercury manometer. The following equation is used to determine the relationship between the measured head and flow rate (Featherstone & Nalluri, 1982):

$$Q = C_d \, a_1 \sqrt{\frac{2gh}{\left(\frac{a_1}{a_2}\right)^2 - 1}}$$

C_d = Coefficient of discharge

a_1 = Inside sectional area of pipe 4.1

a_2 = Inside sectional area of orifice

h = Measured pressure difference

4.2.3 Rectangular notch

On the downstream side of the three meter channel, the flow was measured by means of a rectangular notch. The reason for this second flow measurement, was to ensure that flows stabilized before stage measurements was taken. It obviously also served as a check on the accuracy of the flow measured in the orifice. The following equation is used to determine discharge when the height of flow over the notch is known (Bos, 1976):

$$Q = \frac{2}{3} C_d \sqrt{2g} \times (h + 0.001)^{1.5} \times (w + 0.0043)$$

$$C_d = \left(0.597 + 0.045\left(\frac{h}{P}\right)\right)$$

h = Height of flow over notch 4.2

P = Pool depth upstream of notch

w = Width of rectangular notch

4.2.4 V-notch

On the downstream side of the two meter channel, the flow was measured by means of a triangular or V-notch. The second measurement was again to determine when flow stabilized and to serve as a check on the accuracy of flow measured with the orifice. The following equation was used to measure discharge (Featherstone & Nalluri, 1982):

$$Q = \frac{8}{15} C_d \sqrt{2g} \tan\left(\frac{q}{2}\right) h^{5/2}$$

$$C_d = \text{Coefficient of discharge} (0.59) \qquad 4.3$$

$$q = \text{Angle of V}$$

$$h = \text{Height of flow over V-notch}$$

4.2.5 Experimental set-up

The experimental set-up is shown diagrammatically in Figure 4.1.

The models were constructed within rectangular flow channels in the laboratory. Two flow channels were used i.e. a three-meter wide concrete channel and a two-meter wide glass channel. Water supply to both channels was through 300 mm diameter steel pipes. Upstream from where experiments took place, a row of special bricks were stacked in the channels, in order to create uniform flow. In the wider channel, a floating wooden rack was also used to eliminate surface wave action.

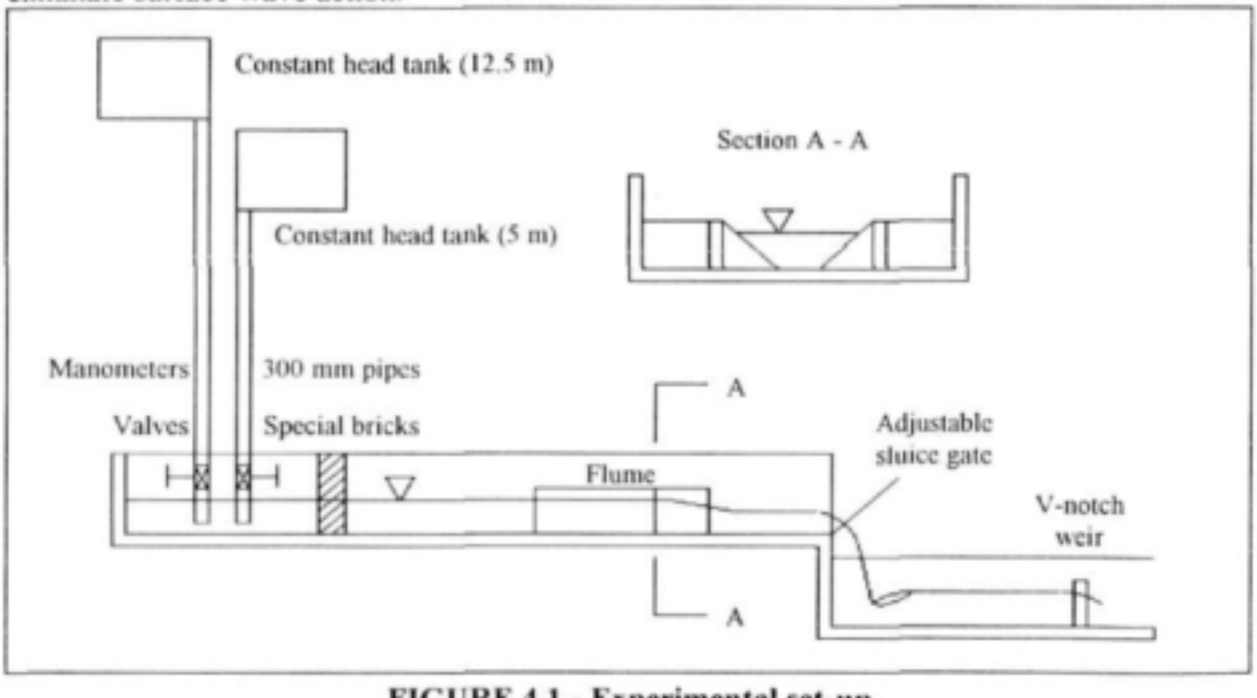

FIGURE 4.1 - Experimental set-up

The two-meter wide channel was fitted with an adjustable horizontal sluice-gate on the downstream side. This sluice gate could be used to cause submergence of the flume from the downstream side, in order to investigate flow conditions in a submerged flume. Figure 4.2 contains a schematic diagram of the channel in which model studies were undertaken.

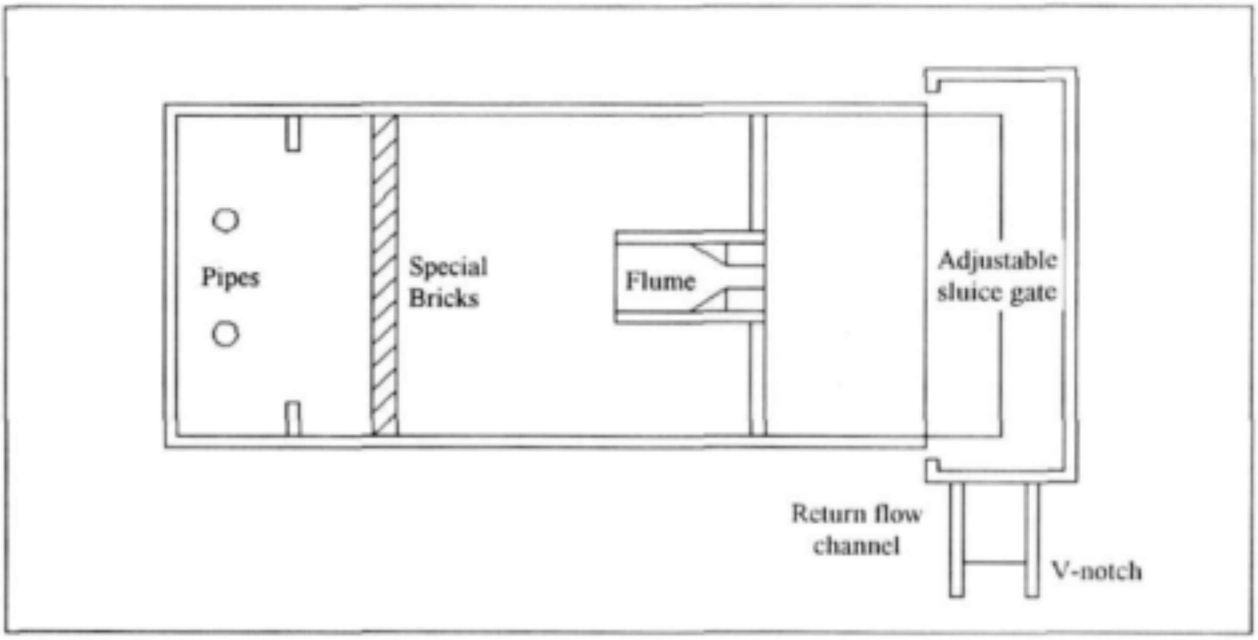

FIGURE 4.2 - Schematic diagram of channel in which model studies were undertaken

Water levels in the models were measured directly by means of needle gauges. In later tests on the recommended structures, additional water levels were measured using tubes connected to stilling wells. This was done to measure stage in areas where vorticity caused uneven water surface profiles, especially next to the flume walls. The wells with their connecting pipes dampened level fluctuations and made accurate stage readings possible. Another reason for this method of measurement, was to imitate the way in which the DWAF measures stage in practice.

Water levels relative to the bed of the flume in most of the tests were measured at eight predetermined positions (see Figure 4.3). Stage was also measured in the wells at six additional points and one original point. Readings at this point were used to compare the results of the two methods of stage measurement.

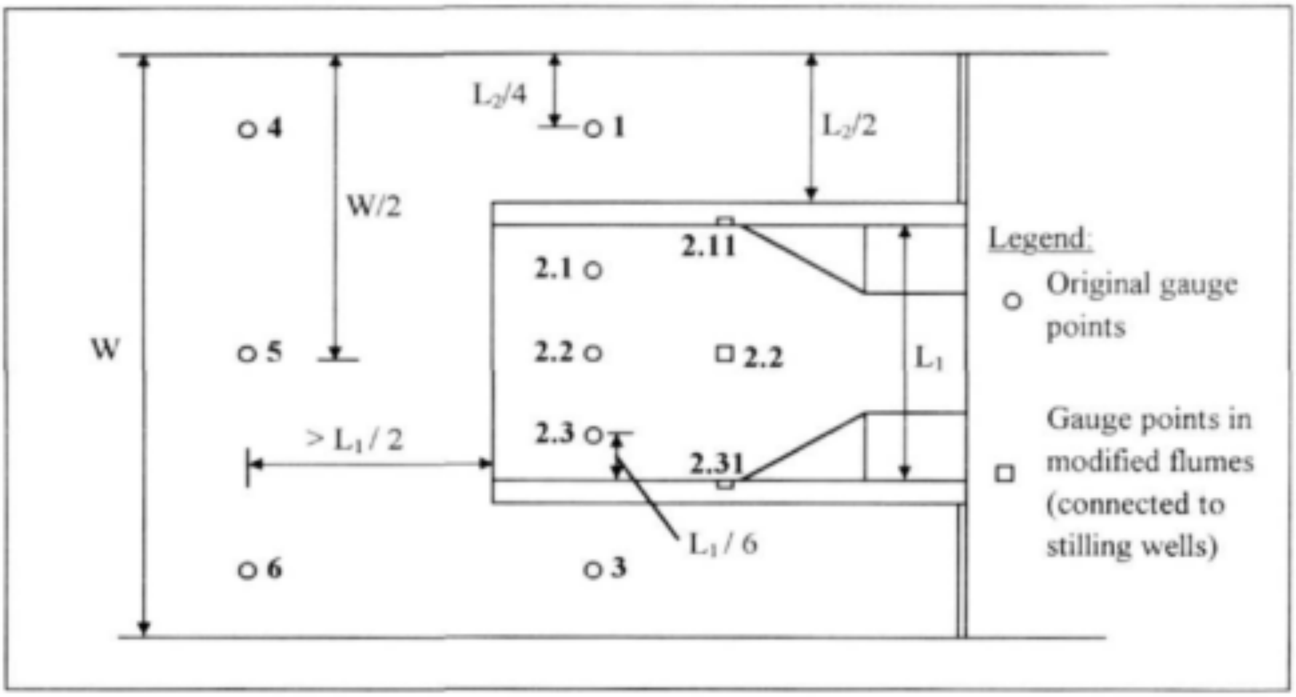

FIGURE 4.3 - Lay-out showing positions of gauge points

4.3 Test procedures

The standard procedure used in the model calibration tests was as follows:

- The model was installed in the flow channel by carefully leveling the flume abutment walls and adjoining weirs, whereafter fixing and sealing of the model took place.
- The water supply to the model was set to a desired rate of flow.
- The flow was allowed to stabilize and discharge was recorded in the supply line as well as in the return channel for the purpose of verification.
- Water levels relative to the bottom of the sluicing flume were recorded at the positions indicated on Figure 4.3.
- The procedure was repeated for a series of discharges for each model set-up.

4.4 Models tested

4.4.1 Model construction

The models of the flumes used in most experiments, were constructed of wood. The flumes of model 2, were however built of wood and mortar. Wooden models of the flumes allowed easy and quick alterations. A model could be removed as a unit, altered and reinstalled in a fraction of the time that alterations to models of mortar would take.

Sharp-crested weirs consisted of wooden lower portions, which ensured easy and accurate installation. The upper portions, which formed the weir, were made of PVC. The sharp-crested weirs were aerated by means of thin perforated perspex pipes. Crump weirs were made of mortar or wood.

4.4.2 Model lay-outs tested

A definition sketch of the dimensions used in the various model lay-outs that were tested is shown in Figure 4.4. Dimensions of all the lay-outs that were tested are summarized in Table 4.1. Three basic lay-outs for d/b ratios of 0.5, 1.0 and 0.25, as shown in Figures 4.5, 4.8 and 4.11, provided the basis for the calibration tests. The majority of the tests were done on lay-out 2 as the authors believe that this lay-out will be used most frequently in practice. This lay-out was tested for a range of L_2/L_1 ratios, in combination with sharp-crested and Crump weirs and for a range of thicknesses for the flume abutment walls.

While tests on the original lay-out 2 were still in progress, siltation was experienced at a comparable prototype structure at Mpambanyoni near Scottburgh in Natal. This caused the test programme to be adjusted in an effort to reduce the siltation problem. The best solution seemed to be to reduce the length of the abutment walls of the flume (see Chapter 6). The short-walled flumes shown in Figures 4.6, 4.9 & 4.12, were then also tested. These lay-outs are denoted by lay-out numbers 2VS (lay-out 2 very short), 2S (lay-out 2 short), 1S and 3S in Table 4.1. Most of the tests on the shortened flumes were for a d/b ratio of 0.5. The tests on the other d/b ratios of 1.00 and 0.25 were limited due to the time constraints and budget of the study. The theoretical calibration procedure which was developed proved to provide accurate calibration curves for all lay-outs which were tested, and eliminated the need for further tests on different lay-outs.

The range of L_2/L_1 and y_2/d ratios that were tested for each of the three flume lay-outs are shown in Table 4.2.

The finally recommended structures evolved from the calibration tests, sediment tests and tests under high tailwater levels. The finally recommended structures were calibrated in detail over a wide range of flow conditions, using the stage recording position favoured by DWAF. The calibration of the finally recommended structures are described in Chapter 10

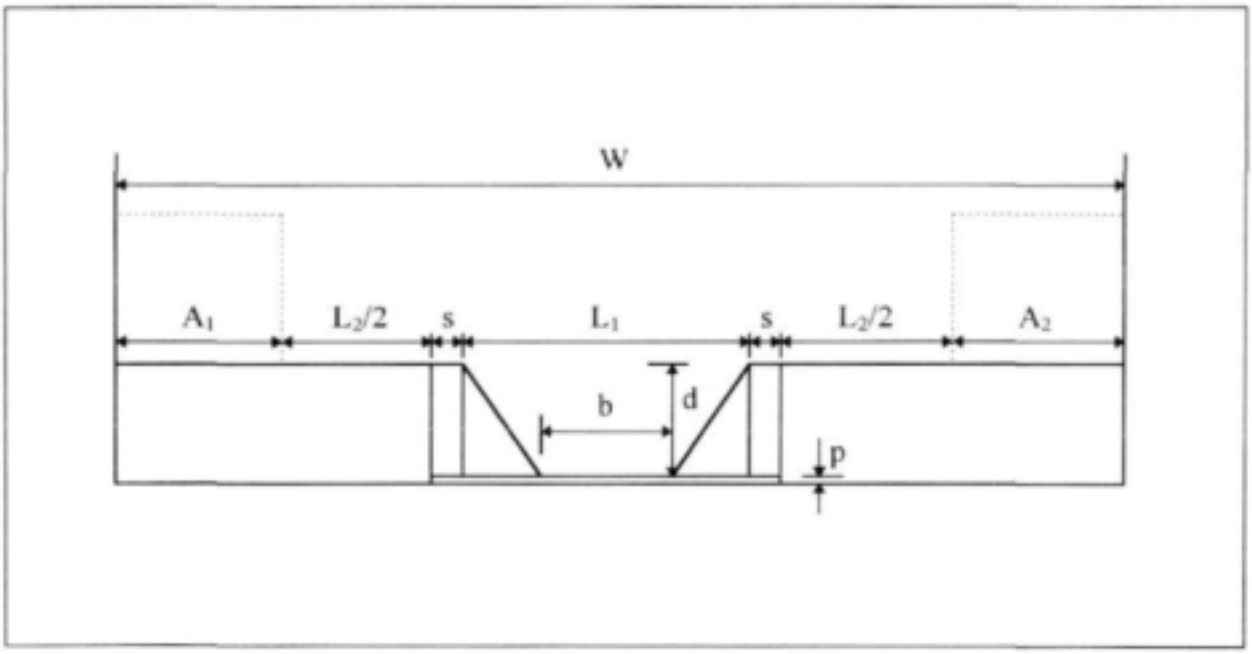

FIGURE 4.4 - Definition sketch of variables in tests

TABLE 4.1 - Dimensions of lay-outs tested (mm)

Lay-out	Test	b	d	L_1	L_2	s	W	p	A_1	A_2	Weir	Flume material	Comments
2	1.1	264	132	528	2340	66	3000	25	0	0	Sharp	Wood	
	1.2	264	132	528	800	66	3000	25	770	770	Sharp	Wood	
	1.3	264	132	528	1340	66	2000	25	0	0	Sharp	Wood	
	2.1	264	132	528	1426	23	2000	0	0	0	Sharp	Wood	Thin wall
	2.2	264	132	528	1262	105	2000	0	0	0	Sharp	Mortar	Thick wall
	2.3	264	132	528	1262	105	2000	0	0	0	Crump	Mortar	
2VS	5.1	264	132	528	1340	66	2000	25	0	0	Sharp	Wood	Very short
2S	6.1	264	132	528	1340	66	2000	25	0	0	Sharp	Wood	
2R	6.2	264	132	528	1340	66	2000	25	0	0	Sharp (end)	Wood	Recom-mended
	6.3	264	132	528	670	66	2000	25	0	670	Sharp (end)	Wood	Recom-mended
	9.1	264	132	528	1340	66	2000	25	0	0	Sharp (end)	Wood	Recom-mended
	9.2	264	132	528	1340	66	2000	25	0	0	Crump	Wood	Recom-mended
1	3.1	174	174	348	1520	66	2000	25	0	0	Sharp	Mortar	
1S	7.1	174	174	348	1520	66	2000	25	0	0	Sharp (end)	Wood	
1R	10.1	174	174	348	1520	66	2000	25	0	0	Sharp (end)	Wood	Recom-mended
3	4.1	412	103	721	1147	66	2000	25	0	0	Sharp	Wood	
3S	8.1	412	103	721	1147	66	2000	25	0	0	Sharp (end)	Wood	
3R	11.1	412	103	721	1147	66	2000	25	0	0	Sharp (end)	Wood	Recom-mended

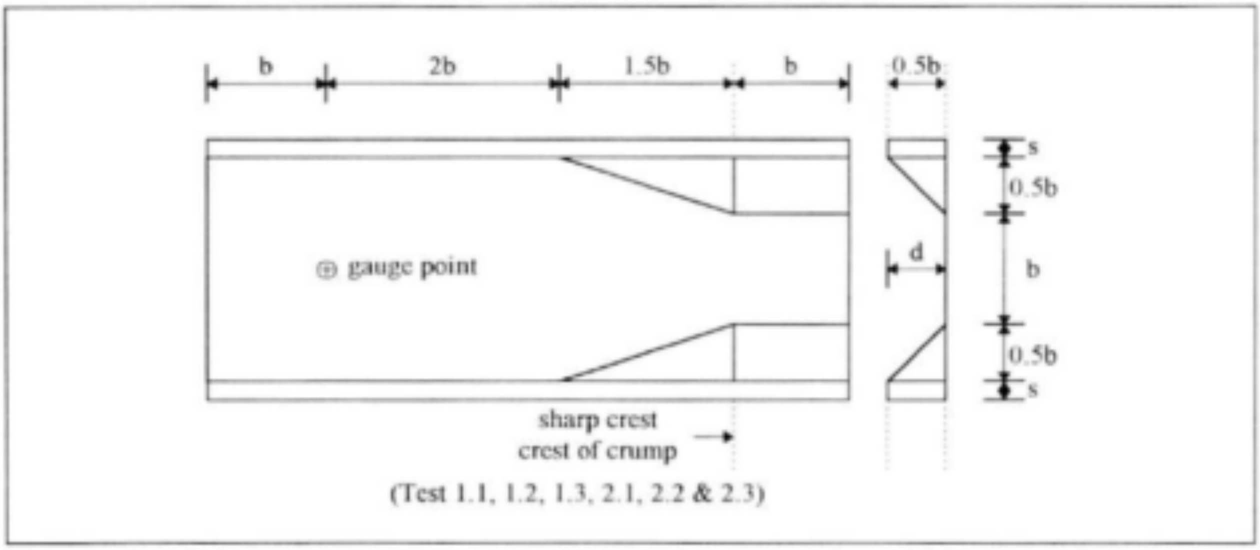

FIGURE 4.5 - Original flume dimensions for lay-out 2 (d/b = 0.5)

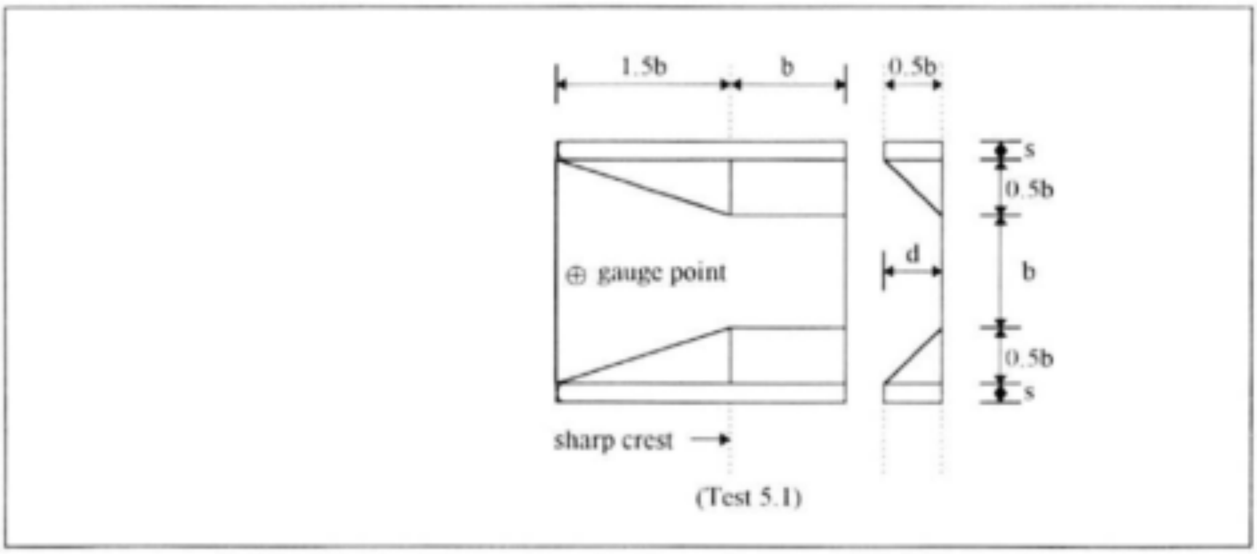

FIGURE 4.6 - Dimensions for flume lay-out 2VS (d/b = 0.5)

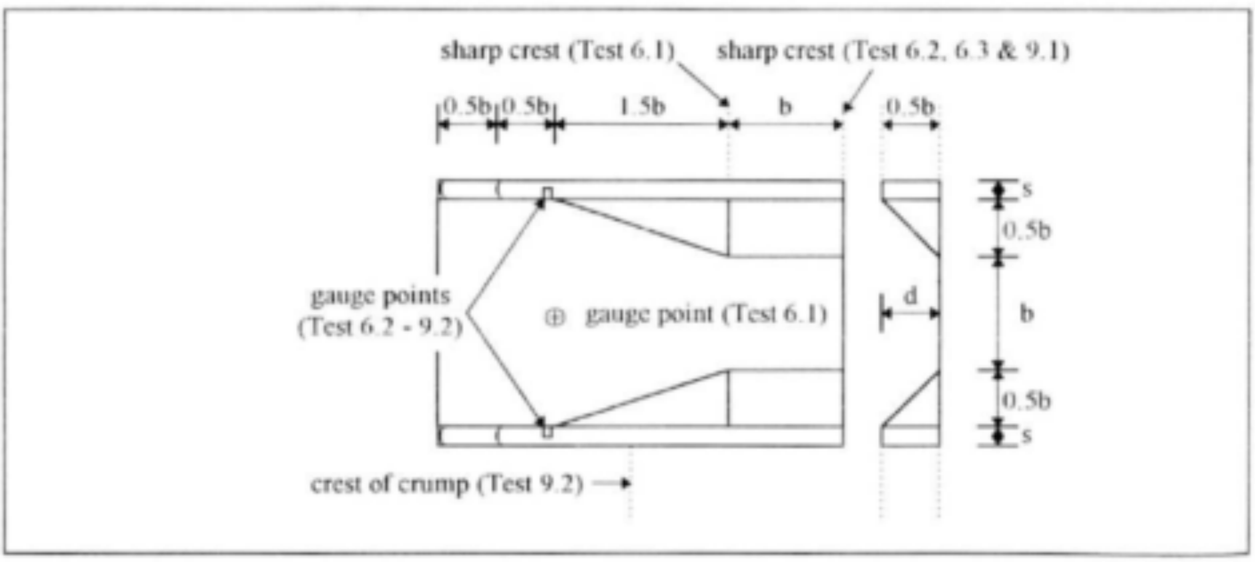

FIGURE 4.7 - Dimensions for flume lay-out 2S & recommended lay-out 2R (d/b = 0.,5)

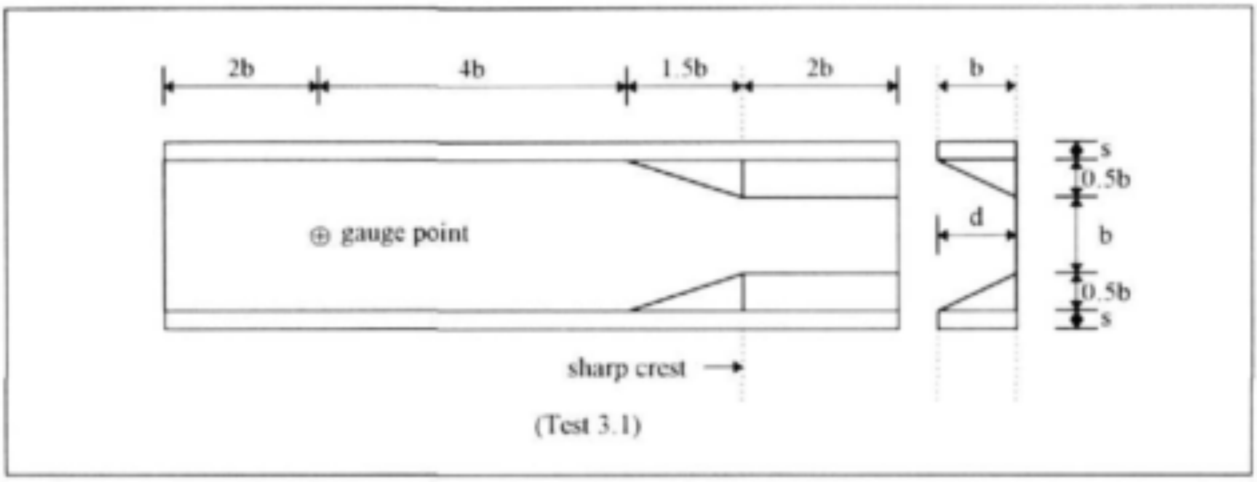

FIGURE 4.8 - Original flume dimensions for lay-out 1 (d/b = 1.0)

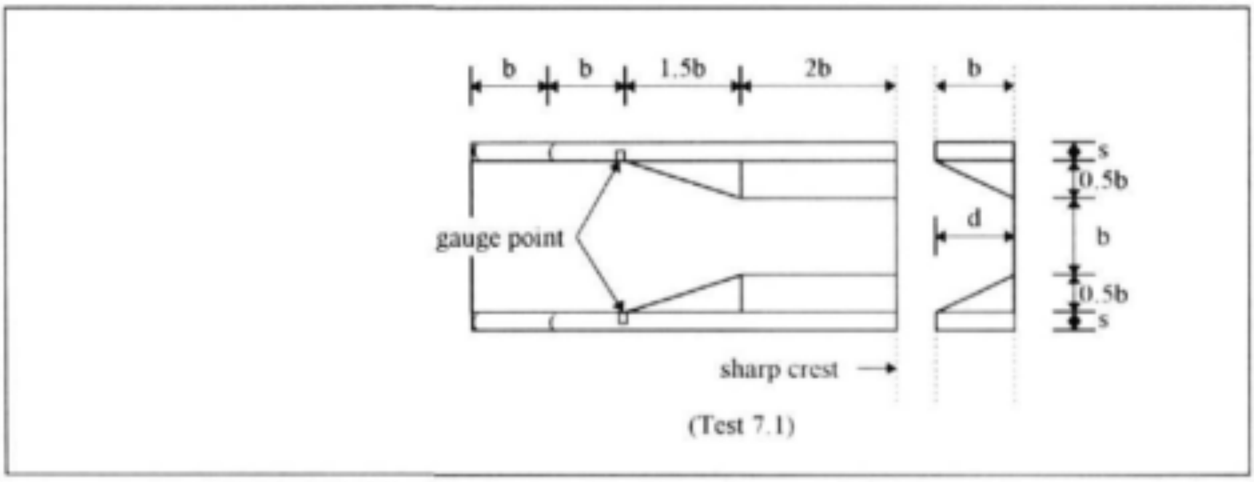

FIGURE 4.9 - Dimensions for flume lay-out 1S (d/b = 1.0)

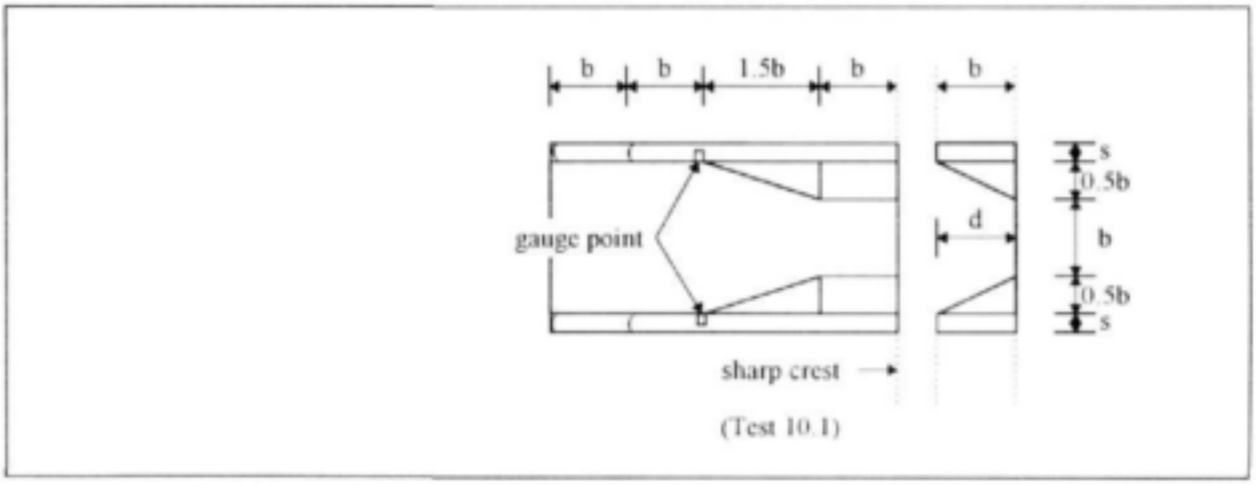

FIGURE 4.10 - Dimensions for recommended flume lay-out 1R (d/b = 1.0)

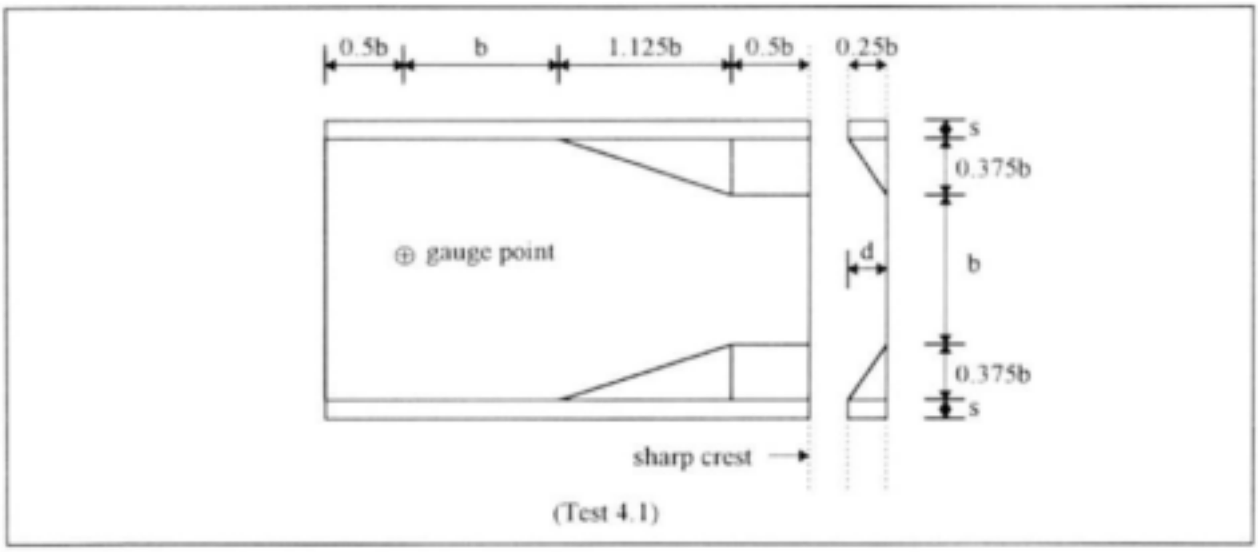

FIGURE 4.11 - Original flume dimensions for lay-out 3 (d/b = 0.25)

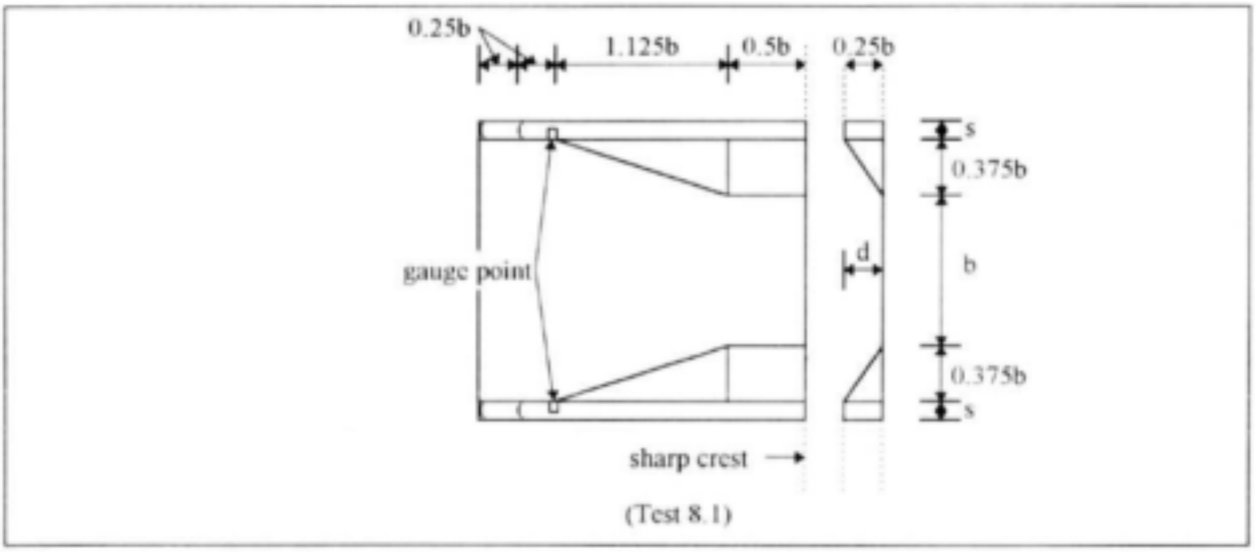

FIGURE 4.12 - Dimensions for flume lay-out 3S (d/b =0.25)

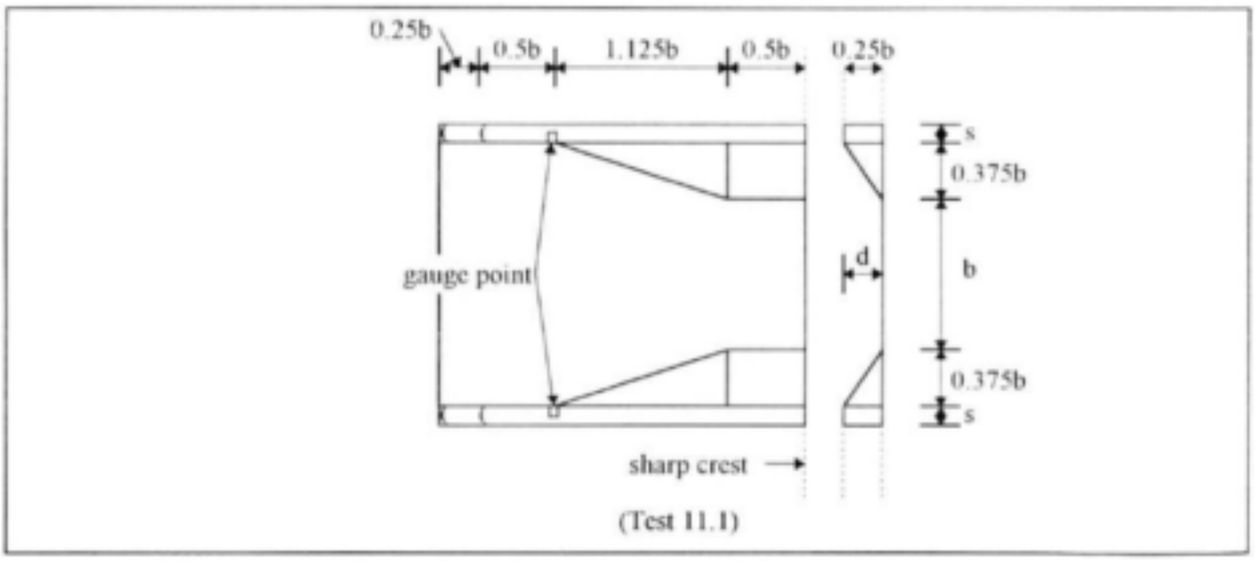

FIGURE 4.13 - Dimensions for recommended flume lay-out 3R (d/b =0.25)

TABLE 4.2 - Different ranges of L_2/L_1 and y_2/d values that were tested

Lay-out	L_2/L_1	s/L_1	y_2/d
2	1.5 - 4.4	0.044 - 0.199	0 - 1.60
2S	1.27 - 2.54	0.125	0 - 1.70
1	4.37	1.90	0 - 1.38
1S	4.37	1.90	0 - 1.34
3	1.59	0.091	0 - 1.57
3S	1.59	0.091	0 - 1.52

4.5 Results

The results of the calibration tests for each lay-out and model set-up are given in Appendix 4. These results are also available in digital form as Excel files in the envelope at the back of the report. This will allow further analyses of the data by interested parties.

The tables where the results of each individual test are given, are summarized in Table 4.3 below.

TABLE 4.3 - Summary of Appendices where results are summarized

Lay-out	Test	Results	Analysis
2	1.1	4.1	5.1
	1.2	4.1	5.1
	1.3	4.1	5.1
	2.1	4.1	5.1
	2.2	4.1	5.1
	2.3	4.1	5.1
2VS	5.1	4.1	5.1
2S	6.1	4.1	5.1
2R	6.2	4.1	5.1
	6.3	4.1	5.1
	9.1	9.1	9.2
	9.2	9.1	9.2
1	3.1	4.1	5.1
1S	7.1	4.1	5.1
1R	10.1	9.1	9.2
3	4.1	4.1	5.1
3S	8.1	4.1	5.1
3R	11.1	9.1	9.2

CHAPTER

FIVE

ANALYSIS OF CALIBRATION TEST RESULTS

5.1 General

As described in chapter 4, the main purpose of the model tests was to establish discharge coefficients for the flume section of the structure, and to establish the relationship between recorded water level and energy level in the pool upstream of the flume. With the known discharge coefficients and upstream energy levels, it should be possible to establish the theoretical stage - discharge relationship for any combination of flume and weir structure within the range of the structures that were tested.

In the case where discharge does not exceed flume capacity, it is possible to convert the recorded water level directly to a discharge by assuming no energy losses between the recording position and the flume outlet. The energy losses are accounted for in the form of a discharge coefficient which is established from the recorded data in the model.

In the case of flow over the adjoining weirs, it is necessary first to establish the energy level in the pool upstream of the flume. This energy level is then used to calculate the discharge over the adjoining weirs and consequently the discharge through the flume.

The analysis of the data in this chapter will concentrate on the tests leading up to the finally recommended structures. The sensitivity of the results to variation in the stage recording position, the dimensions of the flumes, the position of the adjoining weirs and the analysis techniques will be tested. The calibration of the finally recommended structures over a much wider range of flow conditions, will be undertaken in Chapter 9. The results of the tests on the finally recommended structures are therefore not included in the analysis in this chapter.

5.2 Influence of recording position

In all the tests with long flumes (Lay-out 1, 2 and 3), water levels were recorded at three positions in the flume as indicated in Figure 5.1. The average of the water levels at these three points was taken as the stage (y_2) in further analyses.

When tests on the shorter flumes were performed (Tests 6.1, 6.2, 6.3, 7.1 and 8.1 - see Table 4.1), two additional water levels were recorded inside cavities in each of the flume abutment walls (2.11 and 2.31 as shown in Figure 5.1). This is the stage recording position favoured by the DWAF in order to eliminate gauging problems due to sedimentation.

To test the impact of the change in recording position on stage measurements, the levels which were recorded in the cavities were compared to the levels recorded at position 2.2 on the centerline between the two walls.

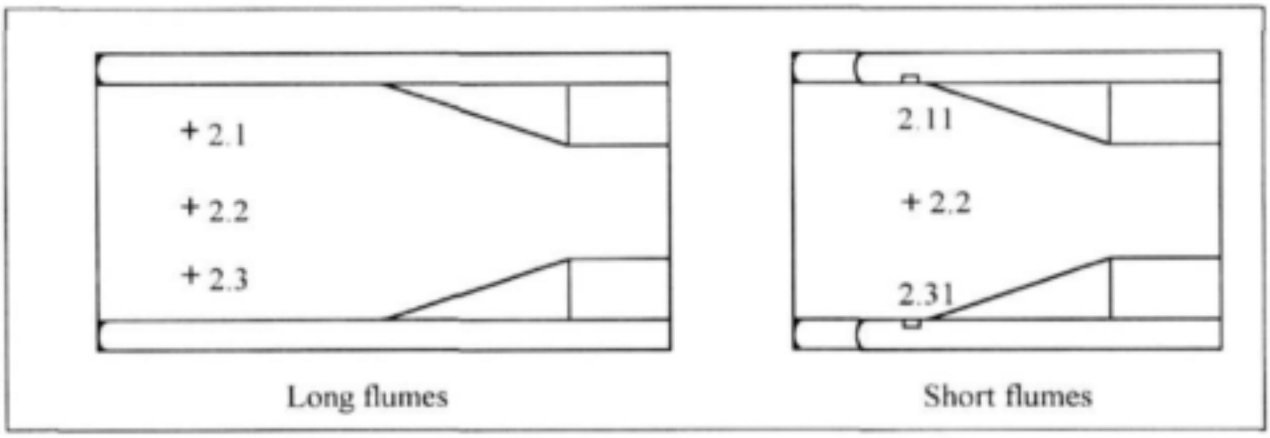

FIGURE 5.1 - Positions for stage measurement in flumes

The average value of stage measured in the cavities on both sides of the flume, were used in this comparison. The results for tests 6.1 to 8.1 are presented in Table 5.1 to Table 5.5.

TABLE 5.1 - Comparison of stage measured in the cavities to those measured in the center (Test 6.1 Lay-out 2S)

$y_{2.11}$ (mm)	$y_{2.31}$ (mm)	$y_{2.2}$ (mm)	Mean($y_{2.11}$+ $y_{2.31}$) - $y_{2.2}$	Difference %	y_2/d
55.5	54.5	56.0	-1.0	-1.79	0.42
82.0	82.0	83.0	-1.0	-1.20	0.63
104.0	103.0	105.5	-2.0	-1.90	0.80
118.0	118.0	122.0	-4.0	-3.28	0.92
142.0	142.0	141.5	0.5	0.35	1.07
155.0	155.0	155.5	-0.5	-0.32	1.18
164.0	164.0	164.5	-0.5	-0.30	1.25
173.0	173.0	172.0	1.0	0.58	1.30
182.0	181.0	180.5	1.0	0.55	1.37
189.5	189.0	188.5	0.8	0.40	1.43
190.0	191.0	191.0	-0.5	-0.26	1.45
197.0	199.5	198.5	-0.3	-0.13	1.50
209.0	211.0	209.5	0.5	0.24	1.59
224.5	226.0	224.5	0.8	0.33	1.70

TABLE 5.2 -Comparison of stage measured in the cavities to those measured in the center (Test 6.2 Lay-out 2S)

$y_{2.11}$ (mm)	$y_{2.31}$ (mm)	$y_{2.2}$ (mm)	Mean($y_{2.11}$+ $y_{2.31}$) - $y_{2.2}$	Difference %	y_2/d
59.0	58.5	58.0	0.8	1.29	0.44
95.0	95.0	96.5	-1.5	-1.55	0.73
111.5	111.0	113.5	-2.3	-1.98	0.86
121.5	120.5	123.5	-2.5	-2.02	0.94
144.5	144.5	144.5	0.0	0.00	1.09
160.0	160.0	160.5	-0.5	-0.31	1.22
169.0	169.0	168.5	0.5	0.30	1.28
177.5	177.5	176.5	1.0	0.57	1.34
185.5	185.5	184.5	1.0	0.54	1.40
192.0	192.0	191.0	1.0	0.52	1.45
189.0	188.5	188.0	0.8	0.40	1.42
197.0	197.0	196.0	1.0	0.51	1.48
206.5	206.5	205.0	1.5	0.73	1.55
216.0	216.0	214.0	2.0	0.93	1.62
225.0	225.0	223.5	1.5	0.67	1.69

TABLE 5.3 - Comparison of stage measured in the cavities to those measured in the center (Test 6.3 Lay-out 2S)

$y_{2.11}$ (mm)	$y_{2.31}$ (mm)	$y_{2.2}$ (mm)	Mean($y_{2.11}$+ $y_{2.31}$) - $y_{2.2}$	Difference %	y_2/d
62.5	62.5	63.0	-0.5	-0.79	0.48
100.5	100.0	102.0	-1.8	-1.72	0.77
126.0	126.5	129.5	-3.3	-2.51	0.98
156.5	157.5	157.0	0.0	0.00	1.19
172.0	174.0	173.0	0.0	0.00	1.31
186.5	187.0	186.0	0.8	0.40	1.41
195.5	196.0	195.5	0.3	0.13	1.48
203.5	204.0	203.5	0.3	0.12	1.54
209.0	209.5	209.0	0.3	0.12	1.58

TABLE 5.4 - Comparison of stage measured in the cavities to those measured in the center (Test 7.1 Lay-out 1S)

$y_{2.11}$ (mm)	$y_{2.31}$ (mm)	$y_{2.2}$ (mm)	Mean($y_{2.11}$+ $y_{2.31}$) - $y_{2.2}$	Difference %	y_2/d
70.0	69.5	69.0	0.8	1.09	0.40
94.5	93.5	93.5	0.5	0.53	0.54
126.5	126.0	125.5	0.8	0.60	0.73
144.5	144.5	141.5	3.0	2.12	0.83
157.0	156.5	150.5	6.3	4.15	0.90
175.5	174.5	173.5	1.5	0.86	1.01
192.5	192.5	193.5	-1.0	-0.52	1.11
203.0	202.5	204.5	-1.8	-0.86	1.17
214.0	213.5	214.5	-0.8	-0.35	1.23
224.0	223.5	223.5	0.3	0.11	1.29
233.5	232.5	233.0	0.0	0.00	1.34

TABLE 5.5 - Comparison of stage measured in the cavities to those measured in the center (Test 8.1 Lay-out 3S)

$y_{2.11}$ (mm)	$y_{2.31}$ (mm)	$y_{2.2}$ (mm)	Mean($y_{2.11}$+ $y_{2.31}$) - $y_{2.2}$	Difference %	y_2/d
46.5	46.0	48.0	-1.8	-3.65	0.47
62.0	62.0	66.5	-4.5	-6.77	0.65
74.5	73.5	80.0	-6.0	-7.50	0.78
83.0	81.0	89.5	-7.5	-8.38	0.87
93.0	92.5	100.0	-7.3	-7.25	0.97
108.0	107.0	110.5	-3.0	-2.71	1.07
122.0	121.5	122.0	-0.3	-0.20	1.18
132.0	132.0	131.5	0.5	0.38	1.28
141.0	141.0	140.0	1.0	0.71	1.36
150.0	150.0	149.0	1.0	0.67	1.45
158.0	157.5	157.0	0.8	0.48	1.52

For lay-out 2S (Tables 5.1, 5.2 and 5.3) maximum differences in stage of 4 mm or 3.3 % were recorded. The water levels in the wall cavities are generally slightly lower than those in the middle between the abutment walls. This difference reaches a maximum value at the stage when overtopping of the walls commences $(y_2/d \approx 0.9)$. Once overtopping starts increasing, these differences become negligible for this lay-out.

For lay-out 1S (Table 5.4), the maximum recorded difference is 6 mm or 4%, but this was for one point only.

For lay-out 3S (Table 5.5), differences up to a maximum of 7.5 mm or 8.4% were observed. Differences exceeding 4% for all but one of the observations were observed for flow in the flume only. Once overtopping of the wall occurs, these differences again become negligible.

The authors believe that differences in levels for lay-outs 2S and 1S are not significant. If the levels recorded in the cavity in the wall are used in both prototype and model, no serious errors in flow measurement will occur.

For lay-out 3S however, the differences become unacceptably high. The length of the flume abutment walls upstream of the gauge point is too short and the gauging position falls in a region where high vorticity causes inaccurate stage measurements. If these walls were to be extended to be 3*d* long (2*d* on the level and 1*d* sloping) as shown in Figure 5.2, the differences will most probably be within acceptable levels. The finally recommended flume for b/d = 0.25 was therefore altered accordingly. The calibration of this structure will be discussed in Chapter 9.

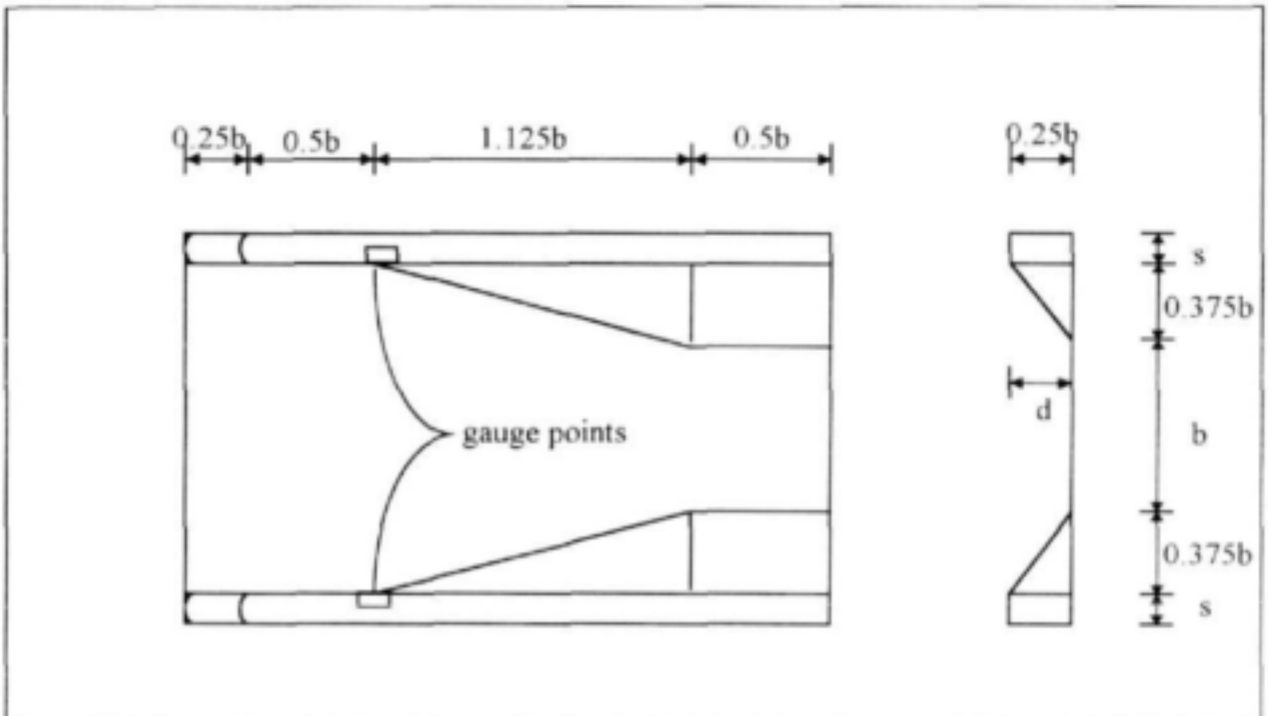

FIGURE 5.2 - New proposed dimensions for lay-out 3S

In further analyses of results for short flumes, the average water level recorded in the cavities in the flume walls will be used for lay-outs 1S and 2S. For flume lay-out 3S the water level recorded in the middle (position 2.2) is used. As mentioned above, the reason for this is that the cavities in the walls were so close to the front end of the abutment walls, that vorticity caused highly inaccurate results.

5.3 Estimating discharge coefficients

5.3.1. Flow through flume only

The basic assumption used to estimate the theoretical discharge associated with each recorded water level is that the specific energy head at gauge point 2 (E_{s2}) is equal to the critical energy head at the flume outlet, E_{sc}.

$$\left(E_{s2} = y_2 + \frac{v_2^2}{2g} = E_{sc} = y_c + \frac{A_c}{2B_c}\right) \qquad 5.1$$

The theoretical discharge Q_T is thus calculated from:

$$Q_T = \left(\frac{g A_c^3}{B_c}\right)^{1/2} \qquad 5.2$$

The procedure is as follows:

- Select a value of y_c.
- Calculate B_c, A_c, E_{sc} and Q_T.
- Calculate y_2 from $E_{sc} = E_{s2} = y_2 + \left(\frac{Q_T}{b_2 y_2}\right)^2 \Big/ 2g$.
- Repeat estimating y_c until y_2 becomes equal to the recorded value.
- The discharge coefficient is then calculated as $C_{d2} = \frac{Q_R}{Q_T}$ where Q_R is the actual discharge in the test.

Examples of these calculations for all the tests done are given in table form in Appendix 5.1.

5.3.2 Flow through the flume and over adjoining weirs

It is assumed here that there is no energy loss between the pool upstream of the flume and the flume outlet. Assume $E_{s5} = E_{sc}$.

From the recorded discharge (Q_{tot}) and water depth in the pool (y_5) it is possible to calculate the upstream specific energy head relative to the flume bed:

$$E_{s5} = y_5 + \frac{v_5^2}{2g}. \qquad 5.3$$

The theoretical value of discharge through the flume, Q_T, can now be calculated as described in 5.3.1 above, i.e. estimate y_c and calculate A_c, B_c and E_{sc} until $E_{sc} = E_{s5}$.

The actual discharge through the flume is obtained from the difference between recorded total discharge and discharge over the adjoining weirs.

The discharge over the weirs is calculated by means of the standard formulas, i.e.
for the sharp-crested weir:

$$Q = \left(0.627 + 0.018\frac{H}{p}\right)\frac{2}{3}\sqrt{2g}\,LH^{3/2} \qquad 5.4$$

for the Crump weir:

$$Q = 1.163\left(1 - \frac{0.0003}{h}\right)^{3/2}\left(\frac{2}{3}\right)^{3/2}\sqrt{g}\,LH^{3/2} \qquad 5.5$$

with: L = crest length

H = energy level = $\left(E_{s5} - d\right)$

p = upstream pool depth

The discharge coefficient for the flume C_{d5} is then calculated as $C_{d5} = \dfrac{Q_R}{Q_T}$.

Examples of these calculations for all the tests done are shown in table form in Appendix 5.1.

The calculated C_d values for each test are given in Appendix 5.1. The mean values of C_{d2} (flow in flume only) and C_{d5} (flow through flume and over adjoining weirs), for each model set-up are also given in Appendix 5.1. The C_{d2} values compensate for energy losses between the recording position and flume outlet, whereas C_{d5} compensates for energy losses between the upstream pool and the flume outlet.

5.4 Discussion of discharge coefficients

The average discharge coefficients C_{d2} and C_{d5} estimated for each model set-up are summarized in Table 5.6 below.

TABLE 5.6 - Mean values of C_{d2} and C_{d5} for each listed lay-out.

Test	Lay-out	C_{d2}	C_{d5}	Remarks
1.1	2	0.961	0.931	
1.2	2	0.953	0.894	
1.3	2	0.930	0.830	
2.1	2	1.016	0.862	Thin flume walls.
2.2	2	0.928	0.896	Thick flume walls.
2.3	2	0.925	0.870	
3.1	1	0.932	0.889	
4.1	3	0.944	0.878	
5.1	2VS	0.959	0.902	Very short flume.
6.1	2S	0.990	0.875	
6.2	2S	0.992	0.876	Sharp-crested weir in line with flume control section at end.
6.3	2S	0.956	0.890	Asymmetrical flow.
7.1	1S	0.966	0.933	Short deep flume at end.
8.1	3S	0.938	0.934	Short shallow flume at end.

A remarkable degree of consistency is evident from the above table. The values of C_{d2} which represent losses between the stage recording position and the flume outlet, are generally around 0.94 for long flumes and 0.98 for short flumes. The only significant deviations from these values are for lay-out 2 with the thin flume walls (test 2.1) and lay-out 3S (test 8.1). Except for these two cases the average C_{d2} values are all within 2 % of the values of 0.94 and 0.98 mentioned above.

Similarly the values of C_{d5} are all around 0.89 except in tests 1.1, 1.3, 7.1 and 8.1 where deviations of between -7 % and +5 % occur.

When flow is confined to the flume, a constant value for C_{d2} of 0.94 for long flumes and 0.98 for short flumes, will cause an error of less than 2% in the estimation of discharge for any model lay-out with any set-up. These values will be used in further analyses.

For discharges exceeding flume capacity, a constant C_{d5} value of 0.89 will cause errors up to a maximum of 7 % for discharges that pass through the flume. As this discharge only forms part of the total discharge because the rest of the flow passes over the adjoining weirs, the error in estimating total discharge can therefore be expected to be less than 7 %.

5.5 Relationship between y_2 and E_{s5}

5.5.1 General

To be able to convert the recorded stage, y_2, to the energy head in the pool upstream of the flume, E_{s5}, for the case where the flume walls are overtopped, the following approach was used. In all the model tests, the discharge, Q, the stage in the flume, y_2, and the water level upstream of the flume, y_5, were recorded. With this information available it is easy to calculate the energy head, E_{s5}, in the pool upstream of the flume, i.e. $E_{s5} = y_5 + \frac{v_5^2}{2g}$.

The relationship between E_{s5} and y_2 can therefore be obtained directly from the model tests. A graph of these two parameters, normalised by dividing by the flume depth, d, for all the tests on the original lay-out 2, is shown in Figure 5.3. This graph contains all the data from tests 1.1 to 2.3.

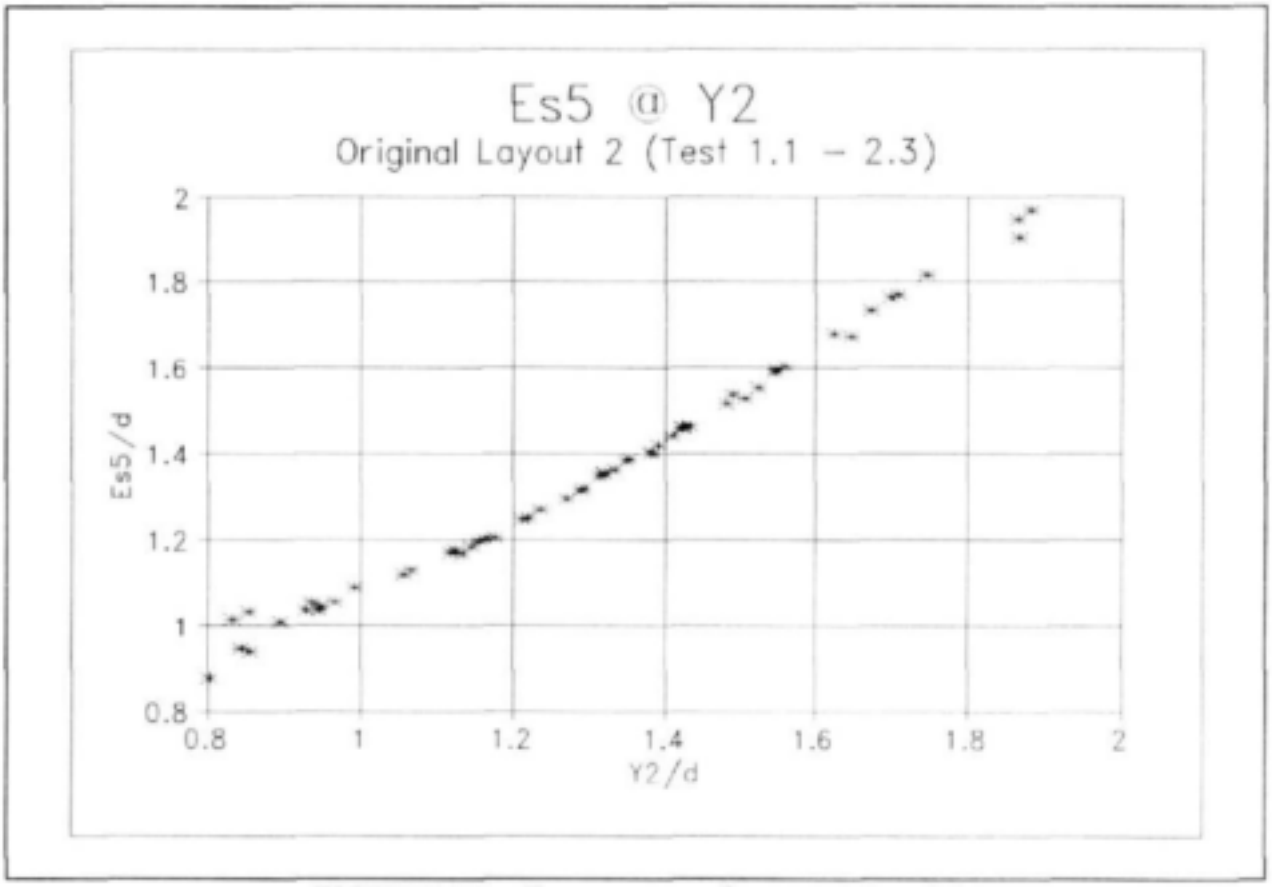

FIGURE 5.3: E_{s5} versus y_2 for tests 1.1 to 2.3

As can be seen from this figure, all the data falls on one line. For a given flume configuration the relationship between y_2 and E_{s5} remains constant. The reason for this constant relationship is that $E_{s5} = y_2 + \frac{v_2^2}{2g} + k\frac{v_2^2}{2g}$ where k represents the coefficient for energy loss between point 2 and 5. If k remains constant and v_2 is a constant function of y_2, the relationship between E_{s5} and y_2 should not be affected by factors such as adjoining weirs etc.

If a sufficient range of y_2/d values can be tested in the model, it will simply be necessary to fit a curve through the data to obtain the necessary relationship. It will be dangerous to extrapolate this relationship beyond the range that was tested unless a sound theoretical basis were to be used for the extrapolation. Since it was not possible to test this relationship for y_2/d values much above 1,8 in the model due to discharge limitations, a theoretical approach was sought.

5.5.2 Theoretical relationship

The relationship between the recorded stage (y_2) and the energy level in the pool upstream of the flume (E_{s5}) should be of the form:

$$E_{s5} = y_2 + \frac{v_2^2}{2g} + k\frac{v_2^2}{2g} \qquad 5.6$$

with k = coefficient to compensate for losses between (2) and (5) (mainly entrance losses).

Velocity measurements in the flume have indicated that the velocity increases as the discharge increases, until the water starts overflowing the abutment walls of the flume. When this happens, the extra flow over the abutment walls, "chokes" the flow in the flume which is controlled by the flume outlet. This causes a reduction of the velocity in the flume as is illustrated in Figure 5.4.

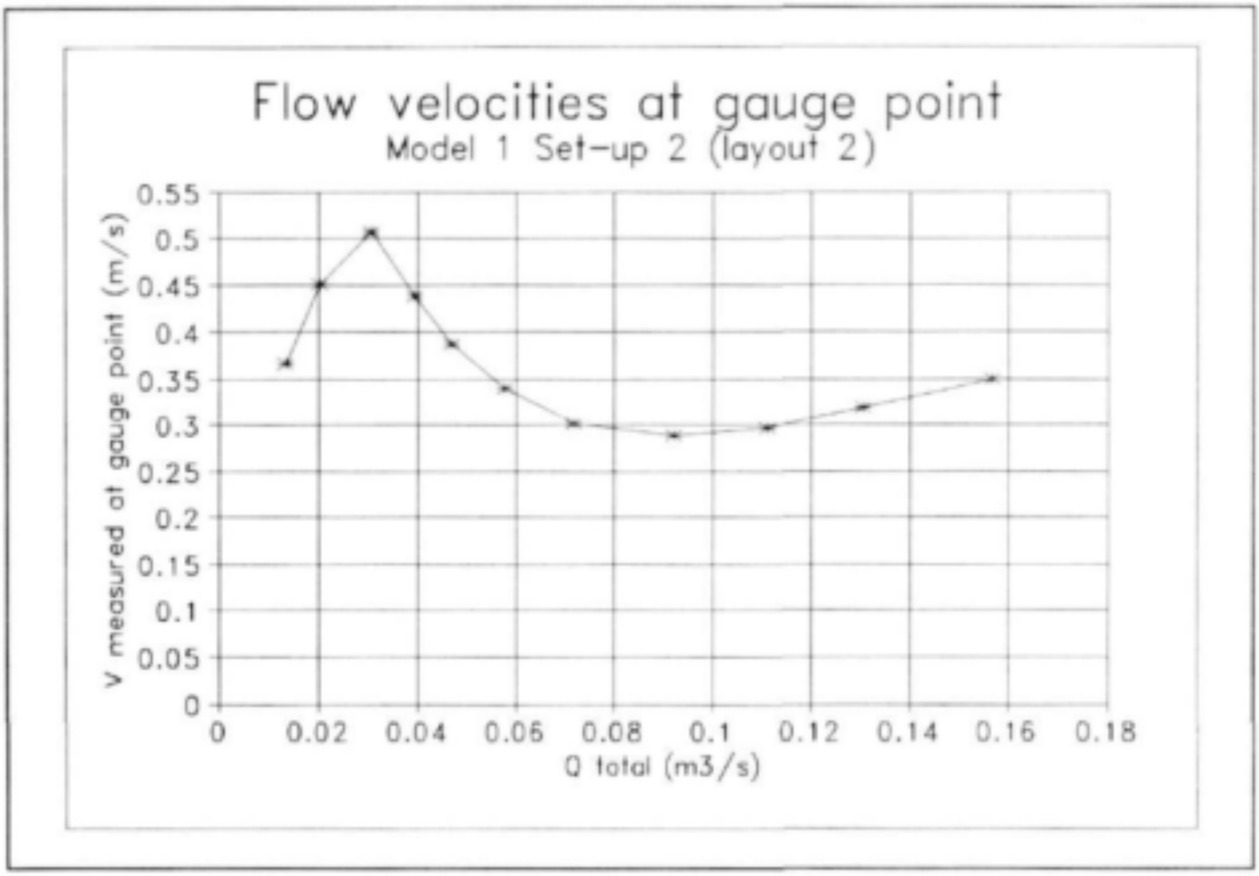

Figure 5.4 - Flow velocities measured inside the flume

As the discharge increases further, the effect of flow across the abutment walls eventually starts reducing and an increase in velocity in the flume is observed. If all the flow across the walls were to stop, the increased velocity could be calculated from continuity i.e.

$$v = \frac{Q}{A} \qquad 5.7$$

Q increases with $y_2^{3/2}$ for a broad crested weir whereas A increases linearly with y_2 i.e.

$$Q = f\left(y^{3/2}\right) \text{ and } A = By_2 \qquad 5.8$$

Thus the velocity at 2 should increase according to:

$$v = f\left(\frac{y_2^{3/2}}{y_2}\right) = f\left(y_2^{1/2}\right) = ky_2^{1/2} \qquad 5.9$$

This means that the energy head at 2 increases as follows:

$$E_{s2} = y_2 + \frac{v_2^2}{2g}$$

$$= y_2 + \frac{\left(k_1 y_2^{1/2}\right)^2}{2g} \qquad 5.10$$

$$= y_2 + \frac{k_2 y_2}{2g} = k_3 y_2$$

The energy head at 5 i.e. E_{s5} therefore should also increase linearly with y_2

$$E_{s5} = y_2 + k_4 y_2 \qquad 5.11$$

The value of k_4 needed to be determined from the calibration test. A graph of $(E_{s5} - y_2)$ versus y_2 is shown in Figure 5.5, using the same data as in figure 5.3 above.

With $E_{s5} = y_2 + k\frac{v_2^2}{2g}$ the value of $(E_{s5} - y_2)$ represents $k\frac{v_2^2}{2g}$. The graph was made dimensionless by dividing by d on both axes.

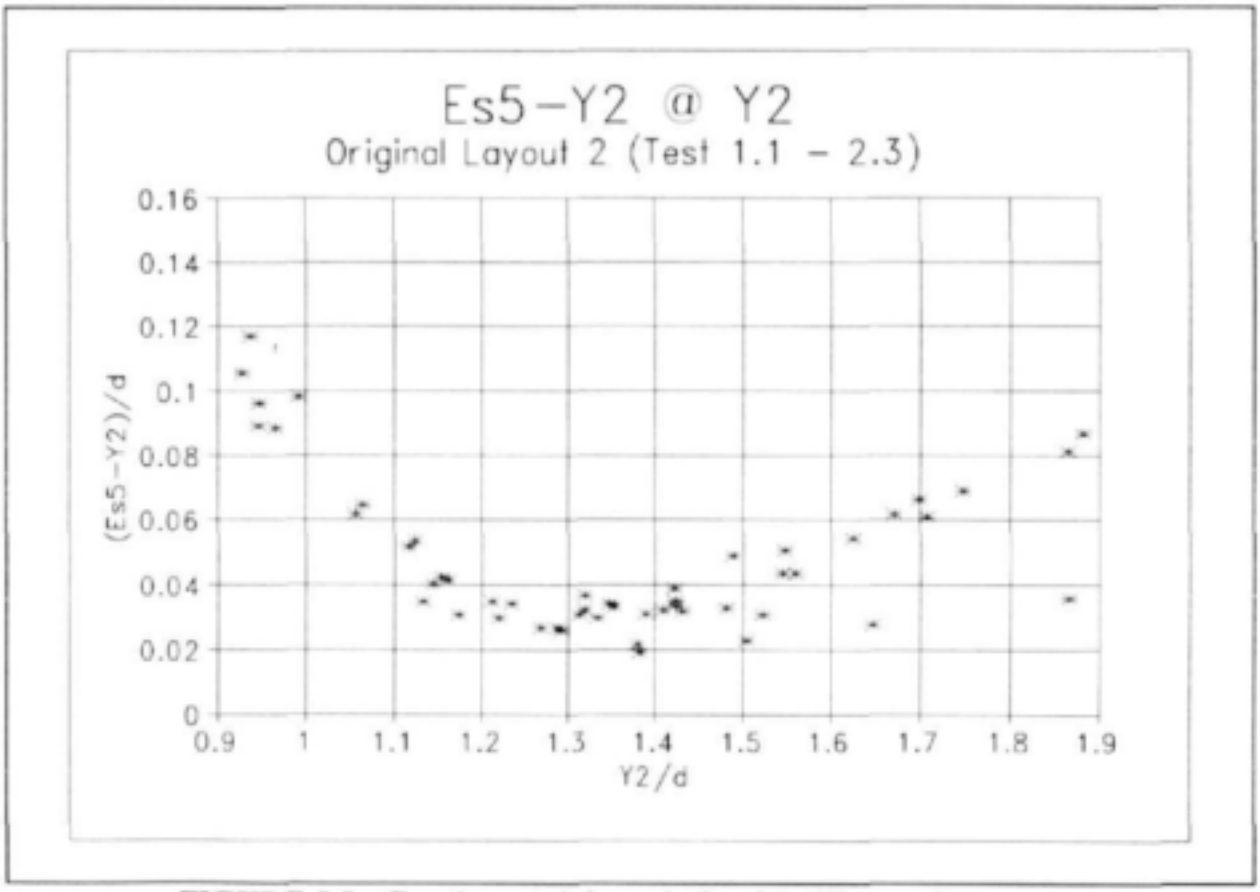

FIGURE 5.5 - Graph containing relationship ($E_{s5} - y_2$) versus y_2

The effect of the initial reduction in the velocity is clearly indicated in this figure. The velocity reaches a minimum value for y_2/d approximately equal to 1,2 to 1,4, whereafter the linear increase of $k\frac{v_2^2}{2g}$ with y_2 can be seen.

Similar graphs could be constructed for each flume lay-out.

For flume lay-out 2, the following relationship was established from the data contained in Figure 5.5:

$$
\begin{aligned}
E_{s5} &= 0.409d + 0.679y_2 && \text{for} \quad 0.9 < \frac{y_2}{d} < 1.17 \\
E_{s5} &= 0.030d + 1.00y_2 && \text{for} \quad 1.17 < \frac{y_2}{d} < 1.40 \qquad\qquad 5.12 \\
\text{and} \quad E_{s5} &= -0.133d + 1.1167y_2 && \text{for} \quad 1.40 < \frac{y_2}{d} < 2.00
\end{aligned}
$$

5.5.3 Direct comparison between y_2 and y_5

While flows are contained within the flume, the stage at the gauge point is used directly to calculate discharge. Under these conditions, the relationship between y_2 and y_5 is not required. As soon as the stage in the flume reaches 90 % of the flume height (0.9d), overtopping of the flume walls will commence and the energy in the upstream pool is required for calibration purposes.

The upstream energy can be determined from the stage at the gauge point as described in section 5.5.2, a method which has the advantage of being insensitive to upstream pool dimensions. Energy in the upstream pool can also be determined iteratively by using empirical relationships to establish flow depths in the upstream pool from the known stage at the gauge point. These empirically determined values for upstream flow depth is a function of upstream pool dimensions however, and must be applied with caution.

The relationship between y_2 and y_5 for the original long flume lay-out 2 (in 2 m channel), is illustrated in Figure 5.6. Values of y_2/y_5 is plotted against values for y_2/d. Because overtopping of the flume commences at 0.9d, y_2/d values of less than 0.9 are not shown in this graph. From the figure it can be seen that the value for y_2/y_5 approaches unity as the rate of flow increases. This means that the stage at the gauge point becomes almost equal to the stage in the upstream pool under conditions of high discharges. The advantage of this method above the method described in section 5.5.2, lies in this fact and more accurate answers under conditions of high rates of flow are expected.

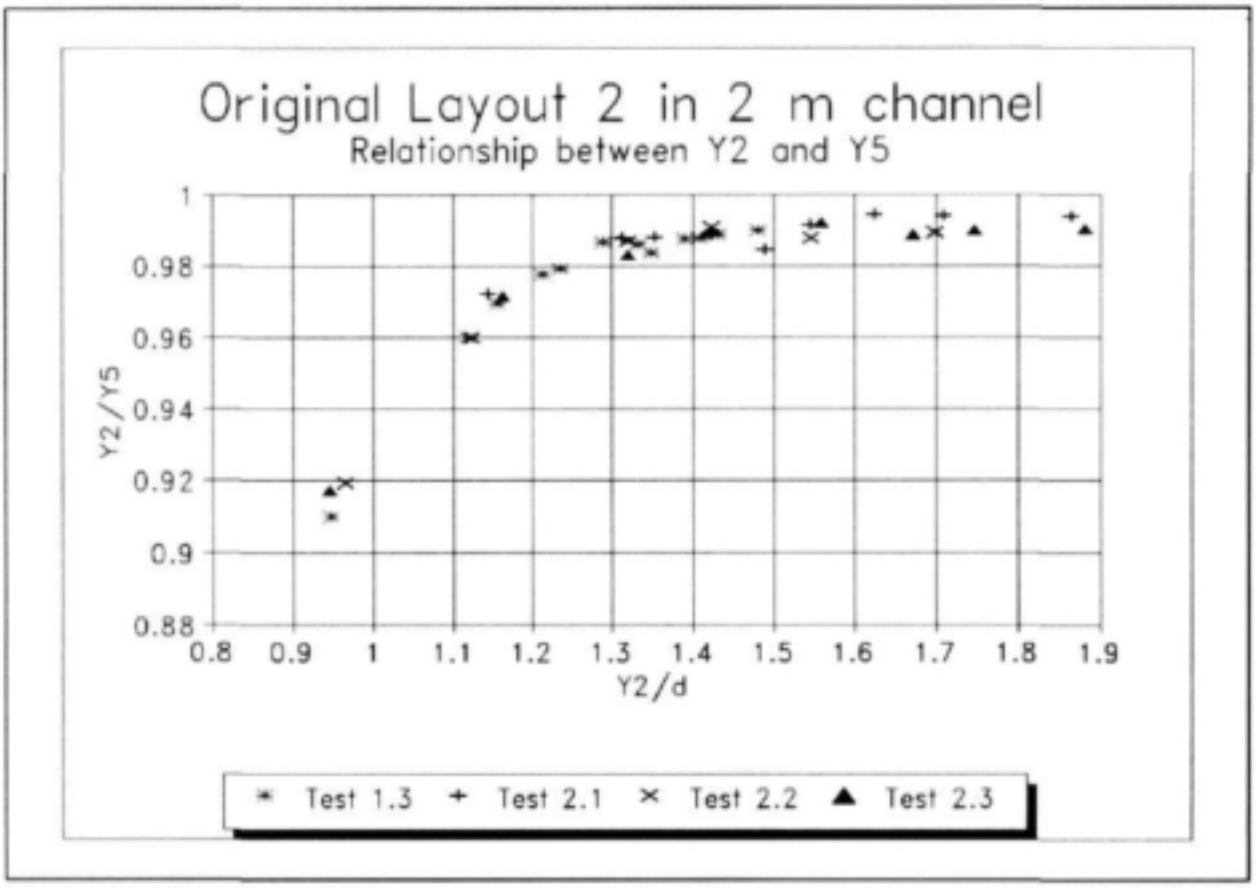

FIGURE 5.6 - Relationship between y_2 and y_5 for original lay-out 2

5.6 Construction of Calibration Curves.

5.6.1 Procedure

With the discharge coefficients C_{d2} and C_{d5}, as well as the relationship between y_2 and E_{s5}, established from model tests, it is now possible to construct calibration curves for any combination of flumes and weirs as follows:

5.6.1.1. Flow in flume only ($y_2 < 0.9d$)

(i) Estimate a value of y_c at flume outlet.

(ii) Calculate A_c, B_c, Q_T and E_{sc}

(iii) Solve for y_2 from $y_2 + \frac{v_2^2}{2g} = E_{sc}$ using $v_2 = \frac{Q_T}{A_2}$.

(iv) The discharge associated with y_2 is now $Q_R = C_D \cdot Q_T$.

(v) Estimate a new y_c value and repeat steps (ii) to (iv).

This process is continued for y_2.-values < 0.9d. When y_2 becomes equal to 0.9d or exceeds it, overtopping of the flume walls will commence.

5.6.1.2. Flow over flume walls ($y_2 > 0.9d$)

(i) Estimate a value of y_c.

(ii) Calculate A_c, B_c, Q_T and E_{sc}
(iii) Assume $E_{s5} = E_{sc}$
(iv) Calculate flow over sharp-crested or Crump weir (Q_W) by means of equations 5.4 or 5.5.
(vi) Calculate actual flow through flume as $Q_R = C_d Q_T$
(vi) Calculate total flow $Q_{TOT} = Q_W + Q_R$
(vii) Calculate y_2 by means of the relationship between E_{s5} and y_2

5.6.2 Example

A complete example of the construction of such a calibration curve for recommended flume lay-out 2, combined with a sharp-crested weir, is given in Chapter 11.

5.7 Accuracy of Calibration Curves

To test the accuracy that can be achieved by means of this method of constructing calibration curves, the discharge obtained by means of this method from the recorded y_2 value, is compared to the corresponding discharge from the model test. This is done for the original flume lay-out 2 (Tests1.1 to 2.3). Constant discharge coefficients of

$C_{d2} = 0.94$ and
$C_{d5} = 0.89$ as established in Section 5.4, were used in combination with the E_{s5} vs y_2 relationships given in Section 5.5, during this exercise.

The results are summarized in Table 5.7

TABLE 5.7 - Accuracy of calibration for original lay-out 2

Test	y_2 (m)	Q observed (m^3/s)	Q calculated (m^3/s)	Difference (%)
1.1	0.066	0.0094	0.0091	-2.37
	0.0795	0.0128	0.0126	-1.77
	0.0885	0.0155	0.0151	-2.42
	0.1	0.0193	0.0188	-2.78
	0.113	0.0245	0.0234	-4.61
	0.1225	0.0298	0.0293	-1.81
	0.1395	0.0415	0.0414	-0.27
	0.1495	0.0495	0.0503	1.59
	0.155	0.0567	0.0553	-2.37
	0.161	0.0665	0.0646	-2.84
	0.1705	0.0817	0.0809	-0.96
	0.1825	0.1049	0.1047	-0.22
	0.201	0.1493	0.1508	1.00

TABLE 5.7 - Accuracy of calibration for original lay-out 2 (cont.)

Test	y_2 (m)	Q observed (m^3/s)	Q calculated (m^3/s)	Difference (%)
2.2	0.0485	0.0055	0.0055	-0.29
	0.0778	0.0119	0.0121	1.87
	0.0935	0.0162	0.0167	2.93
	0.1055	0.0202	0.0207	2.02
	0.1275	0.0280	0.0308	9.93
	0.1485	0.0416	0.0424	2.04
	0.174	0.0688	0.0675	-1.93
	0.1878	0.0873	0.0880	0.86
	0.204	0.1185	0.1165	-1.73
	0.224	0.1595	0.1556	-2.43

The same test was done for modified flume lay-out 2S. Constant discharge coefficients of:

$C_{d2} = 0{,}98$ and
$C_{d5} = 0{,}89$ as established in Section 5.4, were used in combination with the E_{s5} vs. y_2 relationships given in Section 5.5, during this exercise.

The results are summarized in Table 5.8

TABLE 5.8 - Accuracy of calibration for modified lay-out 2

Test	y_2 (m)	Q observed (m^3/s)	Q calculated (m^3/s)	Difference (%)
6.2	0.05875	0.0075	0.0079	4.99
	0.095	0.0175	0.0181	3.34
	0.11125	0.0244	0.0240	-1.47
	0.121	0.0297	0.0280	-5.70
	0.1445	0.0408	0.0404	-0.99
	0.16	0.0536	0.0524	-2.23
	0.169	0.0630	0.0627	-0.50
	0.1775	0.0728	0.0734	0.82
	0.1855	0.0836	0.0854	2.11
	0.192	0.0939	0.0963	2.54

Errors in the estimation of the discharge are normally within 4%. In only 4 cases during these three tests are the errors larger than 4%. The larger errors normally occur near the point where the flume walls start to become overtopped. This is the area where the theory and the accuracy of the stage recording can be expected to lead to the largest errors.

The results of this exercise are very encouraging. The errors are considered to be small bearing in mind that the relationships and coefficients were used over a wide range of flume - weir configurations.

The calibration of the finally recommended structures is described in Chapter 9.

CHAPTER

SIX

SEDIMENT BUILD-UP IN FLUME

6.1 Introduction

Sedimentation causes problems at many flow gauging structures in South African rivers. Sediment is deposited in the pools upstream of the structures, thereby influencing calibration, and also blocking measuring equipment. The primary objective of the newly developed flume, was to reduce sedimentation in the pools and to obtain reliable stage measurements even if the pools were silted up. It was hoped that the low level of the bed of the flume combined with a gauging position inside the flume walls would overcome these problems.

A flume structure as developed during the early phases of this study (similar to Layout 2 with long abutment walls) was constructed in the Mpambanyoni river, near Scottburgh in Natal, where serious sedimentation problems had been experienced. The new flume worked well so far in that sediment levels in the pool were lowered and no blocking of the water level recording system occurred. Sedimentation within the flume was however experienced after a flood had caused high build-up of sediments in the upstream pool. As the flood passed, the rate of flow dropped, and the lower discharges transported a large quantity of sediment into the flume. It then became evident that further studies would be required to resolve these sedimentation problems.

6.2 Developing a standard sedimentation test

Preliminary tests were done on the model in an effort to simulate the problem that had been experienced at Mpambanyoni. In these tests, using the original model (layout 2), different inflow hydrographs and patterns of sand build-up in the pool were tested in the model. The results of a sieve analysis which was performed on the sand used for sedimentation purposes (indicating a fairly coarse sand) is contained in Appendix 6.1. Based on the results of these tests, a number of preliminary conclusions were reached:

- Because of the characteristics of the sand being used in the tests, it was necessary to have a high sand build-up before the sand could be transported into the flume. Build-up to a height of half the wall height (b/4 in this model, layout 2) occurred before this happened.

- With a low rate of flow (10 l/s) maintained over a very short period (2 minutes), the flume could be silted up completely. This could be related directly to the artificially high build-up of sand in the pool during the flood. As the water level dropped during the receding flood stages, steep gradients in the bed and water level were created towards the flume. Under these circumstances the transport rate of sediment towards the flume by far exceeded the transport rate in the flume. Siltation within the flume resulted (see Figure 6.1).

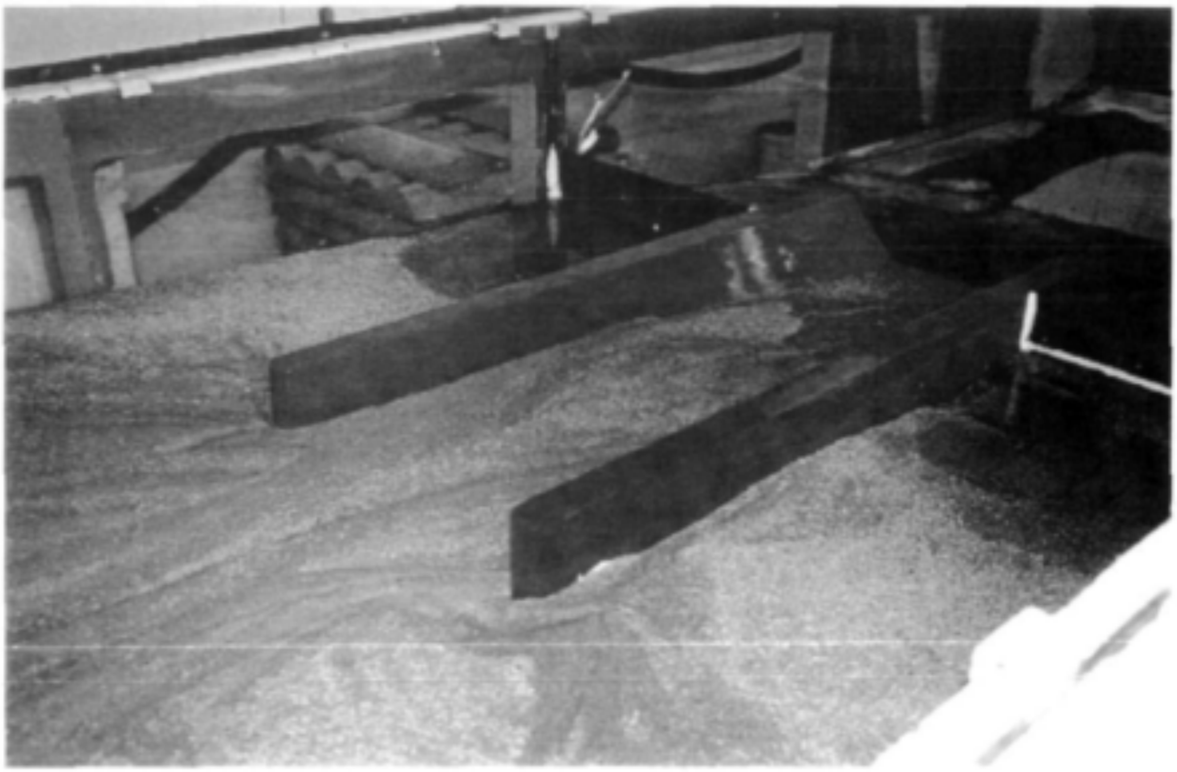

FIGURE 6.1 - Sedimentation in flume

- After initial choking with sand, the vortices around the abutments started clearing the entrance of the flume. The horizontal contraction towards the flume entrance causes acceleration of flow and removal of the sediment here. In the section between the parallel walls no acceleration occured. The sediment transport capacity in the flume decreased from the abutment heads to the parallel-wall section, and sediment accumulated here (see Figure 6.2).

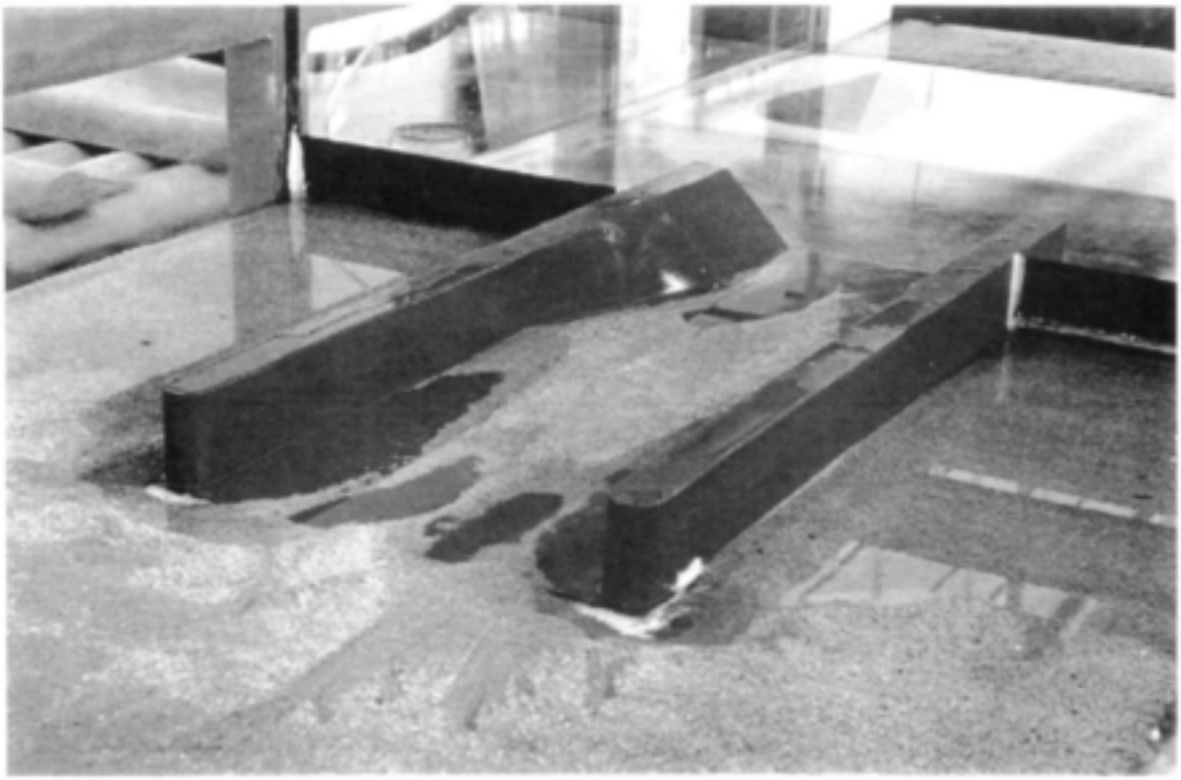

FIGURE 6.2 - Sediment accumulated in parallel-wall section

- If the inflows were maintained, the choked flume eventually became clear of sediment. This happened whilst the rate of sediment transport towards the flume was exceeded by the capacity for carrying sediment through the flume.

For the standardised test it was decided to use one fixed discharge of 30 l/s. This represented the upper limit of the discharge within the flume. The sand was filled in, up to half the abutment wall height initially and not replenished during the test. Photographs were taken at predetermined time intervals to record the sediment situation in the flume. The time for removal of all sediment was recorded and was to be compared in different tests.

In addition, a low discharge (10 l/s) was introduced. This caused severe sediment deposition in the flume, because of the high transporting capacity upstream of the flume. The authors believe that this situation is very similar to what happened at Mpambanyoni. The flood had caused a high build-up of sediment in the upstream pool. When the rate of flow dropped after the flood, there was an abundance of sediment which could readily be transported into the flume. The low discharges, with their high transporting capacities due to high velocities either in wide, shallow streams or narrow, deep streams, caused choking of the flume. It became apparent that this was the problem.

6.3 Possible solutions to the silting problem

The following proposals to alleviate the sediment deposition problem in the flume were tested in the model:

- Shorten the abutment walls to where horizontal contraction begins. This would eliminate the section with parallel walls, where no acceleration occurs, and where deposited sand is not easily removed.

- Move the whole flume downstream relative to the adjoining weir. It was believed that the vortices around the abutments played a major role causing the high sediment transporting capacity into the flume. In order to lessen their effect, it was proposed to move the flume downstream relative to the position of the sharp-crested or Crump weir. The weir, now being at the upstream end of the abutment walls, would eliminate flow around the abutments and therefore lessen the intensity of the vortices.

- Construct a step in the flume entrance. It was hoped that such a step would create sufficient turbulence in the flume to ensure that the sediment reaching the flume would be unable to settle in the flume.

6.4 Tests with shortened abutment walls

The abutment walls were shortened to where horizontal contraction begins in the flume (see Figure 6.3). With the standard test, a substantial improvement was achieved. Although the initial choking of the flume with sediment still occurred, it was completely cleared after 4 minutes in the new model, compared to the 40 minutes that it took in the original model.

FIGURE 6.3 - Shortened abutment walls

The reason for this dramatic improvement lies in the elimination of the section where parallel walls could not induce acceleration of flow with resulting increased sediment transporting capacity.

Under conditions of low discharge, the sediment transporting capacity upstream of the flume again exceeded the capacity in the flume, resulting in silting in the flume under conditions of low discharge (see Figure 6.4). The control section at the flume exit however, remained free of sediment and it is not expected that the silt in the flume will appreciably affect its calibration. If the low flow remains more or less constant for a long period or if the rate of flow increases, the sediment is removed from the flume by the flowing water. This self cleansing characteristic of the flume forms a major improvement over previously tried measuring structures.

6.5 Tests with flume moved downstream relative to sharp-crested weir

The flume was effectively moved downstream, by moving the sharp-crested weirs upstream and by connecting them to the abutment heads. This was done to limit the development of the vortices around the abutments.

The new position of the weir did not have much effect with regard to the effect of the vortices. The flow-lines still had to turn through right angles, creating high sediment transporting capacity. It was also realised that these vortices did not aggravate the silting problem. Large volumes of sediment were transported into the flume from the sides initially, after which equilibrium was reached and sediment inflow into the vortex zone equaled sediment outflow (see Figure 6.5).

FIGURE 6.4 - Siltation of flume under conditions of low discharge

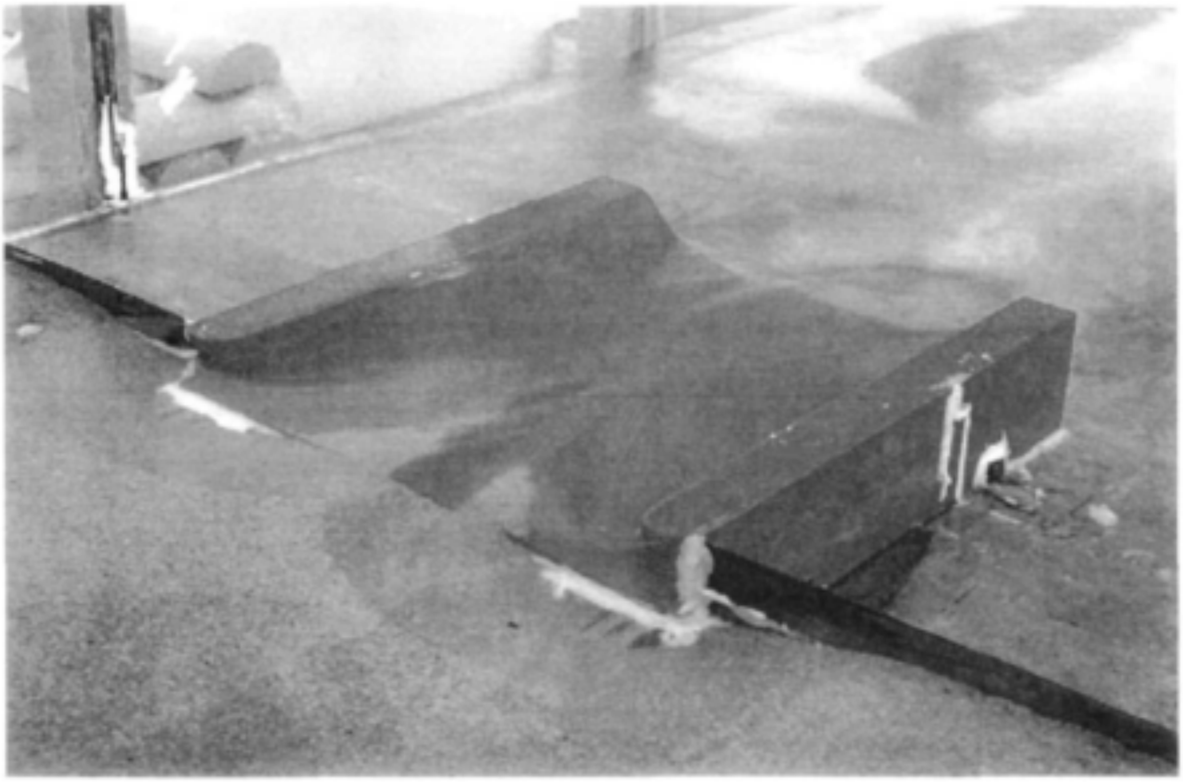

FIGURE 6.5 - Flume with new weir position

The position of adjoining weirs relative to the flume, was such that calibration according to international standards became impossible. The gauge point was situated downstream of the adjoining weir crests, which meant that stage was influenced by the drawdown curve. This set-up was merely used to quantify the effect of the vortices.

With this model, choking still occurred at low discharges, and alternative possible solutions needed to be investigated.

6.6 Tests with low step in mouth of flume

In order to prevent sediment from being deposited within the flume during low flows, a small step was installed in the upstream opening of the flume. It was hoped that the turbulence created downstream of the step, would provide enough transporting capacity to remove sediment which entered the flume under conditions of low flow.

Two different step heights were tested. Initially a step was built to half the height of the abutment walls (b/4). With sediment build-up upstream to the same level, no sediment entered the flume. Unfortunately however, the height of this step made the flume impossible to calibrate since it introduced another control section (see Figure 6.6).

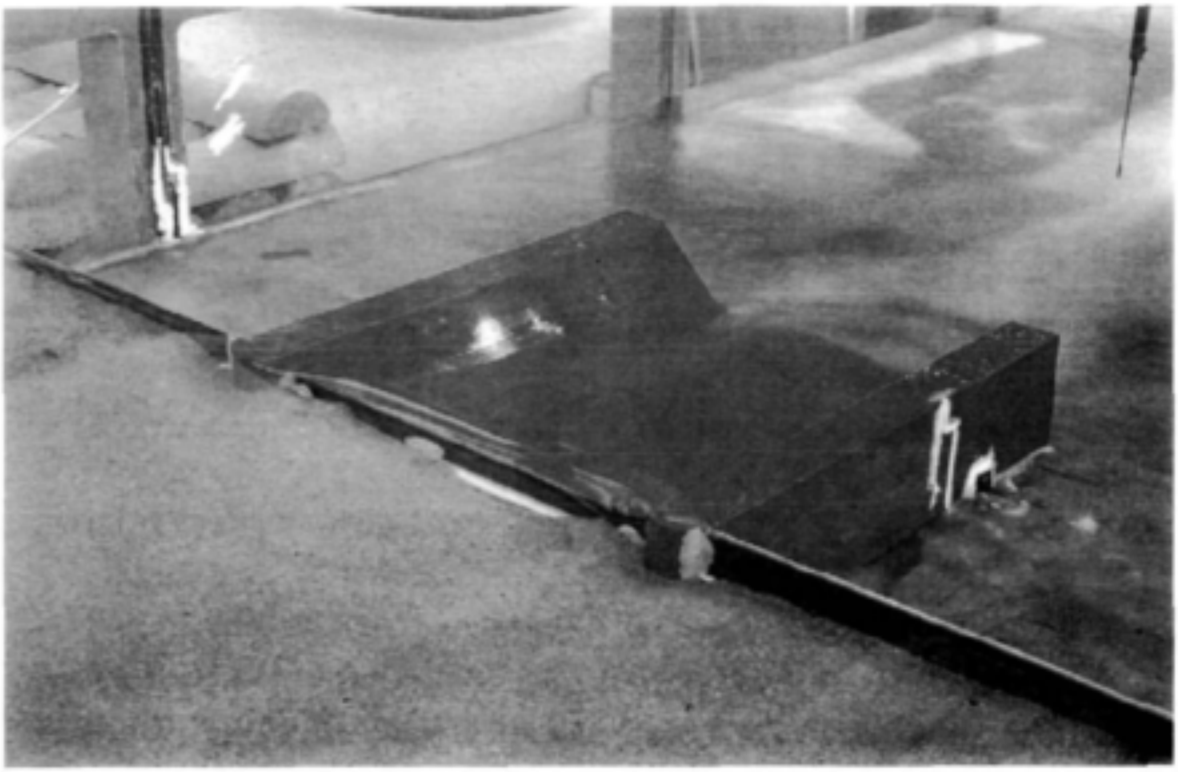

FIGURE 6.6 - Flume with high step in mouth

The step height was lowered to a quarter of the abutment wall height (b/8). With high discharges the flume was kept sediment-free. At lower flows however, the same conditions as without the step prevailed and the flume silted up (see Figure 6.7). The lower wall also formed an alternative control section and made accurate calibration impossible (see Figure 6.8).

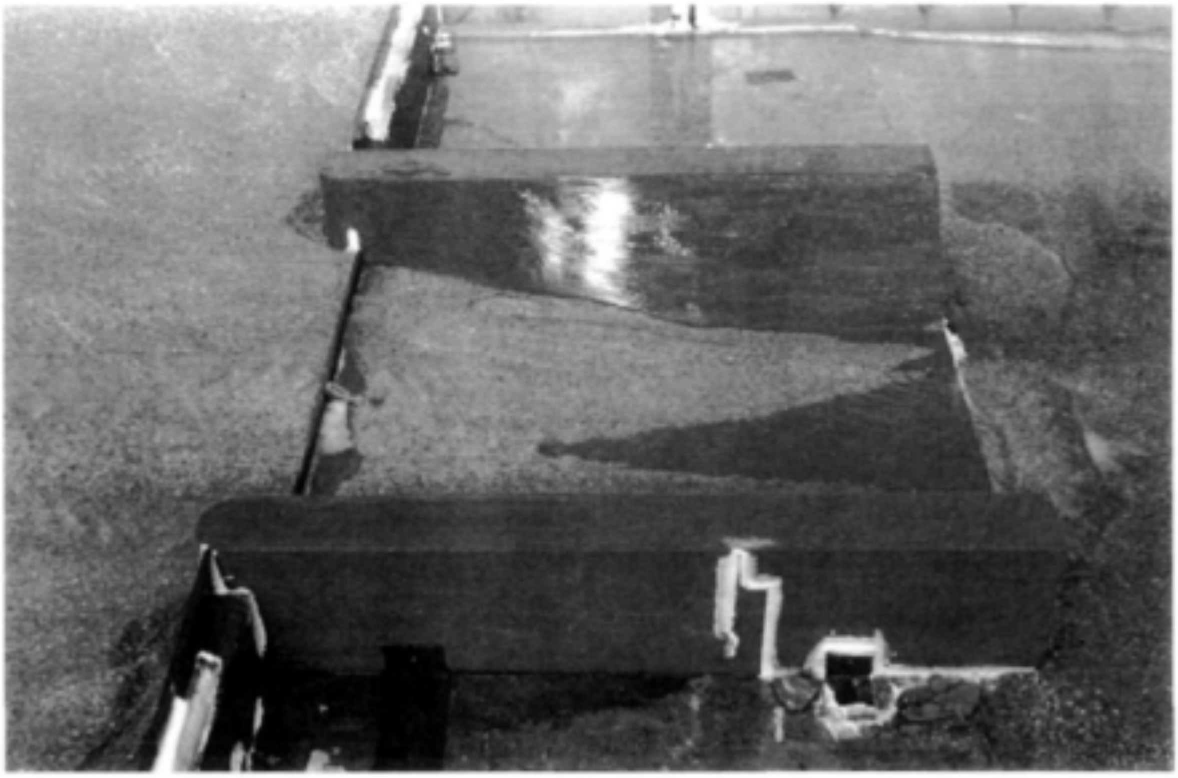

FIGURE 6.7 - Sedimentation in flume with low step in mouth

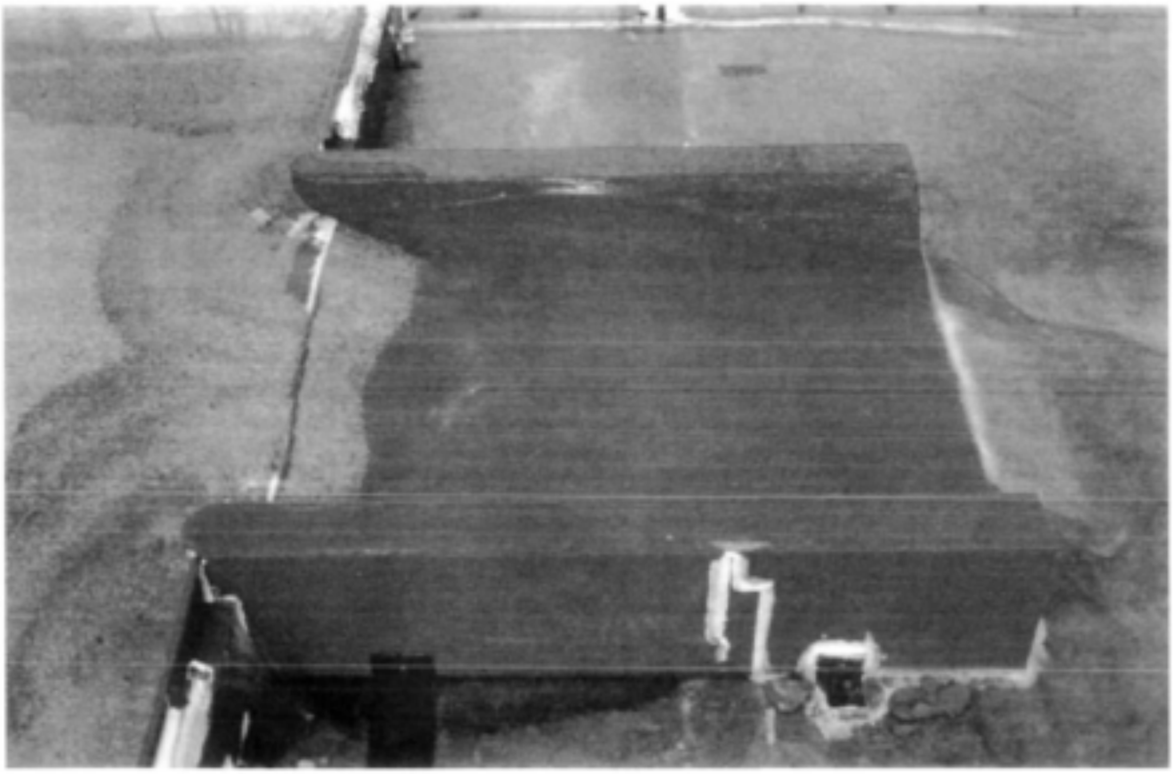

FIGURE 6.8 - Flow conditions in flume with low step in mouth

6.7 Proposed layout

At this stage, the DWAF suggested that the upstream ends of the abutment walls should be sloped rather than vertical. In their experience, vertical abutment heads tend to catch floating trees and other debris when floods occur. Such accumulated debris lead to inaccurate stage measurements in practice, and was unacceptable. They proposed that the abutment heads should be sloped at 45 degree angles (see Figure 6.9).

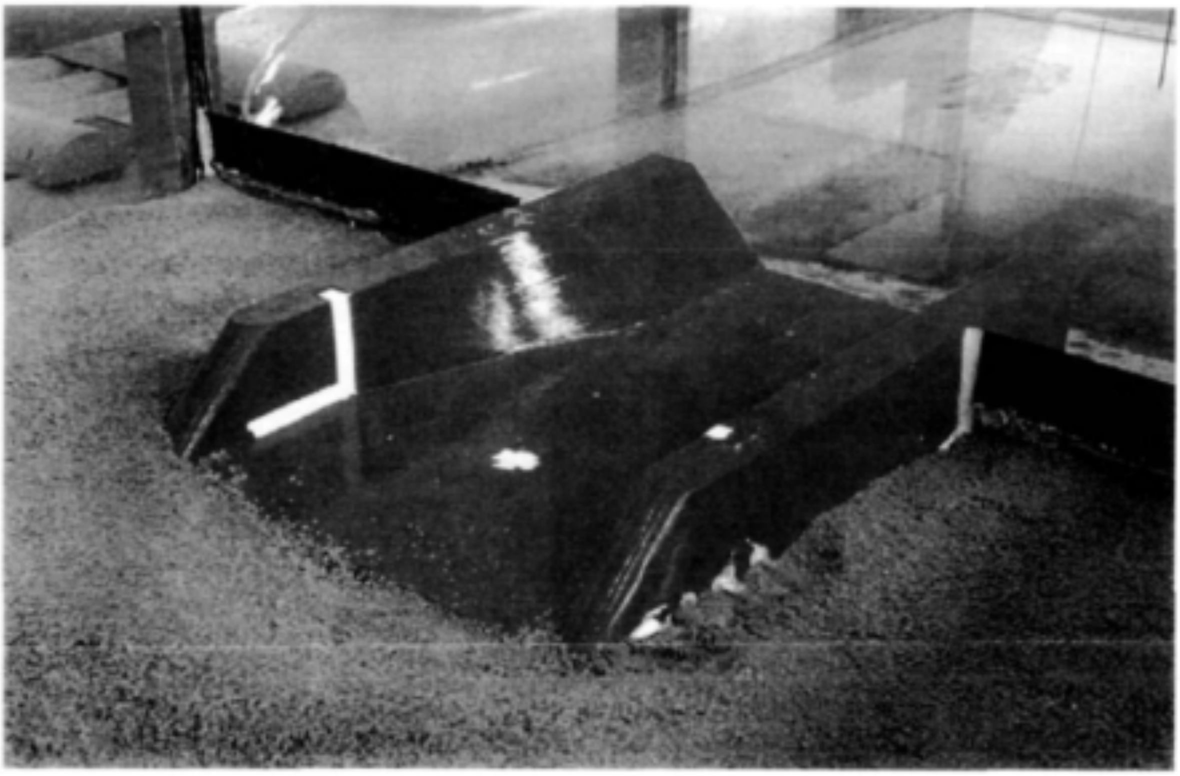

FIGURE 6.9 - Proposed flume (Layout 2)

It was realised that although the short flume possessed favourable sedimentation characteristics, water depths at the gauge point might be influenced by the drawdown curve. The fact that the gauge point was situated in a converging section was a further drawback of the short flume. It was realised that the flume had to be lengthened to find a compromise between sedimentation and calibration requirements.

It was decided to lengthen the short flume, by providing parallel walls with a length of twice the total flume depth upstream of the point where contraction begins. From a distance of one flume depth upstream of this point, the abutment walls were sloped down at 45 degree angles. The gauge point was to be positioned just upstream of the point where convergence starts. All three original layouts were modified according to these prescriptions.

The standardised tests were performed on the new models in order to investigate their sediment handling properties. It was found that, in all three layouts, sediment accumulated under conditions of low discharges (see Figure 6.10). As the discharge increased however, the sediment transporting capacity in the flumes started exceeding the sediment inflow rate. The new flumes were cleared of sediment within 3 to 5 minutes (see Figures 6.11, 6.12 and 6.13). This was even quicker than what was achieved with the walls shortened to where the contraction begins. The reason for this somewhat unexpected result, was probably the fact that the sloped walls increased the three-dimensional acceleration around the abutment heads. This increased acceleration caused improved sediment transporting capacity in the flume.

A test was done to investigate the effect of unsymmetrical flow on the sediment properties in the flume. One side of the sharp-crested weir was now completely filled up with sand. Although the pattern of sediment in the flume initially showed the effect of greater availability of sediment at one of the vortices, the flume was cleared within 3 minutes. The results of this test are shown in Figure 6.14.

The new flume, in all three layouts, therefore possessed satisfactory sediment transporting capacities. It was realised and accepted that the problem of accumulation of sediment under conditions of low discharge, was not curable in a flume of this nature. The sediment transporting capacity in a flume is more or less a direct function of the discharge. If, under any given discharge, the sediment transporting capacity upstream of the flume exceeds the transporting capacity in the flume, sediment will start accumulating here. Conditions like this will be experienced when floods cause high sediment build-up in the upstream pool, creating the potential of high transporting capacities here.

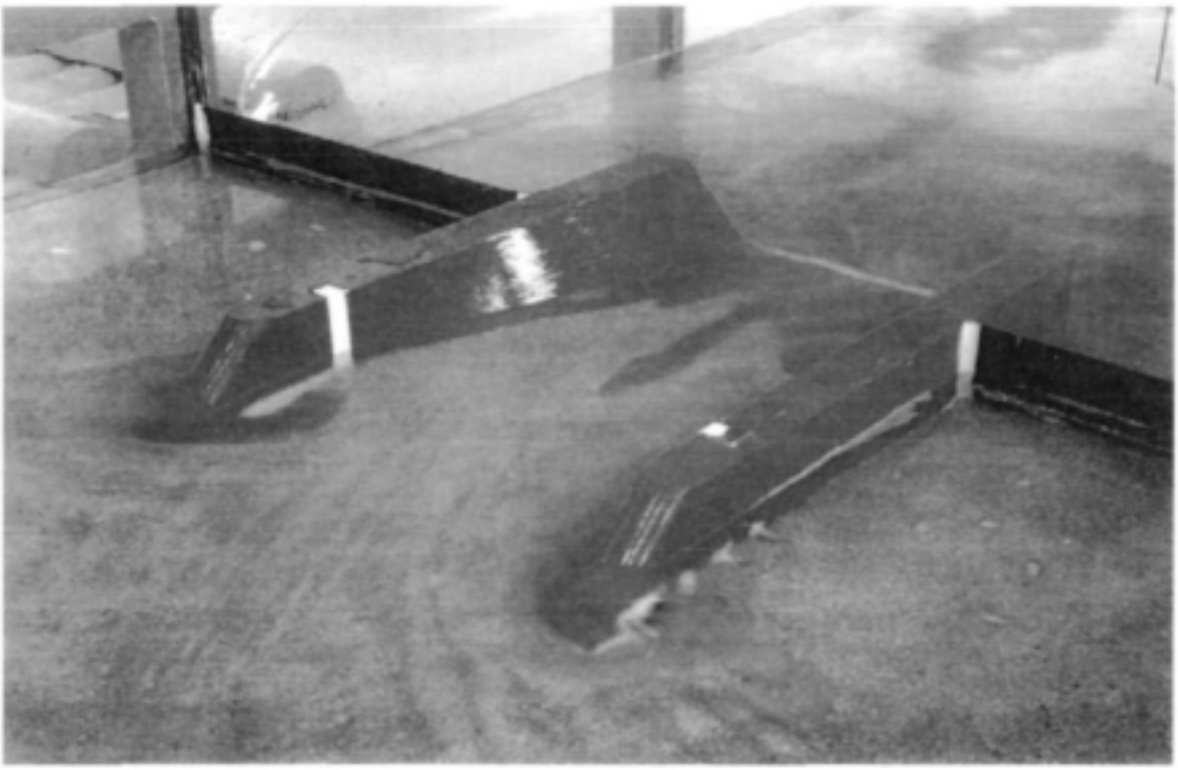

FIGURE 6.10 - Sediment accumulation under conditions of low discharge

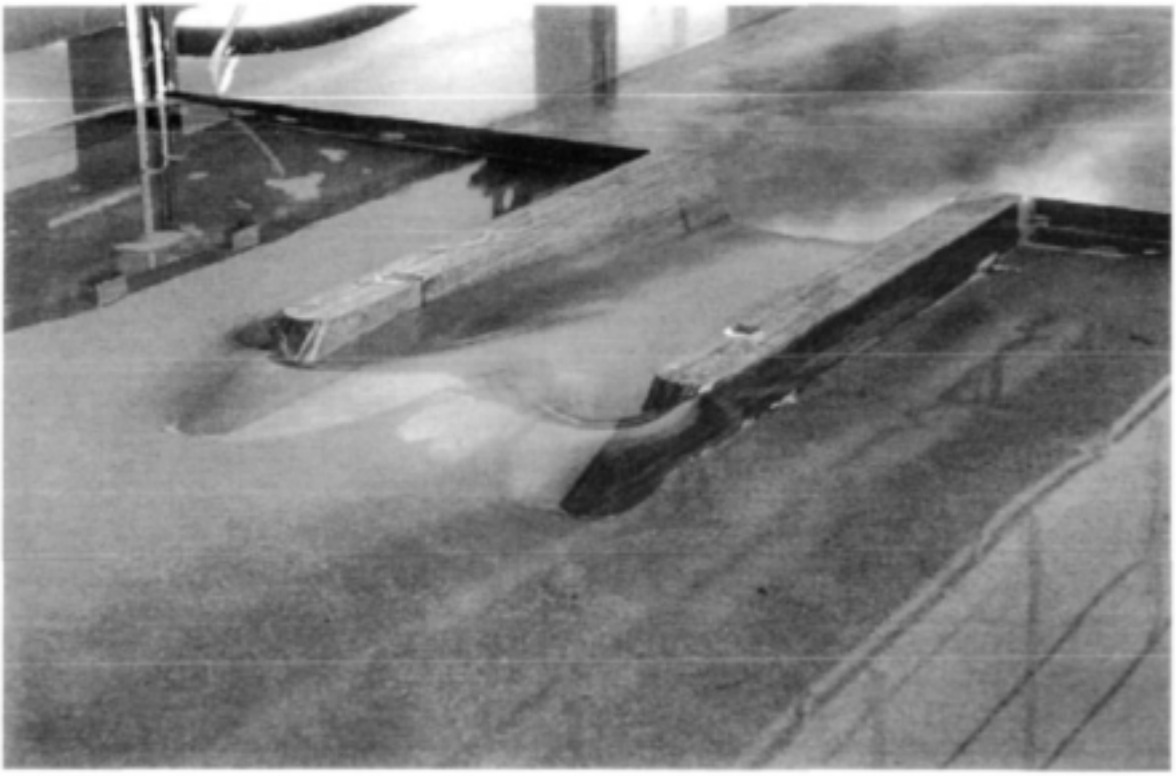

FIGURE 6.11 - Flume (Layout 1) almost completely cleared after 3 minutes

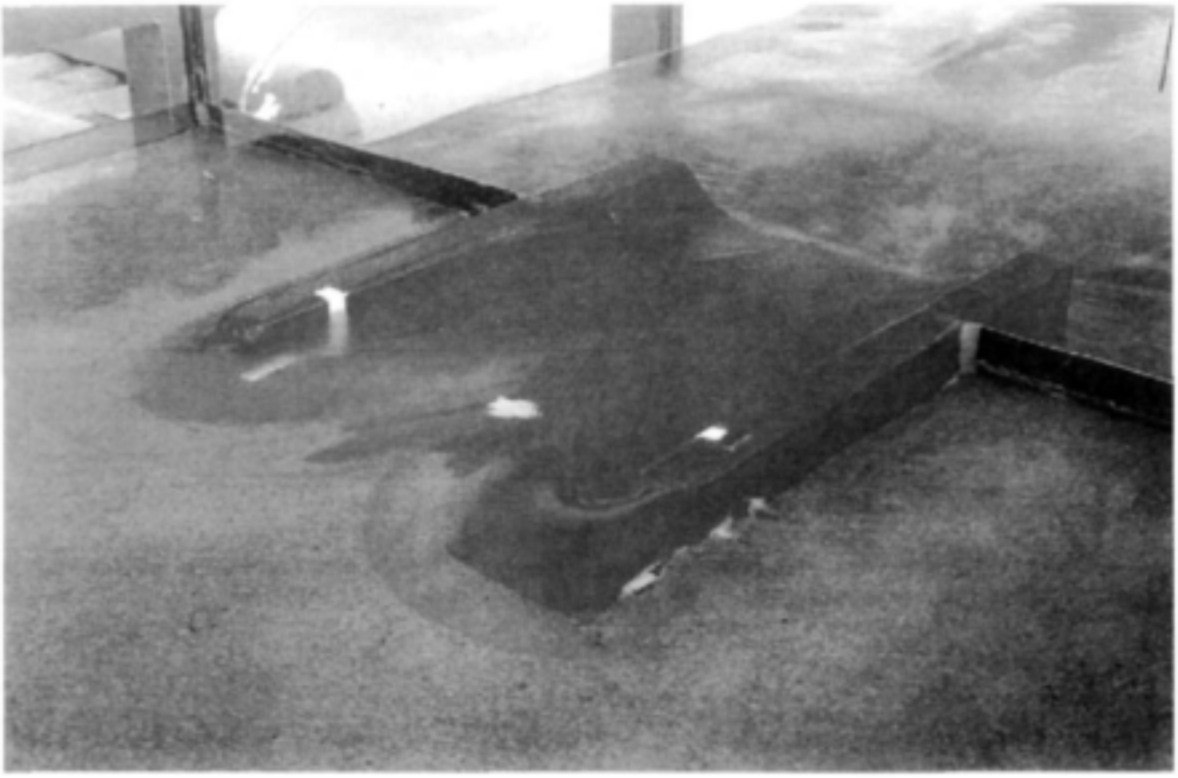

FIGURE 6.12 - Flume (Layout 2) almost completely cleared after 3 minutes

FIGURE 6.13 - Flume (Layout 3) almost completely cleared after 5 minutes

FIGURE 6.14 - Flume after 3 minutes with flow unsymmetrical

6.8 Conclusions

From the tests completed it was clear that the best solution which had been found was the configuration with the shortened, sloping abutment walls, including all three layouts. The removal time for sediment which had accumulated in the flumes, was the shortest of all those for the different configurations tested. It also provided an acceptable structure in terms of calibration, since the measuring point was far enough upstream not to be in the drawdown curve, and also not in a converging section.

As with all the models tested, problems with silting still existed under conditions of low discharge. After further tests were done it became evident that this was a very difficult problem to solve completely. During low discharges with high levels of sediment deposits in the upstream pool, the sediment transporting capacity upstream of the flume was much higher than in the flume itself. The shallow flow depth over the high sand deposits resulted in high flow velocities. This created a high sediment transporting capacity upstream and strong sediment movement into the flume. In the flume the flow was deeper and slower, and the transporting capacity much less than in the upstream pool. The sediment would then accumulate until a higher rate of flow cleared the flume.

With this type of weir-flume combination, an upstream pool with the potential of sediment build-up is created. It is believed that choking of the flume could always occur during the falling stage of the flood if the sediment level in the upstream pool is higher than the bed of the flume.

The new model however, provides an immense improvement from the original model with long abutment walls. The removal rates of sediment accumulated in the flume, were improved by a factor of ten. This was achieved by eliminating the section in the flume where no flow acceleration occurred. The transporting capacity in the new models increased continuously from the flume entrance to the flume outlet.

Major siltation in the flume is not expected during the rising phase of the flood. Sediment is deposited in the flume mainly during the falling phase of the flood when the sediment bed in the pool upstream of the flume becomes higher than the flume bed. Since the control section of the flume remains free of sediment deposits and because the deposited layer is relatively thin the sediment deposition will not seriously affect the calibration of the flume. The deposits in the flume are washed from the flume during long periods of constant discharge or during the rising phase of the flow. This self cleansing ability of the flumes is seen as a major improvement over previously used structures.

CHAPTER

SEVEN

INITIAL TESTS ON SUBMERGED FLOW CONDITIONS

7.1 Background to submergence studies

A flume or weir structure in a river can become submerged as a result of high downstream water levels. Submergence occurs when the water level downstream of the gauge station reaches a point where it influences the control that should exist at the gauging structure.

The point of maximum submergence before recorded levels at the gauge point are influenced, is called the modular limit. The water level at the gauge point of a gauge structure, with a high modular limit, is influenced only when a high degree of submergence occurs. The modular limit had to be determined for the newly developed flume.

Submergence is initiated when the modular limit of a structure is exceeded. Submergence thus influences stage at the gauge point, and the modular relationship between stage and discharge becomes invalid. In order to maintain an accurate, continuous flow data record, it is important to determine an additional stage - discharge relationship for submerged conditions.

In the model, submergence was achieved with an adjustable sluice gate at the downstream end of the channel. The downstream water level was increased until the stage at the gauge point was influenced. This point represents the modular limit. The downstream water level was measured at a point further than ten times the pool depth downstream of the flume. For each discharge, combinations of upstream and downstream water levels were measured, and these combinations were used to draw up curves describing the submergence properties of the flume.

7.2 Differentiating between flume and weir submergence

For discharges not exceeding the flume capacity, a schematic lay-out with definition of terms used, is shown in Figure 7.1. The unsubmerged flow depth for a given discharge is termed h_0. The submerged flow depth h_v, is measured in combination with t, the downstream water head relative to the flume bed.

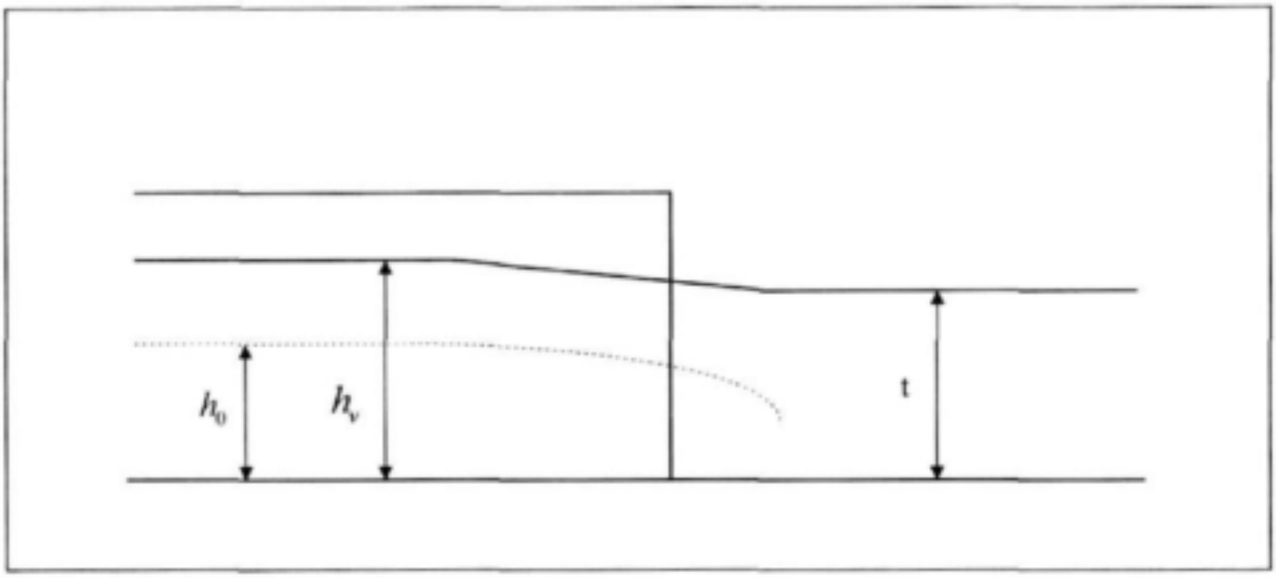

FIGURE 7.1 - Definition sketch of submerged conditions for flow in flume

Discharges which exceed the capacity of the flume, cause the adjoining weirs to come into operation. Figure 7.2 provides a definition sketch describing submergence of the adjoining weirs under these conditions.

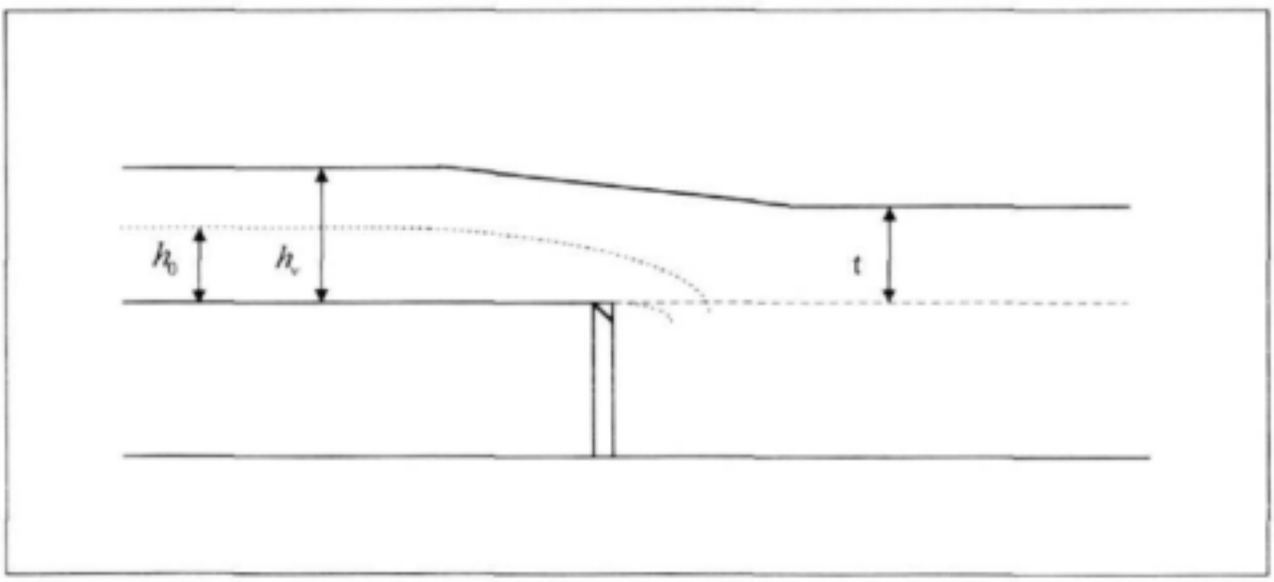

FIGURE 7.2 - Definition sketch of submergence for flow exceeding flume capacity

Initially all analyses were done according to the definition sketch in Figure 7.1. Measurements were taken relative to the flume bed for all discharges and no differentiation was made between flows in the flume and flows exceeding flume capacity. However, the many different combinations of compound weirs and flume structures that exist in practice, necessitate differentiation between submergence of the flume and that of the adjoining weir structures.

Wessels (1986) made a study of the submergence properties of sharp-crested weirs. Since many of the flume models were combined with sharp-crested weirs, these results were used to quantify the effect of submergence of the adjoining weirs. Numerous attempts at differentiating between the submergence of adjoining structures, proved the complexity of the problem and no satisfactory solution could be found. The problems encountered were:

- During submergence tests, stage was measured only at the gauge point and downstream of the flume, and not in the upstream pool. Modular relationships between flow depth at the gauge point and in the upstream pool had to be used to determine the upstream depth under submerged conditions.
- By using Wessels' simplified method, no stable results could be obtained when calculating modular flow depths from submerged flow depths. This could be as a result of the simplified method used or because of the fact that the upstream flow depths reflect the combination of flume and sharp-crested weir, and differ from stages upstream of a continuous sharp-crested weir.
- Submergence of the flume alone was tested to a point where the discharge started exceeding flume capacity. For higher discharges and "overfull" flume sections, submergence characteristics are not known.
- Combination of the effect of submergence of the flume and that of the adjoining weirs proved to be a very complex exercise.

It was decided to present the results of the submergence tests as they were initially analysed. The analyses were done according to Figure 7.1 for flow in the flume only and for flows exceeding flume capacity. The test results are available on a computer disk for further analyses (in envelope at the back of this report). The submergence test on the finally recommended structures under high flow conditions are discussed in Chapter 10.

7.3 Submergence properties of preliminary models

Submergence tests were done on all three lay-outs of the original models with long abutment walls. The most promising and best-tested model, lay-out 2, was tested for submergence in combination with both a sharp-crested and a Crump weir. Lay-outs 1 and 3 were tested in combination with sharp-crested weirs only.

Test results were used to draw up curves with which the effect of submergence could be described. The tables for each model tested, are attached in Appendix 7.1. Figure 7.3 shows submergence characteristics of the original flume lay-out 2, for flows not exceeding flume capacity, with a curve fitted to the data. This curve was fitted to percentages of submergence of more than 80 % and should only be applied in this region. For lower levels of submergence, the flow is modular or nearly modular. In this region a straight-line graph can be used to represent the data points. The value of t/h_v represents the degree of submergence, with terms defined according to Figure 7.1. The value of h_0/h_v can be obtained from the curve and used to determine a stage associated with the flow as if no submergence occurred (h_0). This flow depth can now be used with the original calibration curves to determine discharge.

Curves were fitted using a curve fitting computer package. The curves were mostly fitted only for a range of submergence between 0,8 and 0,98 and should only be applied in this range. In certain areas, specifically when the fitted equations start causing decreasing h_0/h_v values with decreasing percentages of submergence, certain alterations were made to curves. Horizontal portions of the fitted curves are typical examples of this.

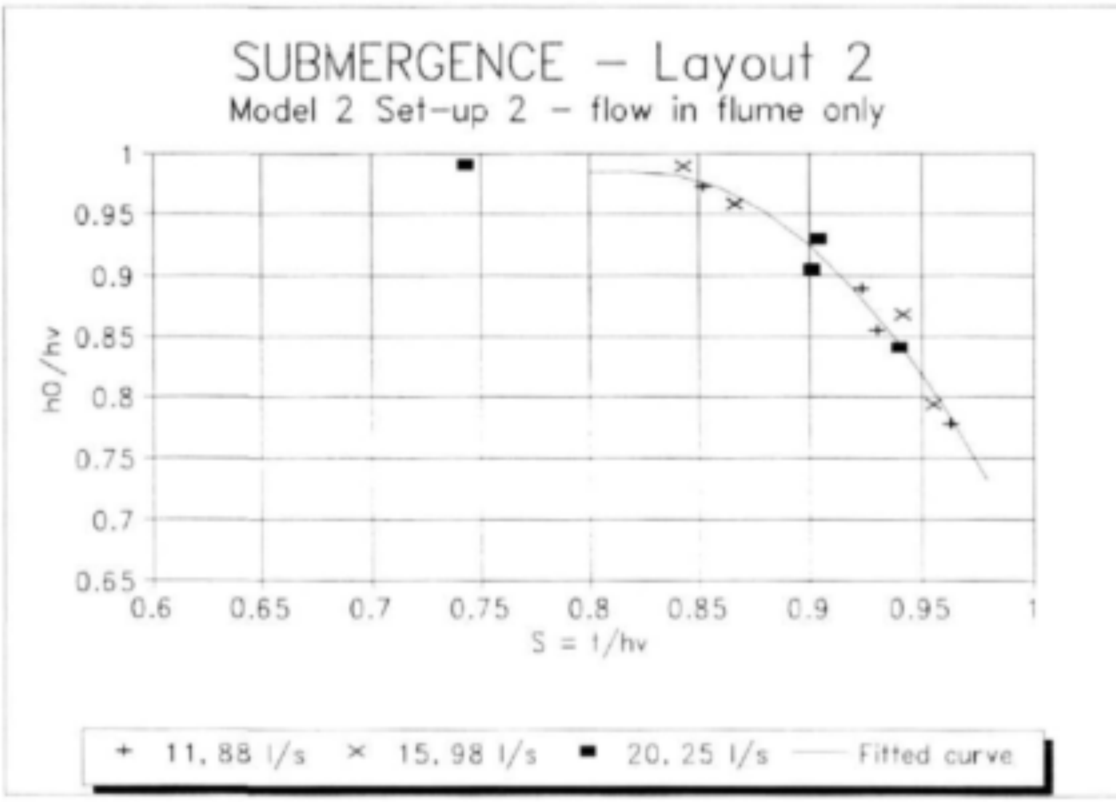

FIGURE 7.3 - Submergence of original model lay-out 2 for flows in flume

The curve fitted in figure 7.3 has the following equation:

$$h_0/h_v = \left(-6.08 + 17.16 \times S - 10.41 \times S^2\right) \qquad 7.1$$

Figure 7.4 shows submergence of the same model for flows exceeding flume capacity. Again, the curve was only fitted for percentages of submergence exceeding 80 %, and must be applied in this region only. This curve, being a combination of submergence characteristics of the flume and adjoining sharp-crested weirs, must be applied with caution, since it is only applicable to scaled combinations of flume and sharp-crested weir dimensions used in laboratory tests.

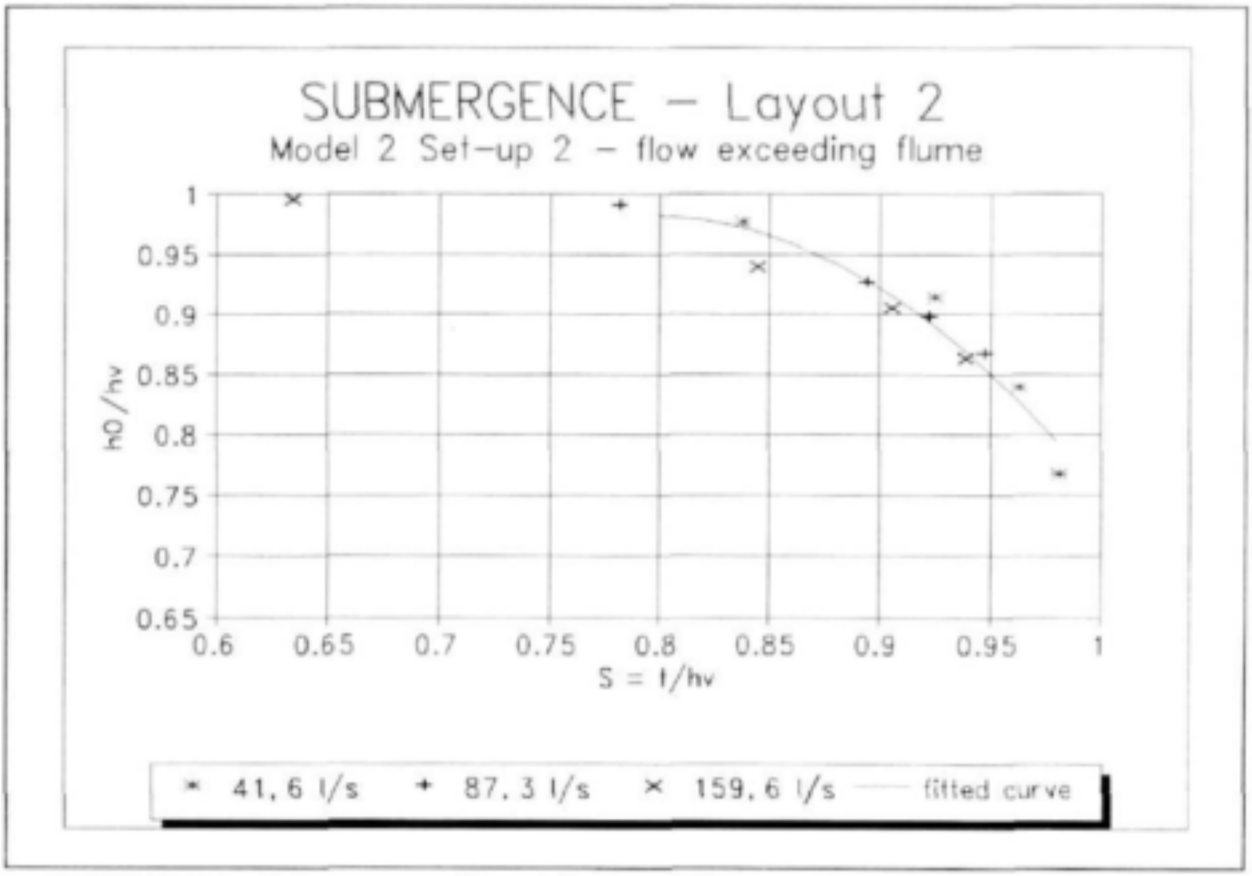

FIGURE 7.4 - Submergence for original model lay-out 2 for flows exceeding flume capacity

The equation for the fitted line in figure 7.4 reads:

$$h_0/h_v = \left(-5.53 \times S^2 + 8.80 \times S - 2.52\right) \qquad 7.2$$

By comparing the submergence results of the flume in combination with a sharp-crested weir, to those obtained in combination with a Crump weir, a considerable improvement was observed in the case of the Crump, as might have been expected. In situations in practice where submergence of a gauging structure is expected, it would be advisable to construct the flume in combination with a Crump weir. Figure 7.5 shows submergence of the original lay-out 2 in combination with a Crump weir for discharges exceeding flume capacity.

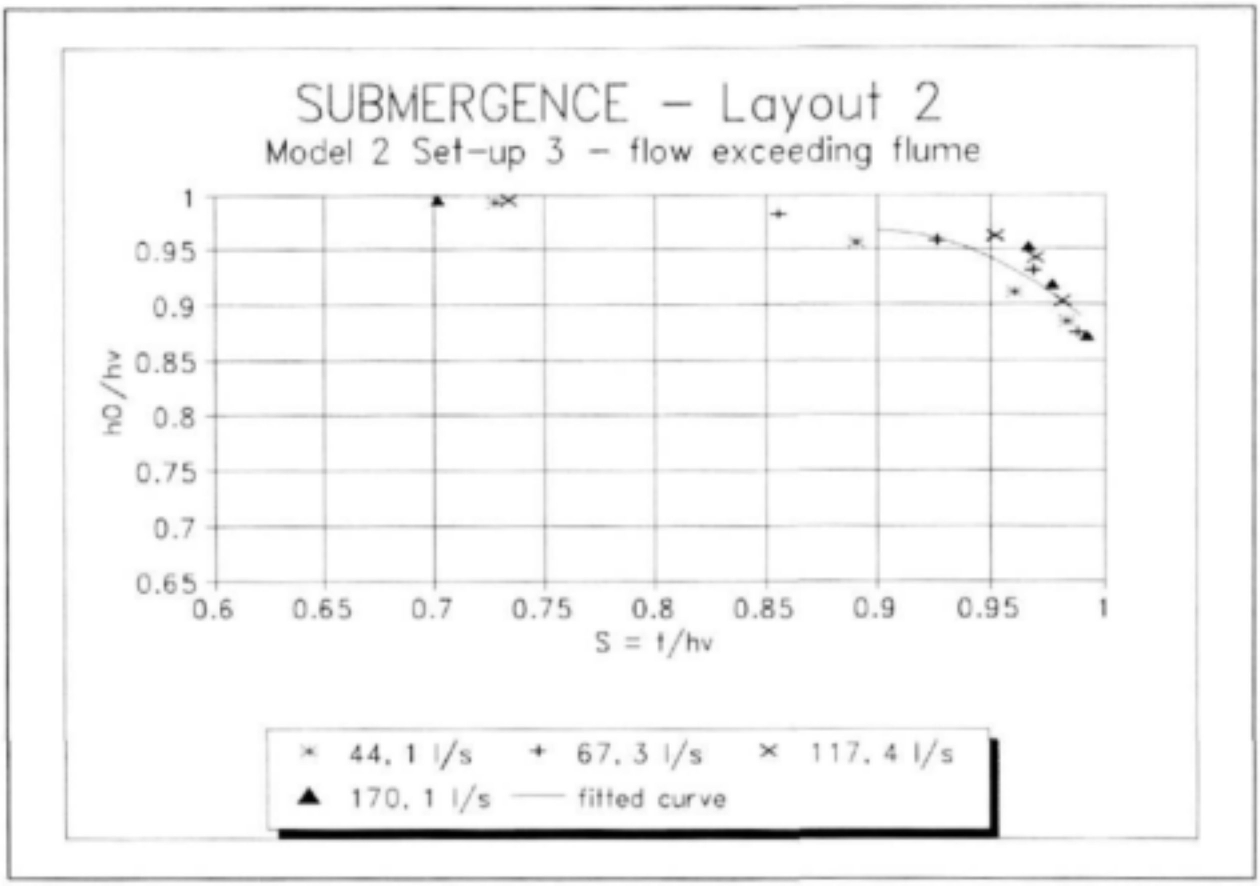

FIGURE 7.5 - Submergence of original model lay-out 2 in combination with a Crump weir

The equation representing the fitted line in figure 7.5 is as follows:

$$h_0/h_v = \left(-9.33S^2 + 16.77S - 6.57\right) \qquad 7.3$$

Again, the curve is fitted for percentage of submergence exceeding 80 % and a linear relationship must be used to describe lower levels of submergence.

For all three lay-outs of the original model tested, the modular limit is reached at a submergence level of 80 %.

7.4 Submergence properties of adapted models

The adapted models with abutment walls shortened and sloped at 45 degree angles were tested under conditions of submergence in combination with sharp-crested weirs. Results for submergence tests performed on all three lay-outs and the resulting curves are shown here, as the authors believe that these structures will be commonly used in practice. In all three cases, curves were fitted for submergence levels exceeding 80 %, and they must be applied only in this region.

Figure 7.6 shows submergence properties of the adapted model lay-out 1, for discharges not exceeding flume capacity, with a curve fitted to submergence levels exceeding 80 %.

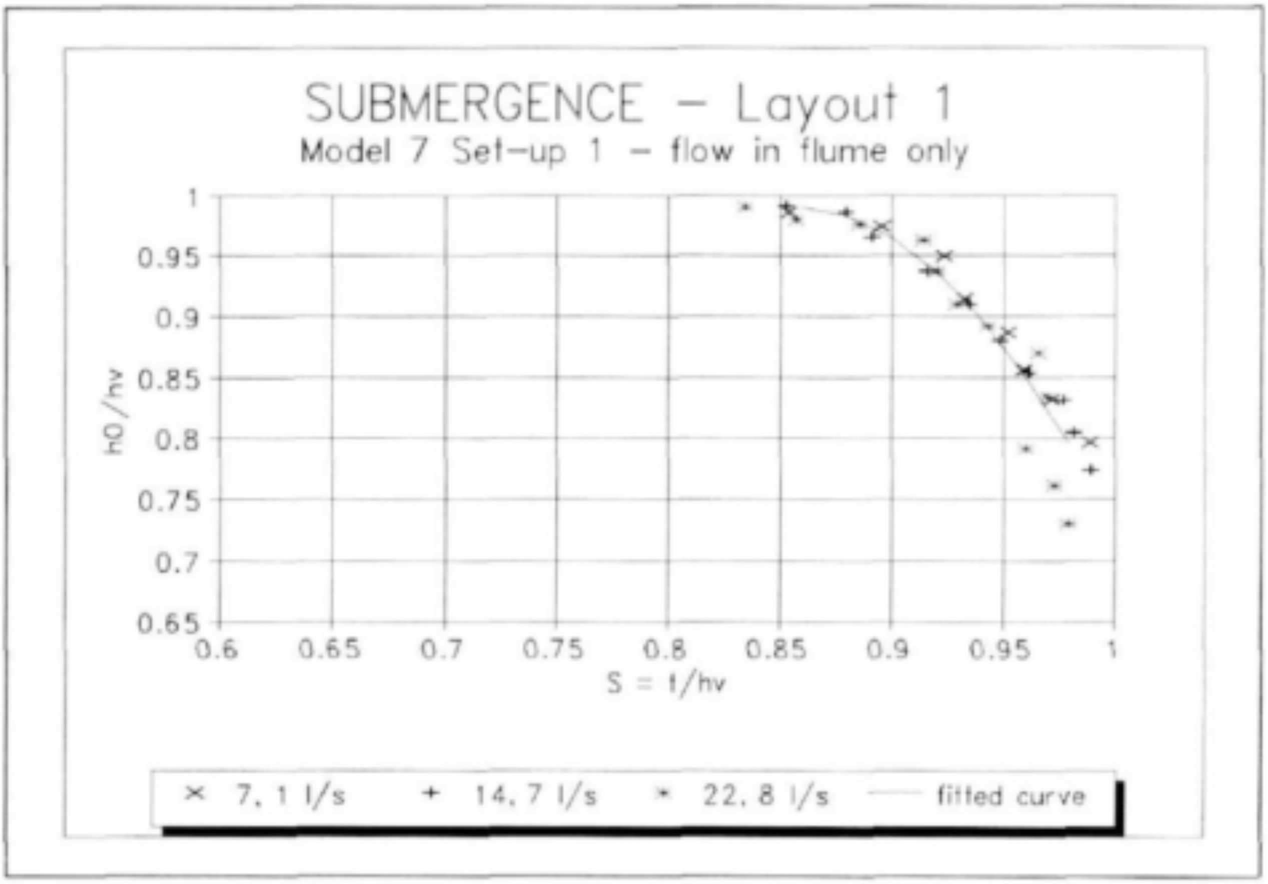

FIGURE 7.6 - Submergence of model lay-out 1S for flows in flume

The following equation represents the curve fitted in figure 7.6:

$$h_0 / h_v = (6.33 - 3.64 \times S^2 - \frac{1.96}{S^2}) \qquad 7.4$$

Figure 7.7 shows the submergence properties of the adapted model lay-out 1, but now with discharges exceeding flume capacity. This curve, representing a combination of submergence of the flume and adjoining sharp-crested weirs, is typical of the models tested and can only be used for approximate calculations.

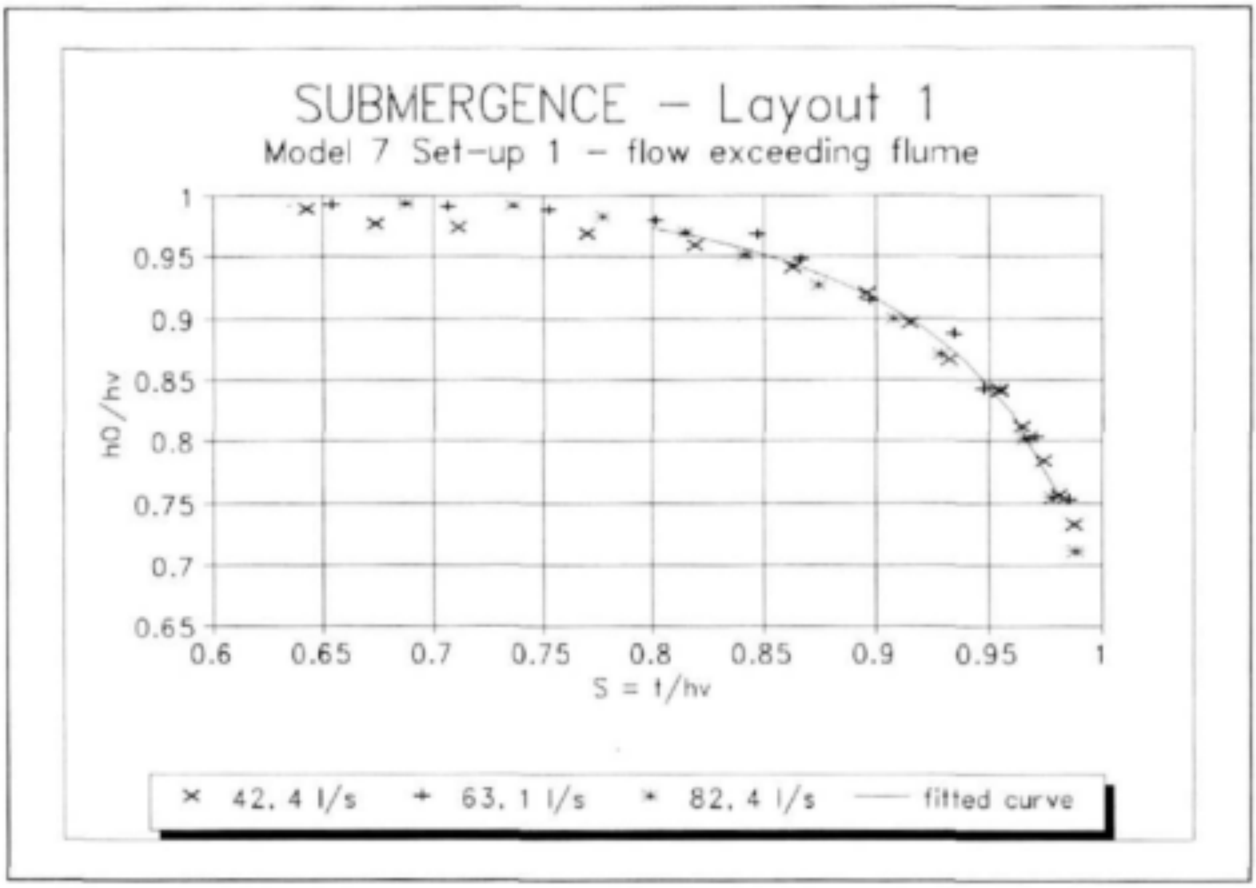

FIGURE 7.7 - Submergence in flume lay-out 1S for flows exceeding flume capacity

The equation representing the curve fitted in figure 7.7 reads:

$$h_0 / h_v = 1/\left(\left(0.96 - 0.91S\right)/\left(1 - 0.97S\right)\right) \qquad 7.5$$

Curves similar to those in figure 7.6 and 7.7, but now for the modified lay-out 2 and 3, follow without further explanation.

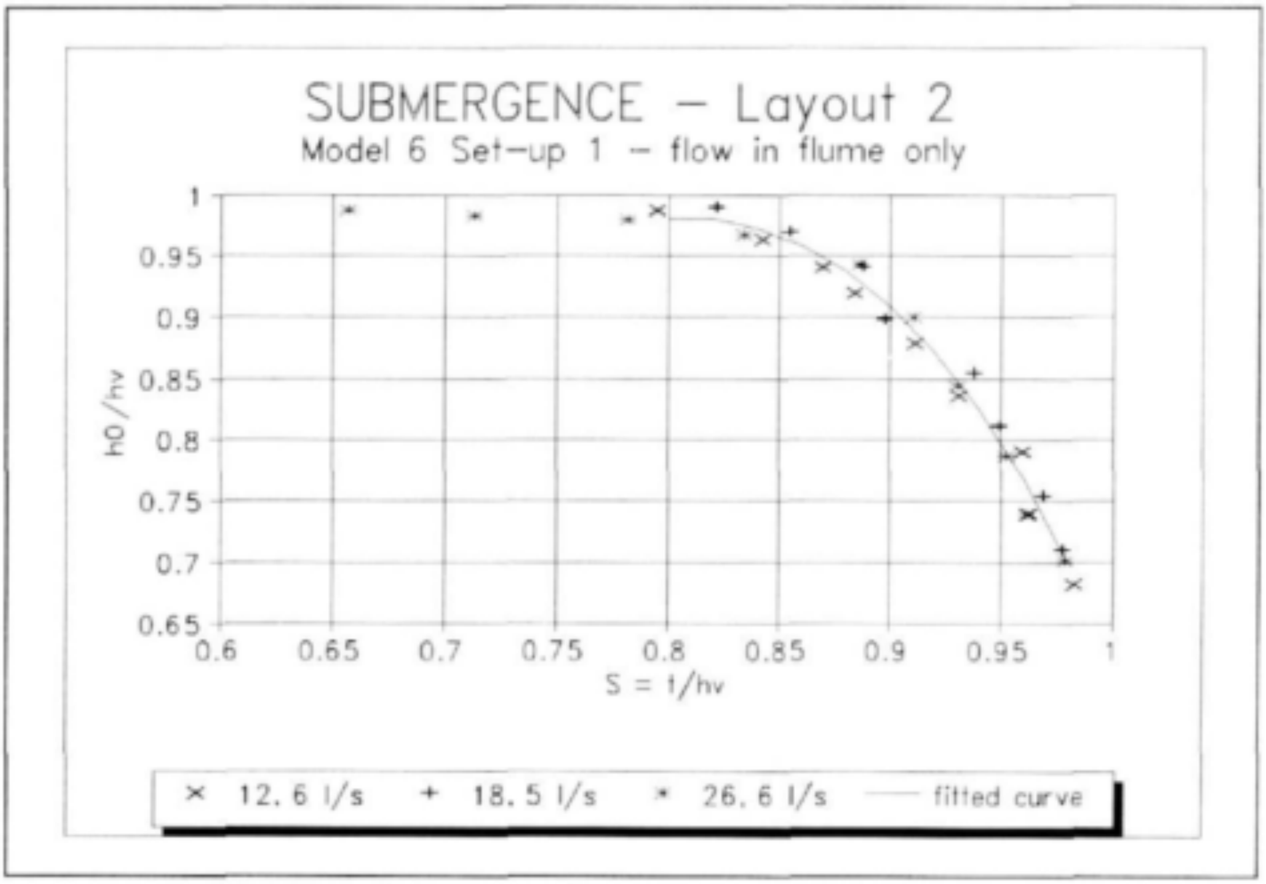

FIGURE 7.8 - Submergence in model lay-out 2S for flows in flume

The equation representing the curve fitted in figure 7.8 reads:

$$h_0 / h_v = \left(-9.44 + 25.75 \times S - 15.94 \times S^2\right)^{1/2} \qquad 7.6$$

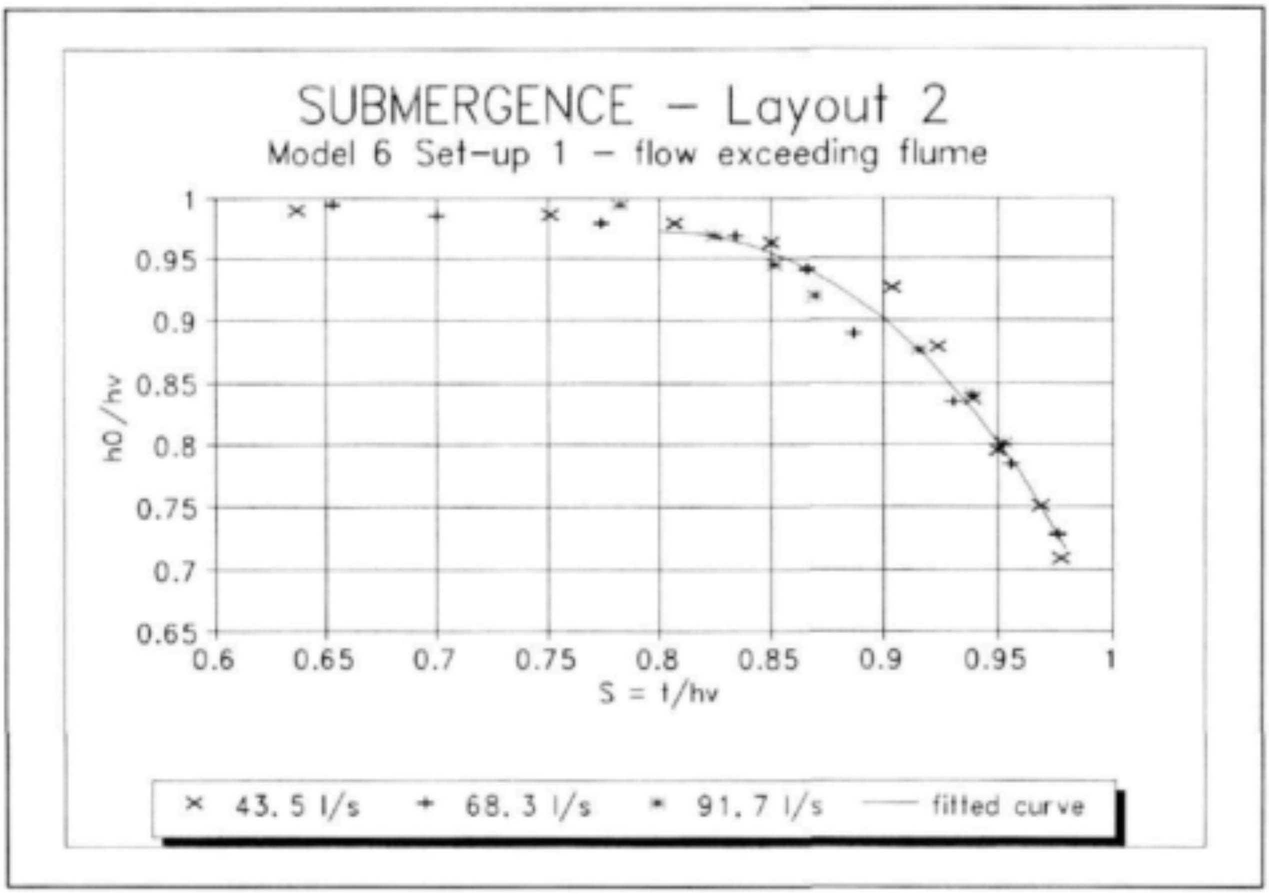

FIGURE 7.9 - Submergence in flume lay-out 2S for flows exceeding flume capacity

The equation representing the curve fitted in figure 7.9 reads:

$$h_0 / h_v = \left(-7.57 + 21.30 \times S - 13.32 \times S^2\right)^{1/2} \qquad 7.7$$

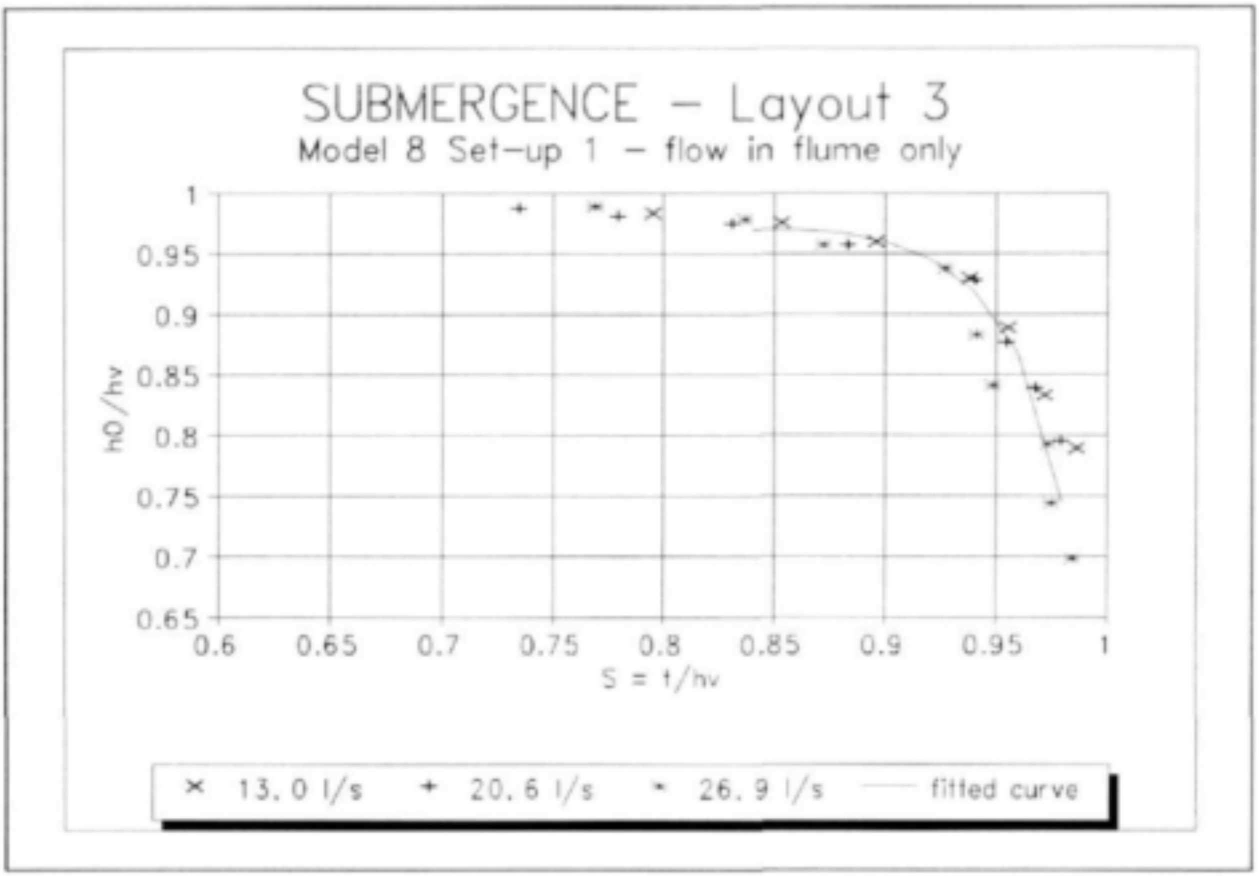

Figure 7.10 - Submergence in model lay-out 3S for flows in flume

The equation representing the curve fitted in figure 7.10 reads:

$$h_0 / h_v = (0.75 - 0.75 \times S) / \left(1 - 1.30 \times S - 0.31 \times S^2\right) \qquad 7.8$$

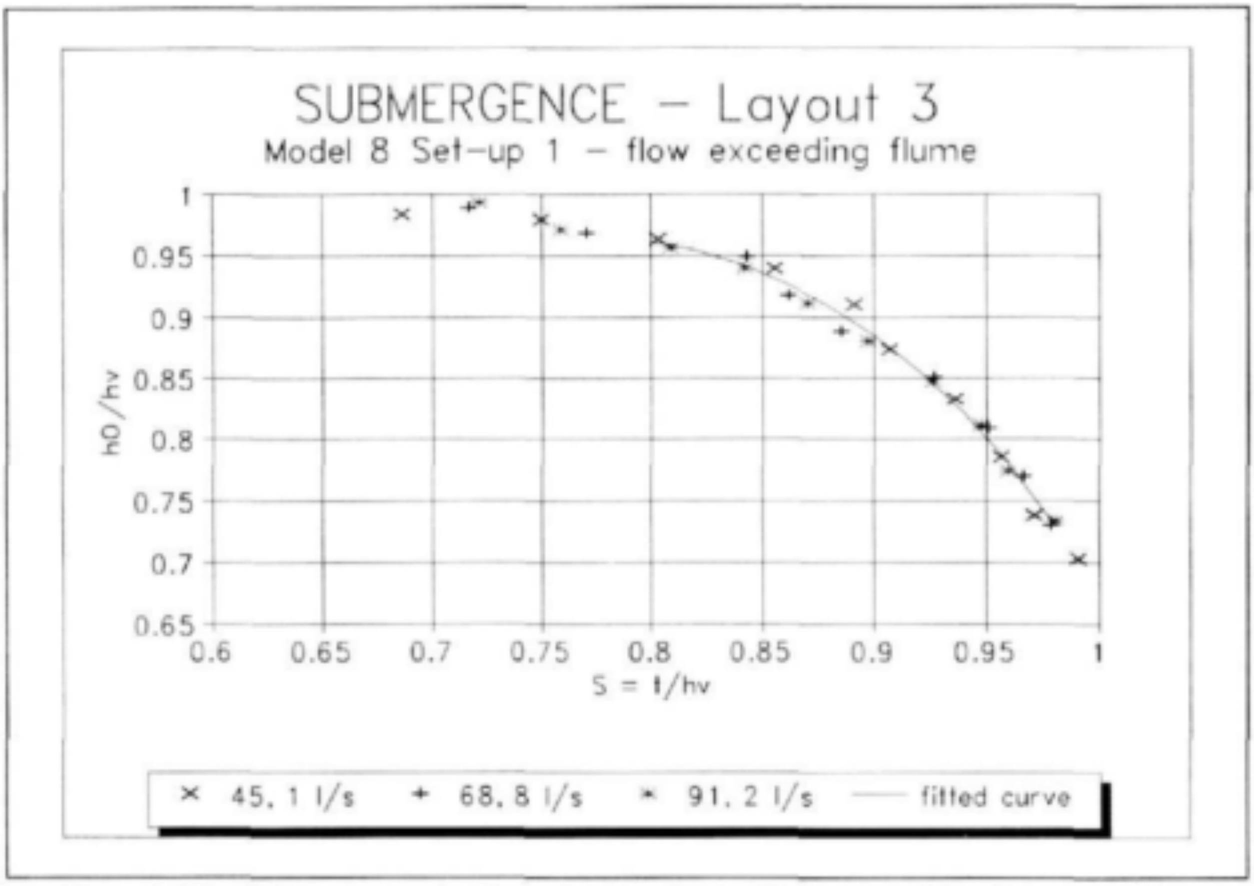

Figure 7.11 - Submergence in flume lay-out 3S for flows exceeding flume capacity

The equation representing the curve fitted in figure 7.11 reads:

$$h_0 / h_v = \left(-4.59 + 14.28 \times S - 9.24 \times S^2\right)^{1/2} \qquad 7.9$$

The procedure followed in obtaining the stage as if modular conditions exist, has been described in paragraph 7.3. The modular limit is again reached at a level of submergence of 80 %.

7.5 Conclusions

The effect that submergence has on calibration can be established as has been described in this chapter. For each model which has been tested, a unique curve which quantifies the effect of submergence, was fitted. Curves were fitted for determining the effect of submergence for submergence levels exceeding 80 %. For lower levels of submergence flow is regarded as modular or close to modular and the effect of submergence can be ignored.

Curves which illustrate submergence under conditions where discharges do not exceed flume capacity (about 30 l/s for all three lay-outs), are accurate and can be used with confidence in practice.

For discharges exceeding flume capacity, the authors were unable to differentiate between the effect of the flume and that of its adjoining weirs. The curves drawn up for discharges exceeding flume capacity, must therefore be regarded as typical of the laboratory set-up where an upstream pool with fixed dimensions and predetermined adjoining weir lengths were used for all tests. These curves can be used to calculate the discharge for submerged flow for similar structure combinations as was used in the model.

For gauge stations where submergence is expected, it is advisable to use a Crump weir in combination with the flume, because of its favourable submergence characteristics. Modular limits are generally reached at a degree of submergence of 80 %, which is very similar to that for the broad-crested weir. These results are also in accordance with the known qualities of Crump weirs.

Submergence causes inaccuracies at gauging stations and must be avoided by constructing flumes at the correct level. When submergence does occur, the authors believe that discharges can be predicted to reasonable degrees of accuracy using the methods described in this chapter.

After the tests described here were completed some adjustments to the flume dimensions were made. The submergence tests on the finally recommended structures under much higher flow rates than before, are described in Chapter 10.

CHAPTER

EIGHT

RECOMMENDED STRUCTURES

8.1 General

The calibration tests which were conducted during this study show that it will be possible to construct stage-discharge relationships for a variety of sluicing flumes in combination with sharp crested and Crump weirs. The results are robust and allow a large degree of freedom in the selection of prototype structure dimensions without the need for further calibration tests in the model.

Because of their superior performance under conditions of serious siltation, the use of flumes with short abutment walls is recommended. In the finally recommended lay-outs the total length of the flume structure was minimized to overcome possible foundation problems. The upstream end of the flume walls are sloped at 45 degrees to reduce the risk of trapping debris at these points.

The thickness of the flume walls recommended are those that were used in the final calibration tests. The DWAF indicated that they prefer to use a constant wall thickness of 0.5 m for ease of construction. This will be acceptable since it was found in the tests that wall thickness did not affect the discharge coefficients of the flumes, provided that very thin walls are not used.

The position of stage recording is invariably in a cavity in the flume wall at the transition from the rectangular to the trapezium section of the flume. The standard cavity used by DWAF will minimise the risk of sediment blocking the recording instruments. The cavity environment was also found to be relatively free from sedimentation during the sedimentation tests in the model.

8.2 Flume with $d/b = 0.5$ (Lay-out 2R)

Flumes with this depth to width ratio were tested extensively during this study. The calibration was found to be insensitive to variation in wall thickness of the flume, length of the flume wall, flow symmetry and position as well as shape of side walls.

The flume shown in Figure 8.1 is a near optimum compromise in terms of accurate flow measurement and minimum siltation problems.

The position of the adjoining weirs are also shown in this figure. The sharp-crested weir is placed at the downward end of the flume. This gives the maximum distance between the control section of the weir and the stage recording position. This lay-out is identical to that in Test 6.1. In the case of the Crump weir, the weir was fitted next to the flume in a position to give the minimum total width of the combined structure to minimize foundation problems. This result in a stage recording position close to the control section of the Crump weir. This aspect will be addressed when the final calibration tests of this weir is discussed.

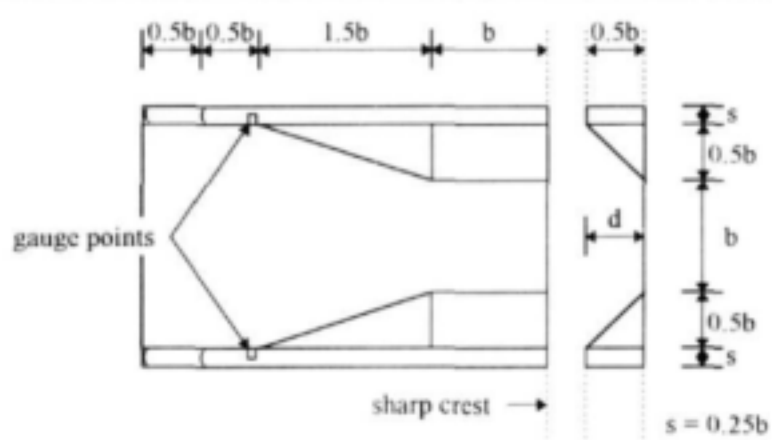

FIGURE 8.1(a): Recommended flume lay-out with sharp crest weir (d/b=0.5)

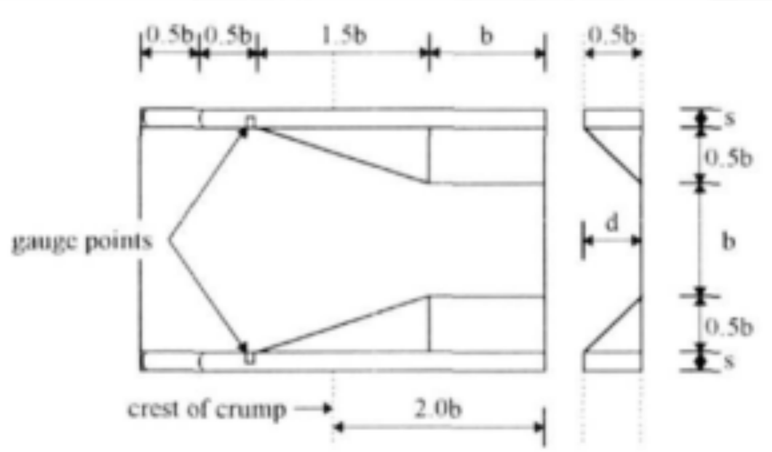

FIGURE 8.1(b): Recommended flume lay-out with Crump weir (d/b=0.5)

8.3 Flume with $d/b = 1.0$ (Lay-out 1R)

Tests on this flume were less extensive than the tests on Flume 2 described above.

The recommended flume dimensions are shown in Figure 8.2.

This flume is similar to the flume previously tested (lay-out 1S, Figure 4.1) except that the trapezium section of the flume was reduced from 2.0b to 1.0b. The reason for the reduction was again to reduce the total length of the flume.

This flume was only tested in combination with a sharp crested weir, placed at the lower end of the flume.

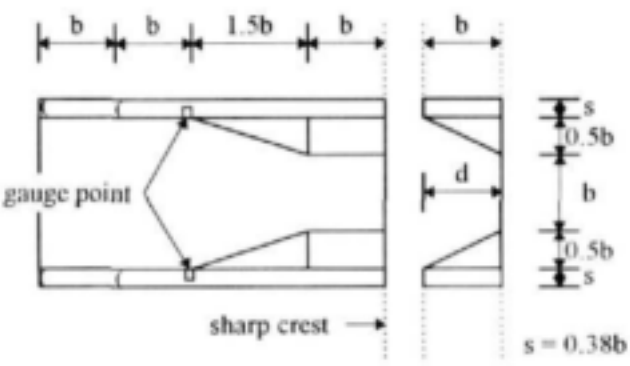

FIGURE 8.2: Recommended flume with d/b=1

8.4 Flume with $d/b = 0.25$ (Lay-out 3R)

The recommended dimensions of a flume with depth to width ratio of 0.25 are shown in Figure 8.3. This flume is not identical to any of the other flumes which have been tested in that the abutment walls of the flume are longer than those tested in test 8.1. The increased wall length is required to ensure that the stage recording position is outside the area of intense vorticity at the flume entrance.

This flume was only tested in combination with a sharp-crested weir, placed at the lower end of the flume.

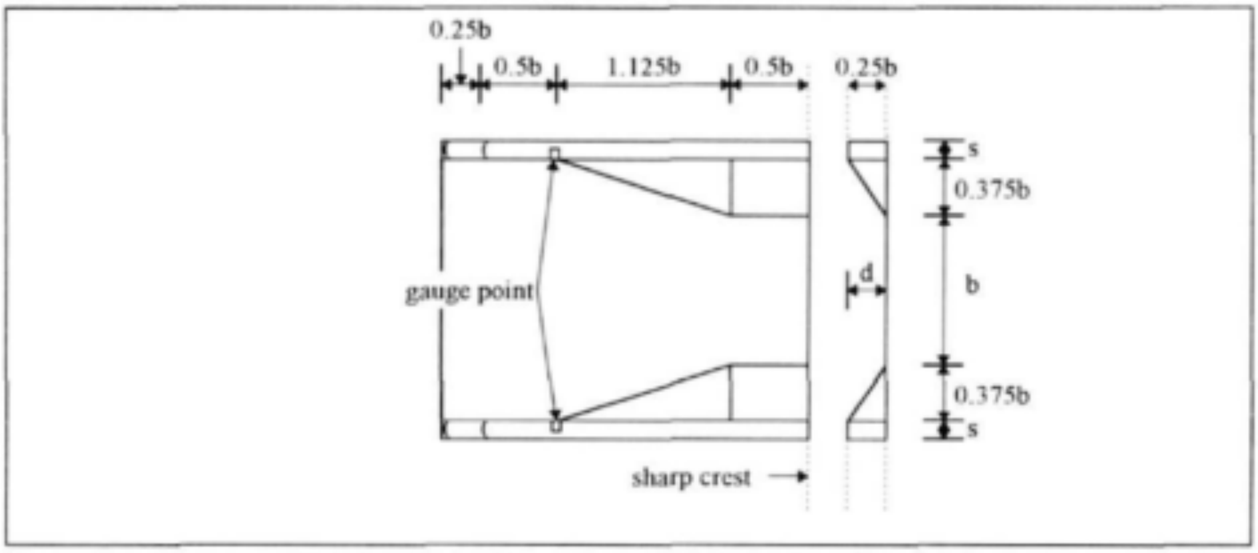

FIGURE 8.3: Recommended flume for d/b= 0.25

CHAPTER

NINE

FINAL CALIBRATION TESTS ON RECOMMENDED STRUCTURES

9.1 Introduction

A final series of calibration tests were performed on the recommended structures. The main purpose in these tests were to accurately calibrate the finally recommended structures. The calibration in these tests was based on a stage recording position favoured by DWAF. The range of discharges were extended to include much higher flows than were previously tested.

These tests were mainly executed with the sluicing flumes in combination with sharp-crested weirs. The sharp-crested weirs were placed at the downstream end of the sluicing flumes in all these tests. A series of tests with a sluicing flume with a d/b ratio of 0.5 in combination with a Crump weir were also done. This combination is expected to be used most frequently when new river gauging structures are constructed.

In these final calibration tests various stage recording positions inside and outside the flume were used. All the analysis were however referred to the stage recording position preferred by DWAF. The discharge coefficients C_{d2} and C_{d5} as well as the relationship between the stage (y_2) and upstream energy (Es_5) were determined for each flume. This enables the determination of the discharge as a function of the recorded stage for a wide range of flow conditions and flume-weir combinations. Using the relationships established in the model tests, stage discharge curves for the tested flume-weir combinations were determined. These stage-discharge curves are compared to the recorded values to establish the accuracy of the relationships.

Tests on the performance of the finally recommended structures under non-modular flow conditions were also performed. In these tests the flumes on their own (i.e. without adjoining weirs) were tested as well as sluicing flumes in combination with adjoining sharp-crested and Crump weirs. These test are described in Chapter 10.

9.2 Stage recording position

The position where water levels are recorded are shown in Figure 9.1. Water levels at positions 2.1, 2.2, 2.3, 4, 5 and 6 were recorded directly by means of a needle gauge. Water levels at positions 2.11 and 2.33 were recorded in a stand tube connected by a 5 mm tube to a cavity in the flume wall. The water level at position 2.22 was also recorded in a stand tube connected to an opening in the bottom of the flume, directly below position 2.2.

The DWAF prefer to record their water level in a cavity in the flume wall to reduce the risk of sediment blocking their recording system. The recording at 2.11 and 2.33 in the model therefore represent the DWAF recordings and the average of the levels recorded at these two

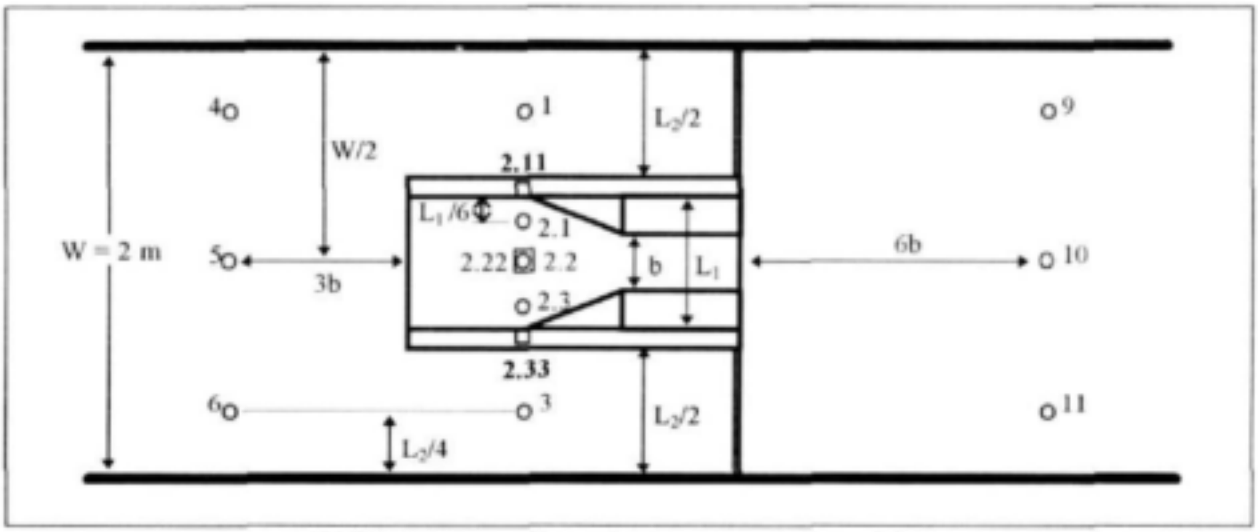

FIGURE 9.1: Water level recording positions

positions will be used to represent the stage y_2 in this study. The water levels recorded at the other positions inside the flume will not be used in this report but the values are included in the observations in the appendix.

Water levels recordings at positions 4, 5 and 6 will normally not be made in the prototype. The average water level at these positions was however used in this study to estimate the upstream energy (Es_5) relative to the flume bottom.

9.3 Determination of C_{d2} and C_{d5}

The discharge coefficient C_{d2}, applicable where all the flow is contained within the flume, was determined exactly as described earlier (See Section 5.3). The theoretical discharge was estimated by assuming no energy loss between the flume exit and the recording position. The true discharge is known in each test. The discharge coefficient, to allow for the losses, was then calculated as the ratio of the true discharge over the theoretical discharge. In the case of flow over the adjoining sharp-crested weirs, the theoretical discharge through the flume was estimated by assuming no losses between the position upstream of the flume and the flume exit. The true discharge through the flume was estimated by subtracting the estimated flow over the adjoining weirs from the total discharge in the model. The discharge coefficient C_{d5}, to allow for losses that occur between the recording position in the pool upstream of the flume and the flume exit, is determined as the ratio of true discharge over theoretical discharge.

9.4 Converting stage to upstream energy head

To be able to calculate the discharge through the flume and over the adjoining sharp-crested weirs for the case where all the flow is not limited to the flume, it is necessary to convert the recorded stage in the flume to an energy level upstream of the flume. The approach of an empirical relationship between the recorded stage (y_2) and the upstream energy (Es_5) relative to the flume bottom, as determined from the model tests, were used throughout.

9.5 Results for sluicing flume with d/b = 0.5 in combination with a sharp crested weir

9.5.1 Lay-out

The dimensions of the recommended flume and the lay-out as tested in the model, are shown in Figure 9.2.

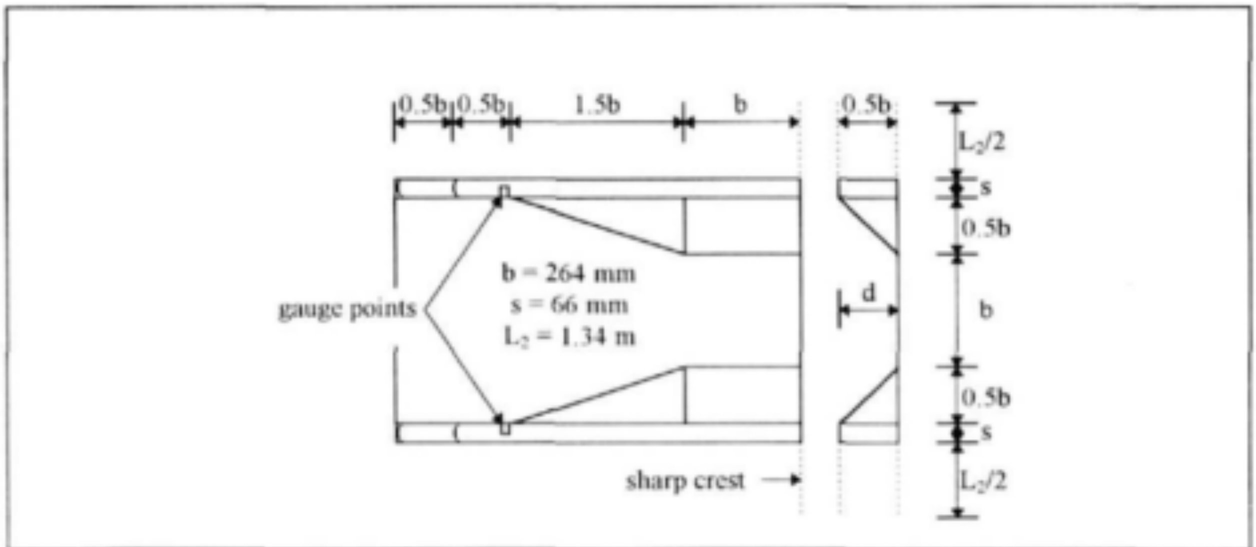

FIGURE 9.2: Flume lay-out - b/d=0.5 with sharp-crested weir

The positions where water levels were recorded are shown in Figure 9.1. A complete record of the water levels recorded in these tests are given in Appendix 9.1. A summary of the water levels at the stage recording position and the upstream pool is given in Table 9.1 below.

9.5.2 Estimates of discharge coefficients C_{d2} and C_{d5}

The discharge coefficients C_{d2} and C_{d5}, as derived from these tests, are also summarised in Table 9.1 below. The analyses of the data can be found in Appendix 9.2.

TABLE 9.1: Recorded water levels and estimated discharge coefficients for flume with d/b=0.5 in combination with sharp-crested weir.

	Q (m^3/s)	2.11	2.33	Ave. (m)	4	5	6	Ave. (m)	C_{d2}	C_{d5}
1	0.0123	7.95	7.95	0.0795	8.65	8.65	8.65	0.0865	0.92	-
2	0.0198	10.10	10.00	0.1005	11.20	11.30	11.30	0.1127	0.97	-
3	0.0058	5.10	5.05	0.0508	5.40	5.40	5.40	0.0540	0.93	-
4	0.0093	6.80	6.75	0.0678	7.30	7.30	7.30	0.0730	0.92	-
5	0.0131	8.20	8.15	0.0818	8.90	8.90	8.95	0.0892	0.93	-
6	0.0159	9.05	9.05	0.0905	10.00	10.00	10.05	0.1002	0.95	-
7	0.0211	10.40	10.35	0.1038	11.65	11.65	11.70	0.1167	0.98	-
8	0.0247	11.20	11.20	0.1120	12.75	12.75	12.75	0.1275	0.99	-
9	0.0344	13.35	13.35	0.1335	14.50	14.50	14.55	0.1452	-	0.88
10	0.0389	14.25	14.25	0.1425	15.05	15.05	15.10	0.1507	-	0.87
11	0.0429	14.85	14.80	0.1483	15.50	15.50	15.55	0.1552	-	0.86
12	0.0481	15.50	15.50	0.1550	16.05	16.05	16.10	0.1607	-	0.85
13	0.0511	15.80	15.80	0.1580	16.25	16.30	16.30	0.1628	-	0.86
14	0.0932	19.15	19.05	0.1910	19.35	19.35	19.45	0.1938	-	0.86
15	0.0683	17.35	17.35	0.1735	17.65	17.65	17.70	0.1767	-	0.87
16	0.0573	16.35	16.35	0.1635	16.70	16.75	16.80	0.1675	-	0.88
17	0.0784	18.15	18.15	0.1815	18.35	18.35	18.45	0.1838	-	0.87
18	0.0855	18.60	18.60	0.1860	18.80	18.85	18.85	0.1883	-	0.87
19	0.1538	22.15	22.15	0.2215	22.35	22.35	22.40	0.2237	-	0.94
20	0.2009	24.20	24.20	0.2420	24.40	24.45	24.45	0.2443	-	0.97
21	0.2510	26.40	26.40	0.2640	26.45	26.50	26.50	0.2648	-	0.97
22	0.3013	28.10	28.10	0.2810	28.15	28.15	28.20	0.2817	-	1.01
23	0.3513	29.85	29.90	0.2988	30.00	30.00	30.05	0.3002	-	1.00
24	0.3961	31.25	31.25	0.3125	31.35	31.40	31.35	0.3137	-	1.01
25	0.4507	32.80	32.90	0.3285	32.85	32.90	32.90	0.3288	-	1.04
26	0.4810	33.70	33.75	0.3373	33.85	33.90	33.90	0.3388	-	1.03
27	0.0544	16.15	16.20	0.1618	16.55	16.55	16.60	0.1657	-	0.87
28	0.0735	18.00	18.00	0.1800	18.10	18.15	18.15	0.1813	-	0.85
29	0.1052	19.95	20.00	0.1998	20.05	20.05	20.15	0.2008	-	0.87
30	0.1273	21.20	21.20	0.2120	21.25	21.25	21.30	0.2127	-	0.88
31	0.1504	22.35	22.30	0.2233	22.35	22.35	22.40	0.2237	-	0.91
32	0.1735	23.30	23.25	0.2328	23.35	23.35	23.35	0.2335	-	0.93
33	0.0852	18.75	18.80	0.1878	18.85	18.85	18.95	0.1888	-	0.86
34	0.0904	19.15	19.10	0.1913	19.20	19.25	19.25	0.1923	-	0.85
35	0.0961	19.50	19.50	0.1950	19.55	19.55	19.60	0.1957	-	0.86

The tests covered a range of y_2/d values from 0.5 to 2.6. A graph of C_{d2} and C_{d5} vs. y_2/d is shown in Figure 9.3.

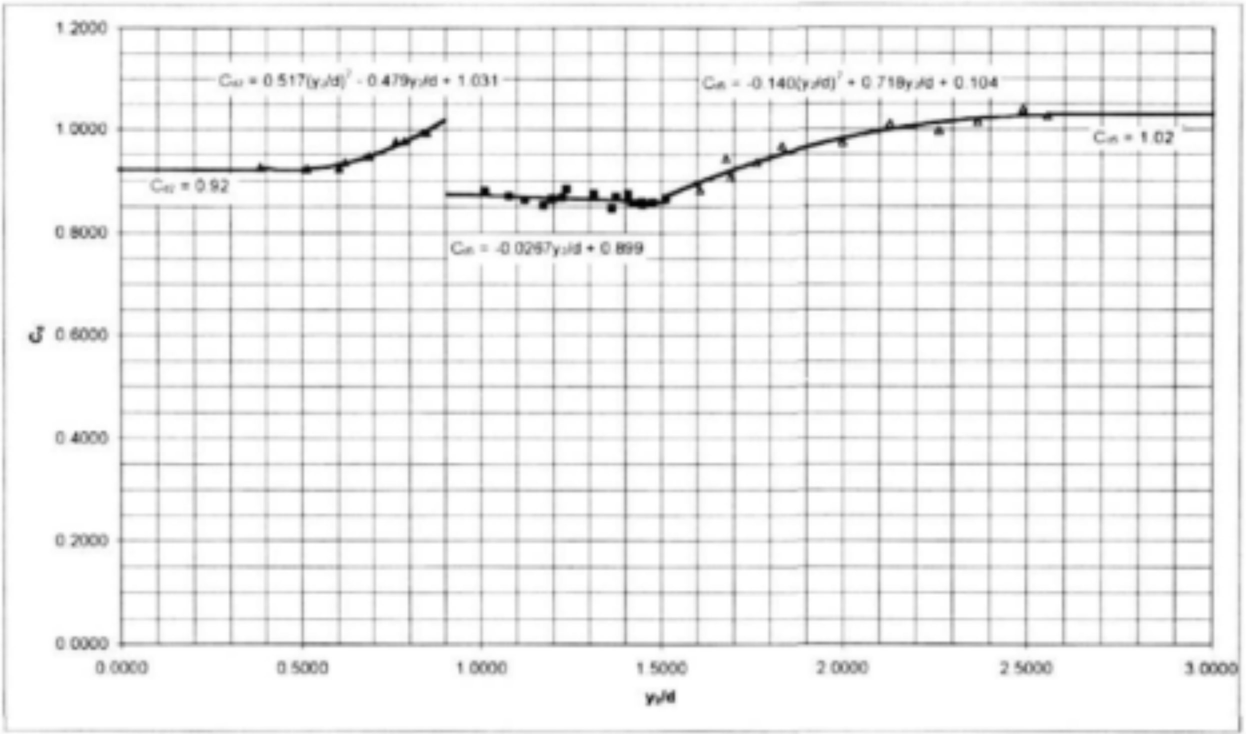

FIGURE 9.3: Discharge coefficients for flume with b/d=0.5 in combination with a sharp-crested weir

Curves were fitted to the data as follows:

When the flow is contained in the flume

$$C_{d2} = 0.92 \qquad \text{for} \qquad 0 < y_2/d < 0.5$$

$$\text{and} \quad C_{d2} = 0.517(y_2/d)^2 - 0.479y_2/d + 1.031 \qquad \text{for} \qquad 0.5 < y_2/d < 0.9$$

When the sidewalls of the flume are overtopped:

$$C_{d5} = -0.0267y_2/d + 0.899 \qquad \text{for} \qquad 0.9 < y_2/d < 1.5$$

$$\text{and} \quad C_{d5} = -0.140(y_2/d)^2 + 0.7184y_2/d + 0.104 \qquad \text{for} \qquad 1.50 < y_2/d < 2.50$$

$$\text{and} \quad C_{d5} = 1.02 \qquad \text{for} \qquad 2.5 < y_2/d < 3$$

9.5.3 Converting stage (y_2) to upstream water level (y_5) and upstream energy (E_{s5})

In Figure 9.4 a graph of y_2/d versus y_2/y_5 is shown.

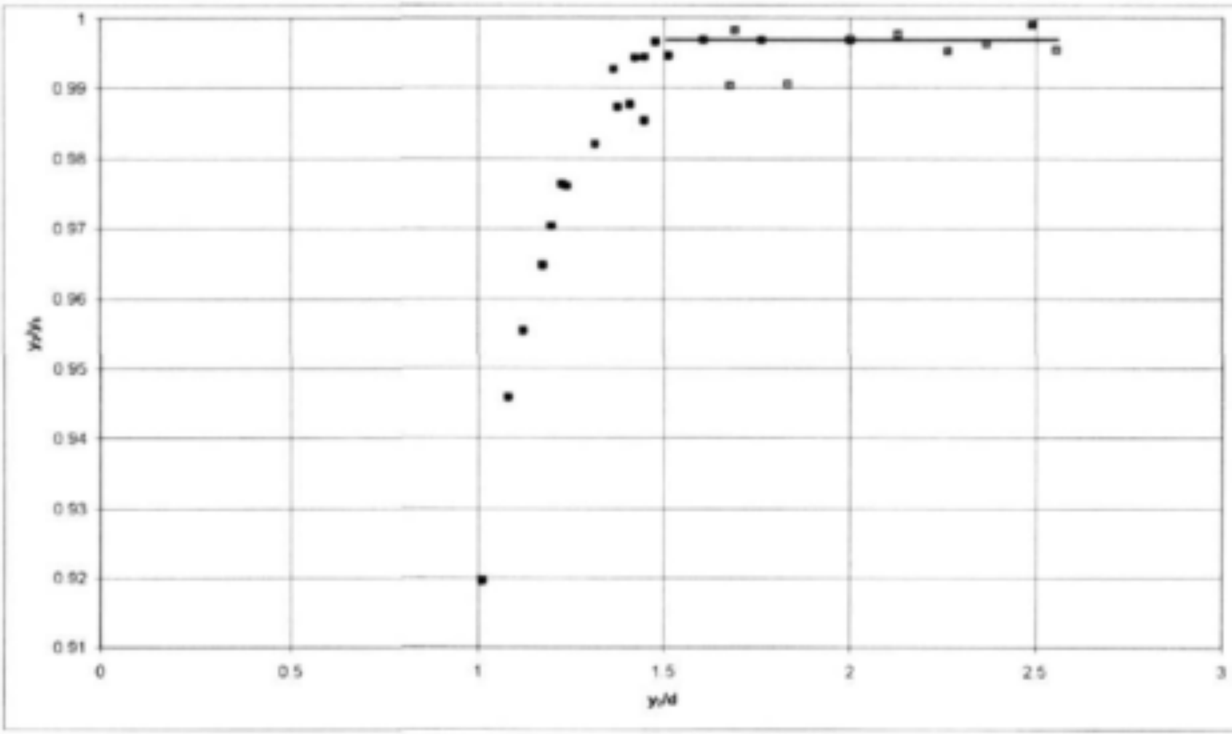

FIGURE 9.4: Relationship between stage (y_2) and water level in pool (y_5) for d/b=0.5 with sharp-crested weir

For y_2/d exceeding 1.5, y_2/y_5 reaches a constant value of 0.997. At high flow rates the water level at the recording position therefore approximates the water level in the upstream pool. This information can be used to extrapolate the records to higher flows than were recorded during the tests.

A graph of E_{s5}/d vs. y_2/d is shown in Figure 9.5.

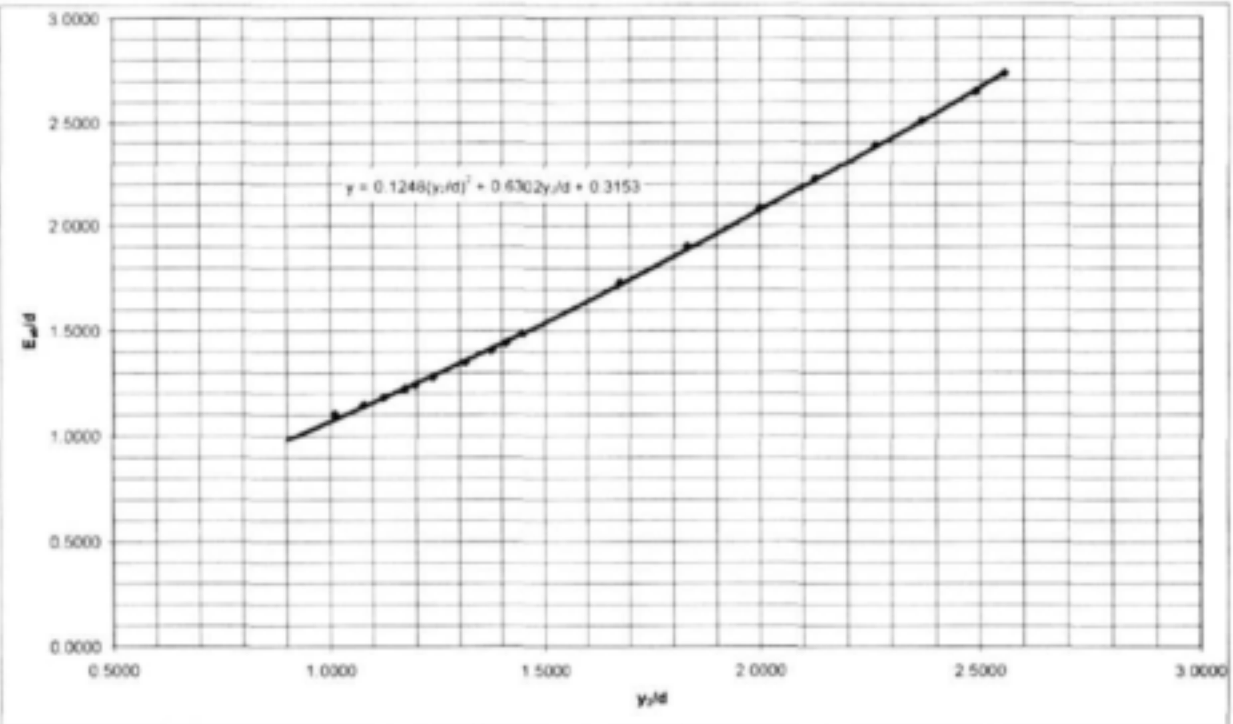

FIGURE 9.5: Relationship between stage (y_2) and energy level in pool (E_{s5}) for d/b=0.5 with sharp-crested weir

A curve was fitted through the data as follows:

$$E_{s5}/d = 0.315 + 0.630(\,y_2/d) + 0.125(\,y_2/d)^2 \qquad \text{for} \qquad 0.9 < y_2/d < 2.5$$

9.5.4 Construction of calibration curves

The equations in sections 9.5.2 and 9.5.3 above, provide all the information required to be able to calculate the discharge through the flume for modular flow conditions if the stage is measured at the recommended position. It also provides the energy level in the pool upstream of the adjoining weirs for calculating the flow over the weirs. An example of the construction of a calibration curve for a sluicing flume in combination with a adjoining weir, is given in section 11.6 . The calibration curve calculated from the equations given above, are compared with the recorded calibration curve, in Figure 9.6.

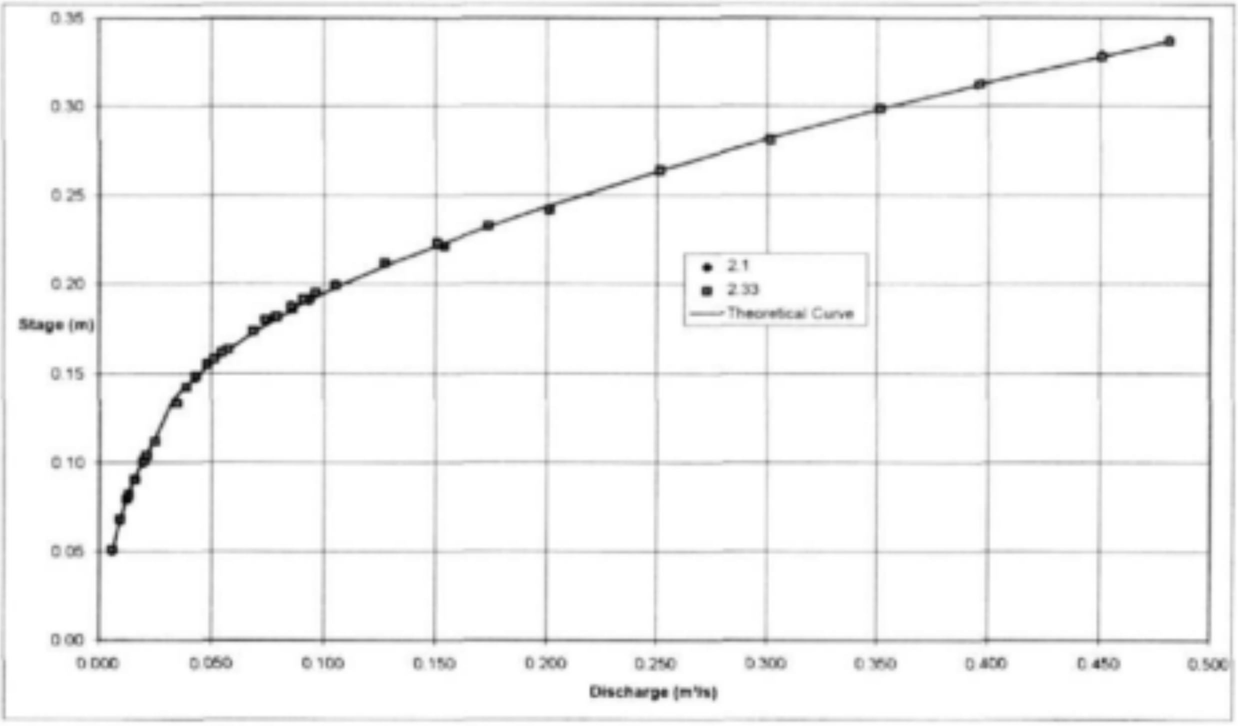

FIGURE 9.6: Calibration curve for flume with d/b=0.5 with sharp crested weir as tested in the model

As can be seen the fit of the data to the theoretically obtained curve, is good.

9.5.5 Accuracy of discharge calculated from the stage

The differences between the recorded and calculated discharge for a given stage, are summarised in Figure 9.7.

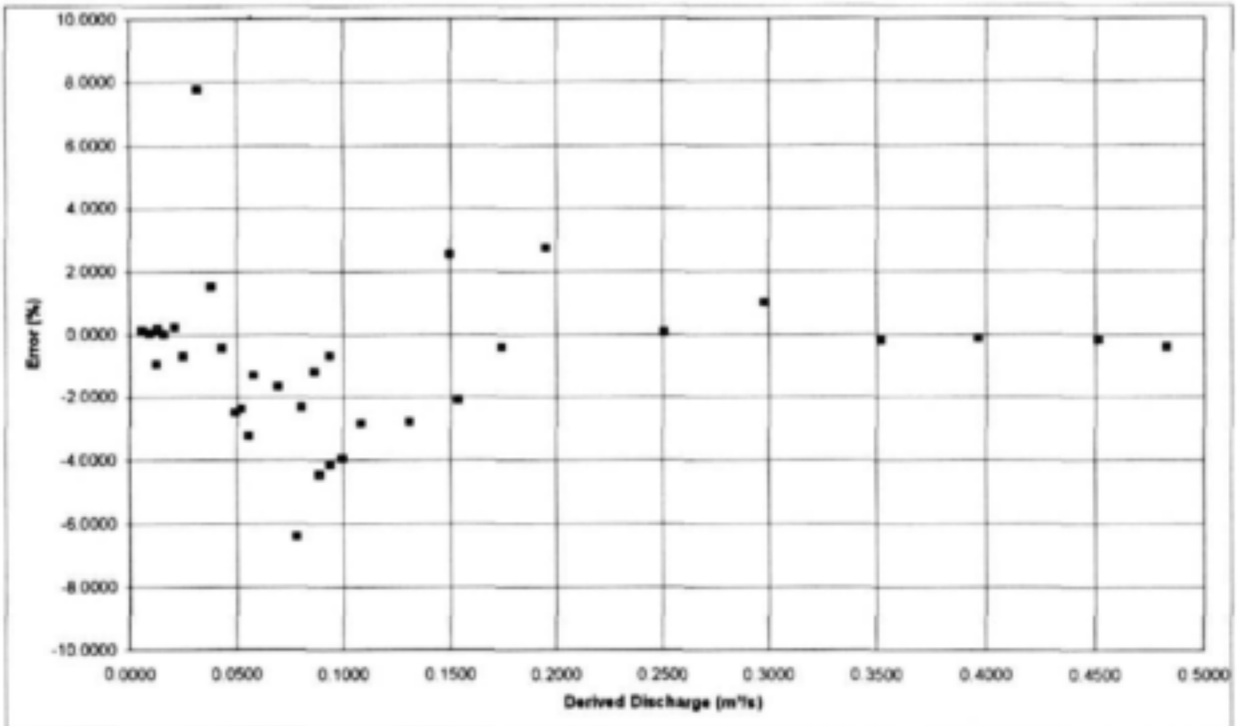

FIGURE 9.7: Error in derived discharge relative to measured discharge

As can be seen on this figure, the maximum error is +7.9 %. The errors are less than 4.0 % for all but four of the tests. The error of +7.9 % occur near the point when the flume walls start to be overtopped and is due to a deviation in the fit of the E_{s5} vs. y_2 diagram to the recorded data (see Figure 9.5).

9.6 Results for sluicing flume with d/b = 0.5 in combination with a Crump weir

9.6.1 Lay-out

The dimensions of the recommended flume and the lay-out as tested in the model, is shown in Figure 9.8.

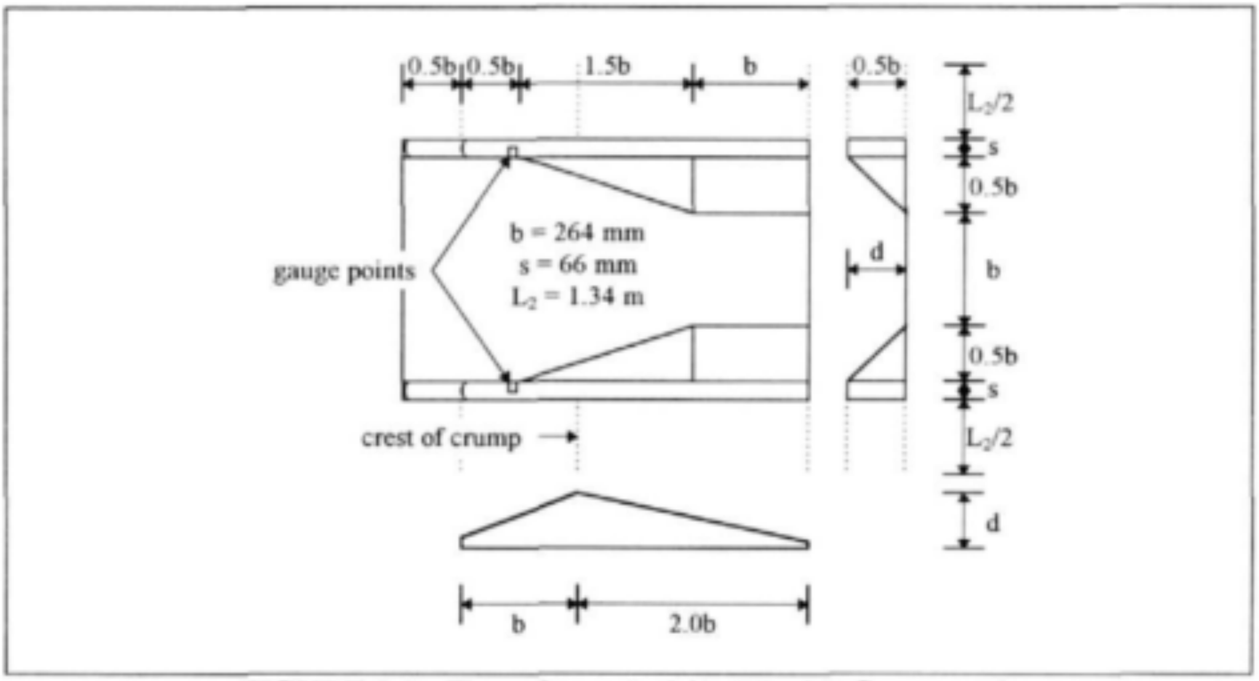

FIGURE 9.8: Flume lay-out - b/d=0.5 with Crump weir

The positions where water levels were recorded are shown in Figure 9.1. The water levels associated with each discharge as recorded in the model, are listed in Appendix 9.1 This data is also summarised in Table 9.2 below.

9.6.2 Estimates of discharge coefficients C_{d2} and C_{d5}

The discharge coefficients C_{d2} and C_{d5}, as derived from these tests, are also summarised in Table 9.2. The analyses of the data can be found in Appendix 9.2.

TABLE 9.2: Recorded water levels and estimated discharge coefficients for flume with d/b = 0.5 in combination with a Crump weir

	Q (m^3/s)	2.11	2.33	Ave. (m)	4	5	6	Ave. (m)	C_{d2}	C_{d5}
1	0.0063	5.35	5.40	0.0538	5.80	5.80	5.80	0.0580	0.92	-
2	0.0154	8.90	8.90	0.0890	9.95	9.95	9.95	0.0995	0.95	-
3	0.0243	11.05	11.05	0.1105	12.80	12.80	12.80	0.1280	1.00	-
4	0.0503	14.90	15.00	0.1495	16.20	16.20	16.15	0.1618	-	0.85
5	0.0753	16.75	16.85	0.1680	18.00	18.00	18.00	0.1800	-	0.88
6	0.0960	18.20	18.25	0.1823	19.35	19.35	19.35	0.1935	-	0.87
7	0.1496	21.15	21.15	0.2115	22.15	22.20	22.20	0.2218	-	0.89
8	0.1977	23.15	23.25	0.2320	24.35	24.35	24.30	0.2433	-	0.90
9	0.2510	25.20	25.25	0.2523	26.45	26.45	26.45	0.2645	-	0.92
10	0.3013	26.95	27.00	0.2698	28.35	28.40	28.40	0.2838	-	0.92
11	0.3469	28.40	28.45	0.2843	29.95	29.95	29.95	0.2995	-	0.93
12	0.4025	30.15	30.25	0.3020	31.75	31.75	31.75	0.3175	-	0.94
13	0.4536	31.50	31.60	0.3155	33.20	33.25	33.25	0.3323	-	0.96
14	0.4877	32.45	32.55	0.3250	34.25	34.25	34.20	0.3423	-	0.96

The tests covered a range of y_2/d values from 0.5 to 2.5. A graph of C_{d2} and C_{d5} vs. y_2/d is shown in Figure 9.9.

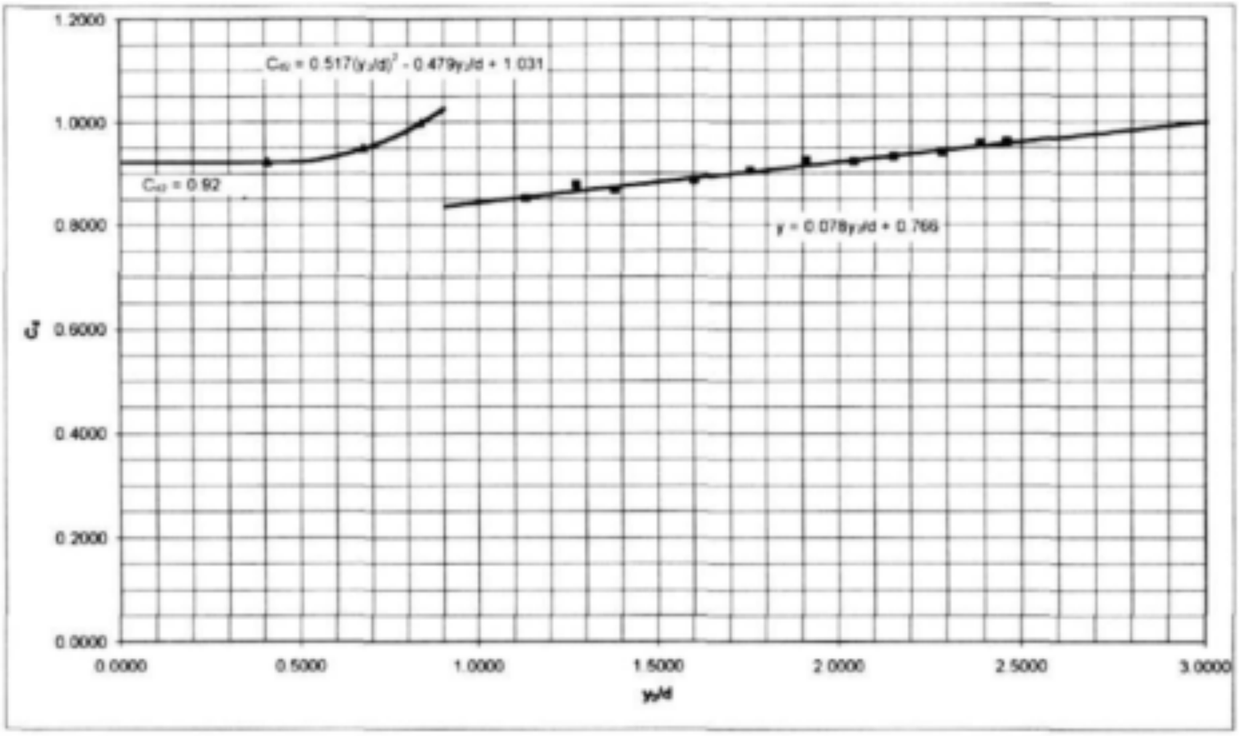

FIGURE 9.9: Discharge coefficients for flume with d/b=0.5 in combination with a Crump weir.

A curve was fitted to the data as follows:

When the flow is contained in the flume

$$C_{d2} = 0.92 \qquad \text{for} \qquad 0 < y_2/d < 0.5$$

$$\text{and} \quad C_{d2} = 0.517(y_2/d)^2 - 0.479y_2/d + 1.031 \qquad \text{for} \qquad 0.5 < y_2/d < 0.9$$

When the sidewalls of the flume are overtopped:

$$C_{d5} = 0.078y_2/d + 0.766 \qquad \text{for} \qquad 0.9 < y_2/d < 3.0$$

9.6.3 Converting stage(y_2) to upstream water level (y_5) and upstream energy (E_{s5})

In Figure 9.10 a graph of y_2/d versus y_2/y_5 is shown.

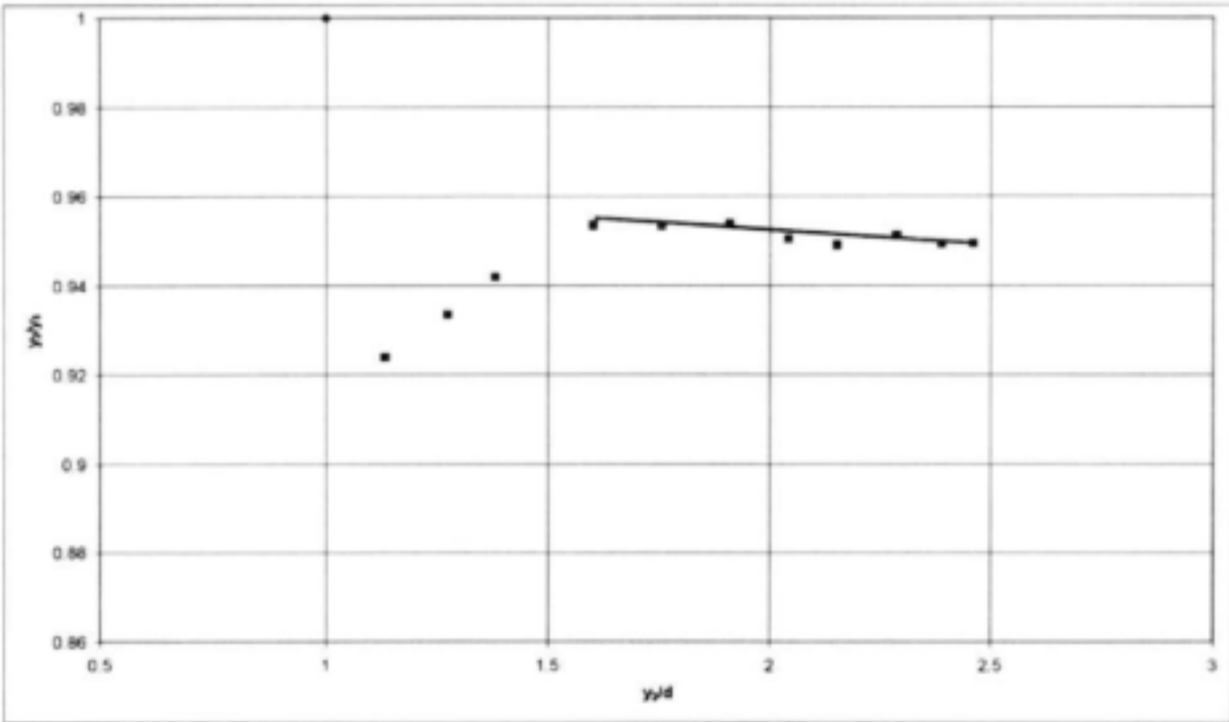

FIGURE 9.10: Relationship between stage (y_2) and water level in pool (y_5) for d/b=0.5 with Crump weir

For y_2/d =1.5, y_2/y_5 reaches a maximum value of 0.955. For y_2/y_5 exceeding 1.5, there is a tendency for y_2/y_5 values to decrease slightly. This is due to the fact that the stage recording position at high flows, is on the drawdown curve caused by the nearby control point at the adjacent Crump weir crest. The limiting case will therefore not be that y_2/y_5 will approach a value of 1 as was the case with the sharp-crested weir at the downstream extremity of the flume (see 9.5.3 above). Figure 9.10 can be used to extrapolate the records to higher flows than were recorded during the tests.

A graph of E_{s5}/d vs. y_2/d is shown in Figure 9.11.

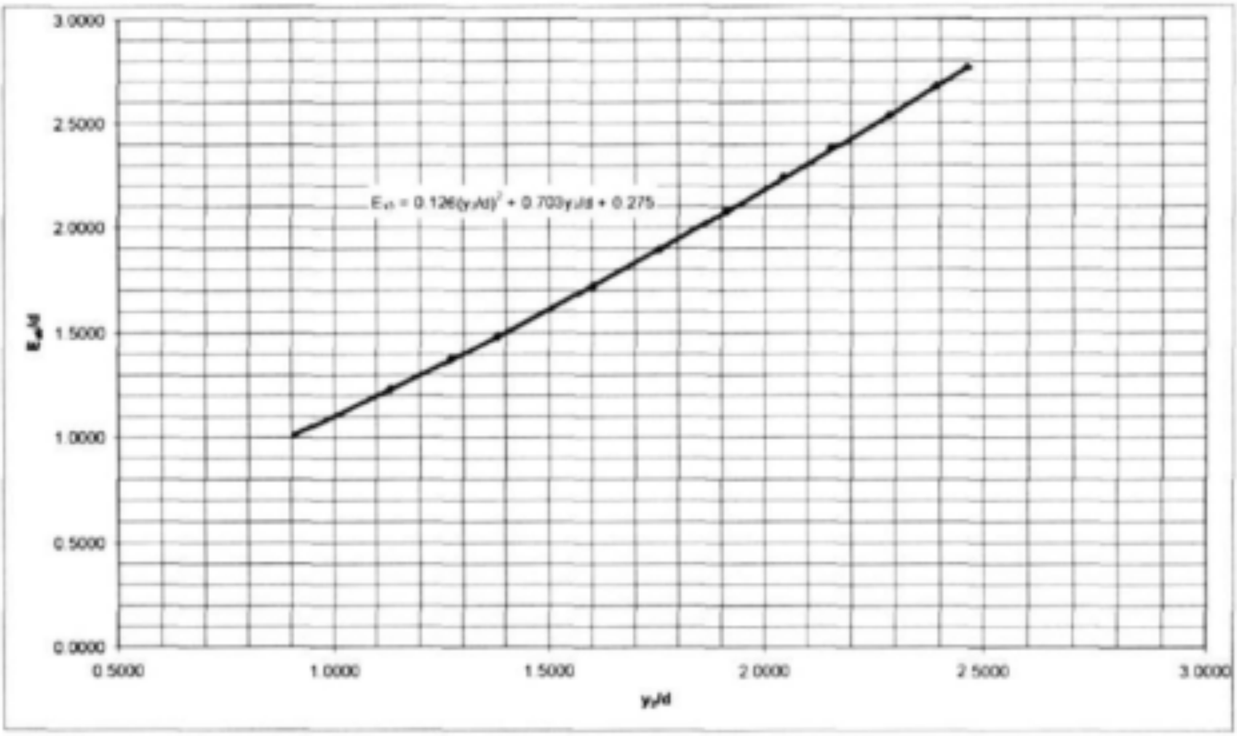

FIGURE 9.11: Relationship between stage (y_2) and energy level in pool (Es_5) for d/b=0.5 with Crump weir

A curve was fitted through the data as follows:

$$E_{s5}/d = 0.275 + 0.703(y_2/d) + 0.126(y_2/d)^2 \qquad \text{for} \qquad 0.9 < y_2/d < 2.5$$

9.6.4 Construction of calibration curves

The equations in sections 9.6.2 and 9.6.3 above, provide all the information required to be able to calculate the discharge through the flume for modular flow conditions if the stage is measured at the recommended position. It also provides the energy level in the pool upstream of the adjoining weirs for calculating the flow over the weirs. An example of the construction of a calibration curve for a sluicing flume in combination with a adjoining weir, is given in section 11.6. The calibration curve calculated from the equations given above, is compared with the recorded calibration curve, in Figure 9.12.

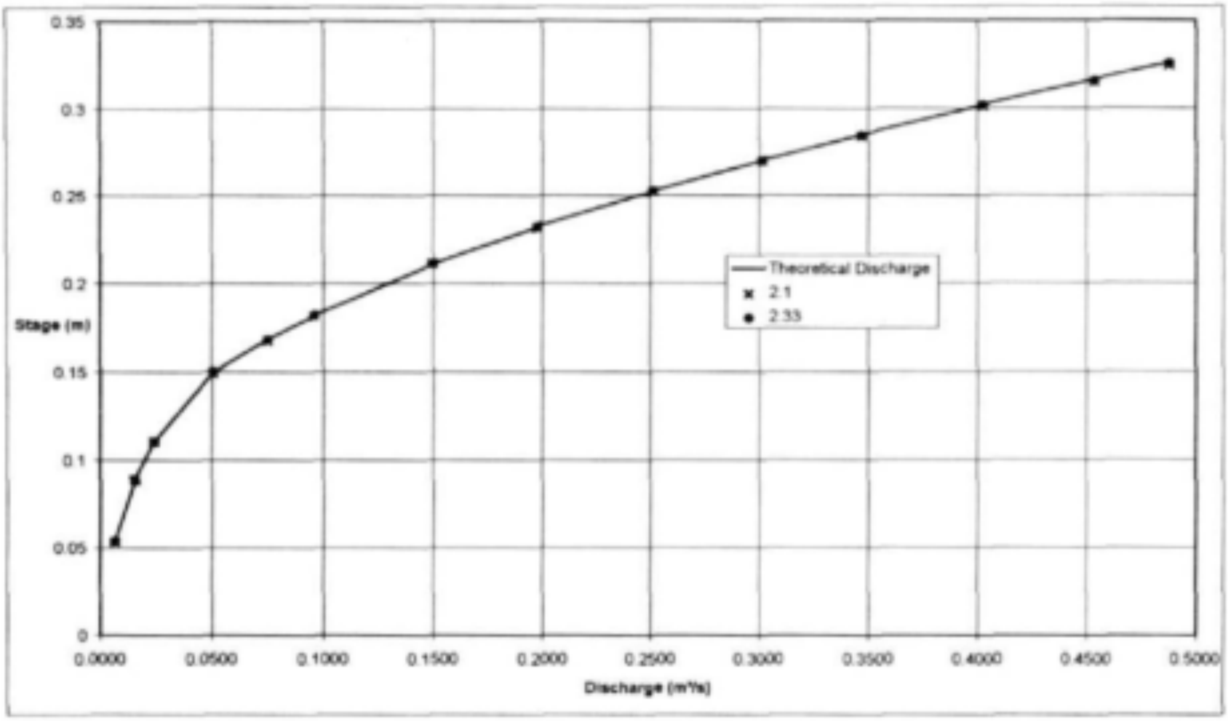

FIGURE 9.12: Calibration curve for flume with d/b=0.5 with Crump weir as tested in model

As can be seen the fit of the data to the theoretically obtained curve, is excellent.

9.6.5 Accuracy of discharge calculated from the stage

The differences between the recorded and calculated discharge for a given stage, are summarised in Figure 9.13.

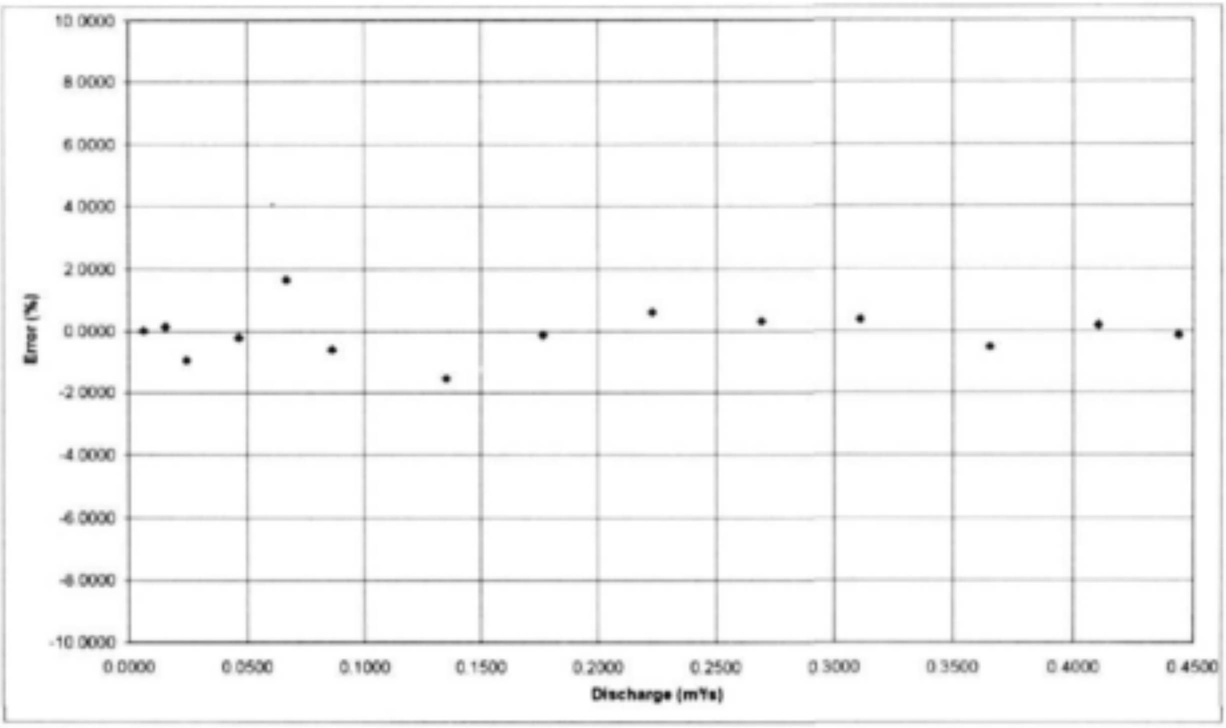

FIGURE 9.13: Error in estimated discharge relative to measured discharge

As can be seen on this figure, the maximum error is less than 2 % for all of the tests.

9.7 Results for sluicing flume with d/b = 1.0 in combination with a sharp crested weir

9.7.1 Lay-out

The dimensions of the recommended flume and the lay-out as tested in the model, are shown in Figure 9.14.

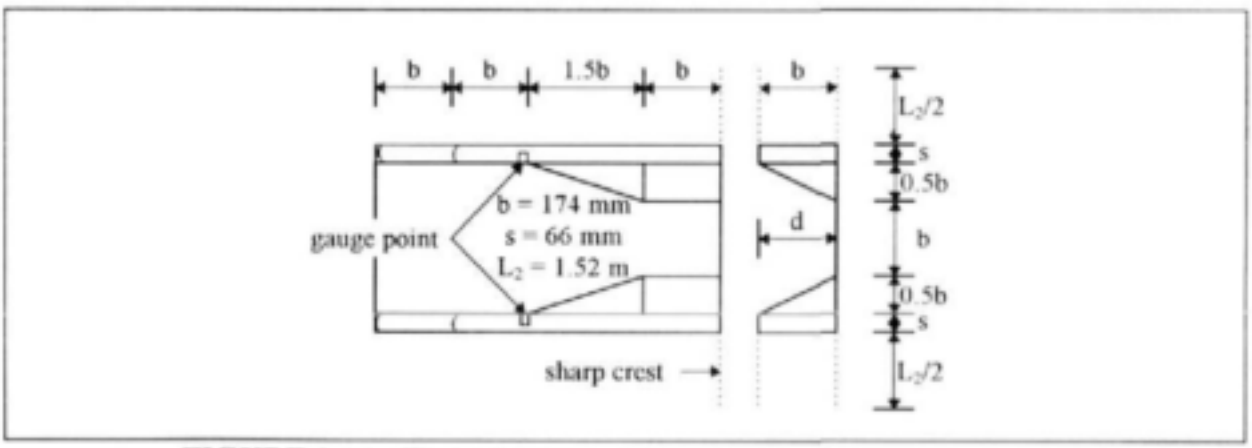

FIGURE 9.14: Flume lay-out - b/d=1.0 with sharp-crested weir

The positions where water levels were recorded are shown in Figure 9.1 . A complete record of the water levels associated with each discharge as recorded in the model, are listed in Appendix 9.1 A summary of this information is given in Table 9.3 below.

9.7.2 Estimates of discharge coefficients C_{d2} and C_{d5}

The discharge coefficients C_{d2} and C_{d5}, as derived from these tests, are summarised in Table 9.3. The analyses of the data can be found in Appendix 9.2.

TABLE 9.3: Recorded water levels and estimated discharge coefficients for flume with d/b=1.0 in combination with sharp-crested weir.

	Q (m^3/s)	2.11	2.33	Ave. (m)	4	5	6	Ave. (m)	Cd2	Cd5
1	0.0013	2.80	2.80	0.0280	2.90	2.95	2.90	0.0292	0.86	-
2	0.0030	4.60	4.55	0.0458	4.80	4.85	4.80	0.0482	0.88	-
3	0.0069	7.40	7.35	0.0738	7.90	7.95	7.90	0.0792	0.93	-
4	0.0102	9.30	9.20	0.0925	9.95	10.00	9.95	0.0997	0.95	-
5	0.0120	10.00	9.95	0.0998	10.85	10.85	10.85	0.1085	0.97	-
6	0.0151	11.20	11.20	0.1120	12.35	12.35	12.35	0.1235	1.00	-
7	0.0174	12.10	12.05	0.1208	13.35	13.40	13.35	0.1337	1.00	-
8	0.0200	13.00	13.00	0.1300	14.50	14.55	14.50	0.1452	1.01	-
9	0.0225	13.75	13.75	0.1375	15.50	15.55	15.50	0.1552	1.02	-
10	0.0245	14.25	14.30	0.1428	16.25	16.30	16.25	0.1627	1.03	-
11	0.0277	15.00	15.05	0.1503	17.30	17.30	17.30	0.1730	1.06	-
13	0.0402	17.70	17.60	0.1765	19.30	19.35	19.30	0.1932	-	0.93
14	0.0448	18.30	18.40	0.1835	19.80	19.80	19.80	0.1980	-	0.93
15	0.0503	19.05	19.05	0.1905	20.30	20.35	20.30	0.2032	-	0.93
16	0.0556	19.65	19.60	0.1963	20.75	20.75	20.75	0.2075	-	0.95
17	0.0603	20.05	20.00	0.2003	21.15	21.20	21.15	0.2117	-	0.94
18	0.0650	20.50	20.45	0.2048	21.50	21.55	21.50	0.2152	-	0.95
19	0.0699	21.00	20.95	0.2098	21.90	21.90	21.90	0.2190	-	0.95
20	0.0757	21.50	21.50	0.2150	22.30	22.35	22.30	0.2232	-	0.96
21	0.0796	21.90	21.90	0.2190	22.65	22.65	22.65	0.2265	-	0.95
22	0.0854	22.40	22.35	0.2238	23.00	23.05	23.00	0.2302	-	0.95
23	0.0899	22.75	22.70	0.2273	23.35	23.40	23.35	0.2337	-	0.93
24	0.0948	23.10	23.05	0.2308	23.65	23.70	23.65	0.2367	-	0.93
25	0.1014	23.45	23.45	0.2345	24.00	24.05	24.05	0.2403	-	0.95
26	0.1252	24.65	24.70	0.2468	25.25	25.30	25.25	0.2527	-	0.98
27	0.1487	26.05	26.05	0.2605	26.60	26.60	26.60	0.2660	-	0.96
28	0.1742	27.10	27.15	0.2713	27.65	27.70	27.65	0.2767	-	1.01
29	0.2009	28.40	28.35	0.2838	28.95	28.95	28.95	0.2895	-	0.99
30	0.2251	29.30	29.30	0.2930	29.95	29.95	29.95	0.2995	-	1.00
31	0.2484	30.30	30.30	0.3030	30.90	30.95	30.90	0.3092	-	1.00
32	0.2764	31.25	31.20	0.3123	31.80	31.80	31.80	0.3180	-	1.05
33	0.3030	32.10	32.20	0.3215	32.90	32.95	32.90	0.3292	-	1.03
34	0.3247	32.90	32.90	0.3290	33.60	33.60	33.60	0.3360	-	1.05
35	0.3488	33.70	33.70	0.3370	34.45	34.45	34.45	0.3445	-	1.05
36	0.3751	34.65	34.65	0.3465	35.30	35.40	35.35	0.3535	-	1.05
37	0.3977	35.30	35.30	0.3530	36.10	36.10	36.10	0.3610	-	1.05

The tests covered a range of y_2/d values from 0.2 to 2.0. A graph of C_{d2} and C_{d5} vs. y_2/d is shown in Figure 9.15.

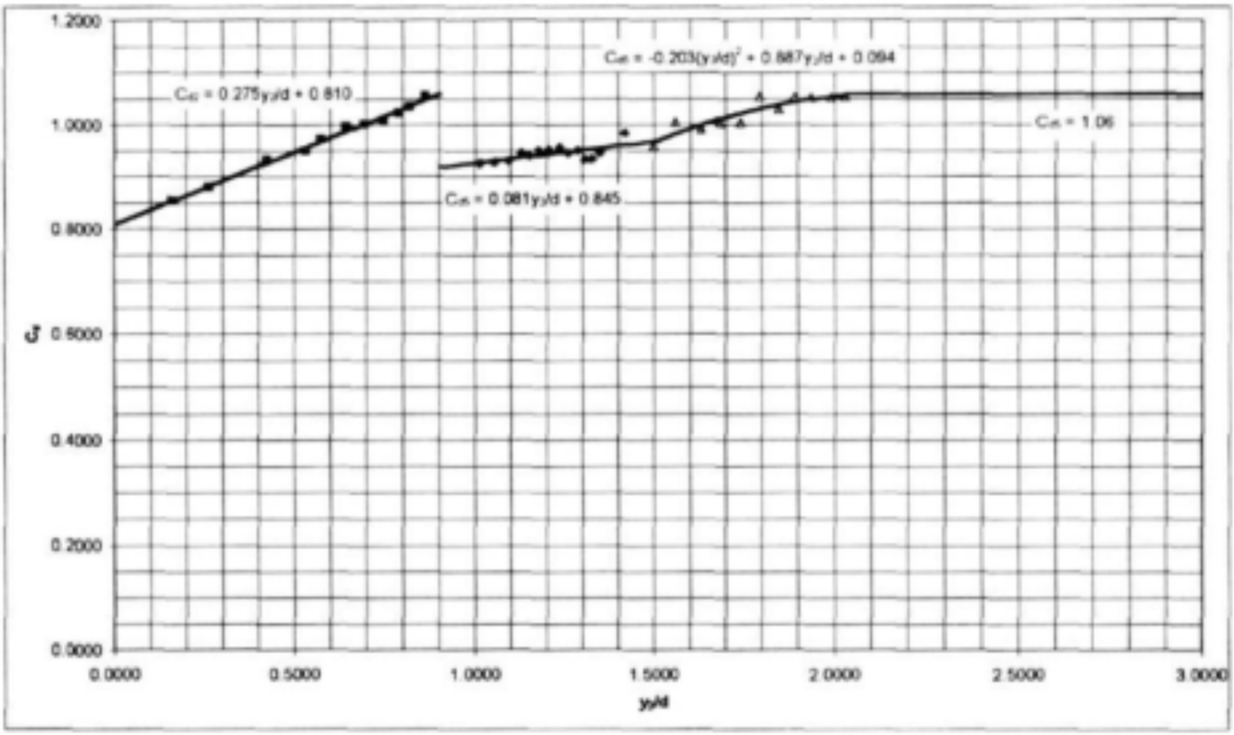

FIGURE 9.15: Discharge coefficients for flume with b/d=1.0 in combination with a *sharp-crested weir*

A curve was fitted to the data as follows:

When the flow is contained in the flume

$$C_{d2} = 0.811 + 0.275y_2/d \qquad \text{for} \qquad 0 < y_2/d < 0.9$$

When the sidewalls of the flume are overtopped:

$$C_{d5} = 0.845 + 0.081y_2/d \qquad \text{for} \qquad 0.9 < y_2/d < 1.5$$

$$\text{and} \quad C_{d5} = 0.094 + 0.887y_2/d - 0.203(y_2/d)^2 \qquad \text{for} \qquad 1.50 < y_2/d < 2.0$$

$$\text{and} \quad C_{d5} = 1.06 \qquad \text{for} \qquad 2.0 < y_2/d < 3.0$$

9.7.3 Converting stage(y_2) to upstream water level (y_5) and upstream energy (Es_5)

In Figure 9.16 a graph of y_2/d versus y_2/y_5 is shown.

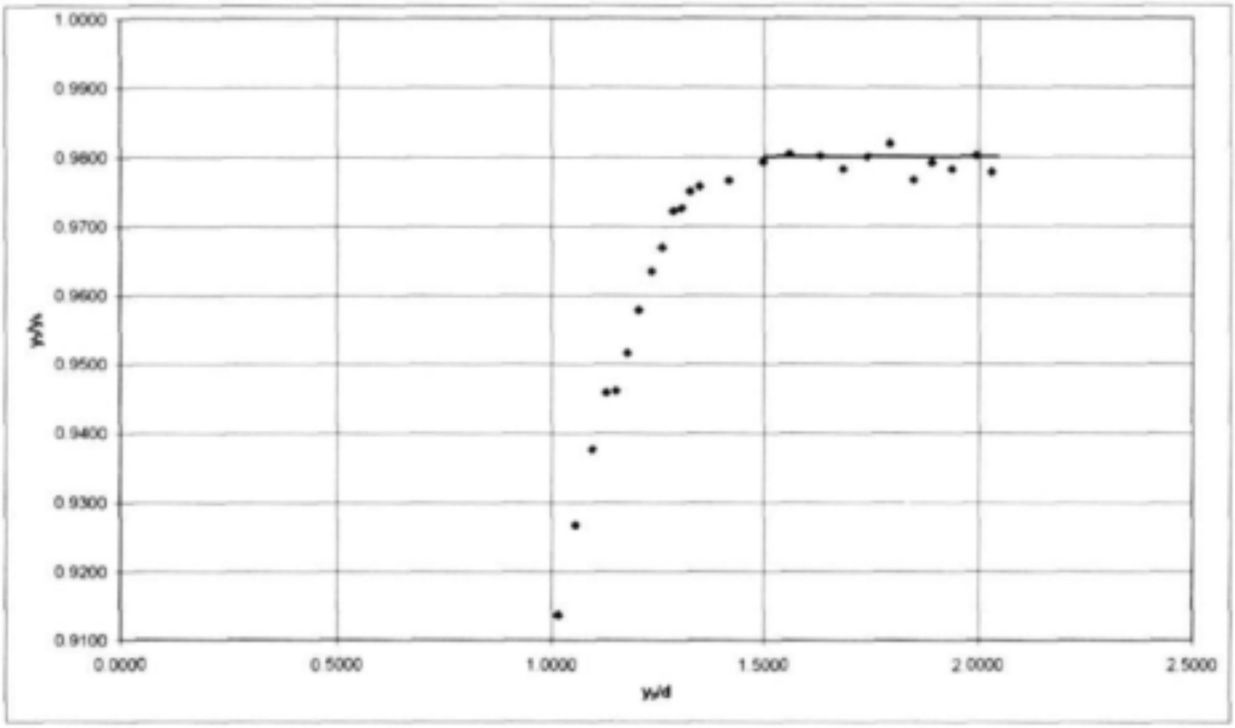

FIGURE 9.16: Relationship between stage (y_2) and water level in pool (y_5) for d/b=1.0 with sharp-crested weir

For y_2/d exceeding 1.5, y_2/y_5 reaches a constant value of 0.98. This is lower than the value of 0.997 that was reached by the flume with $d/b = 0.5$ in combination with a sharp-crest weir (see Figure 9.4). The reason for this slightly lower value is that the stage recording position for the flume with $d/b = 1.0$, is at a point where the draw-down curve starts at the higher flows. This information can be used to extrapolate the records to higher flows than were recorded during the tests.

A graph of E_{s5}/d vs. y_2/d is shown in Figure 9.17.

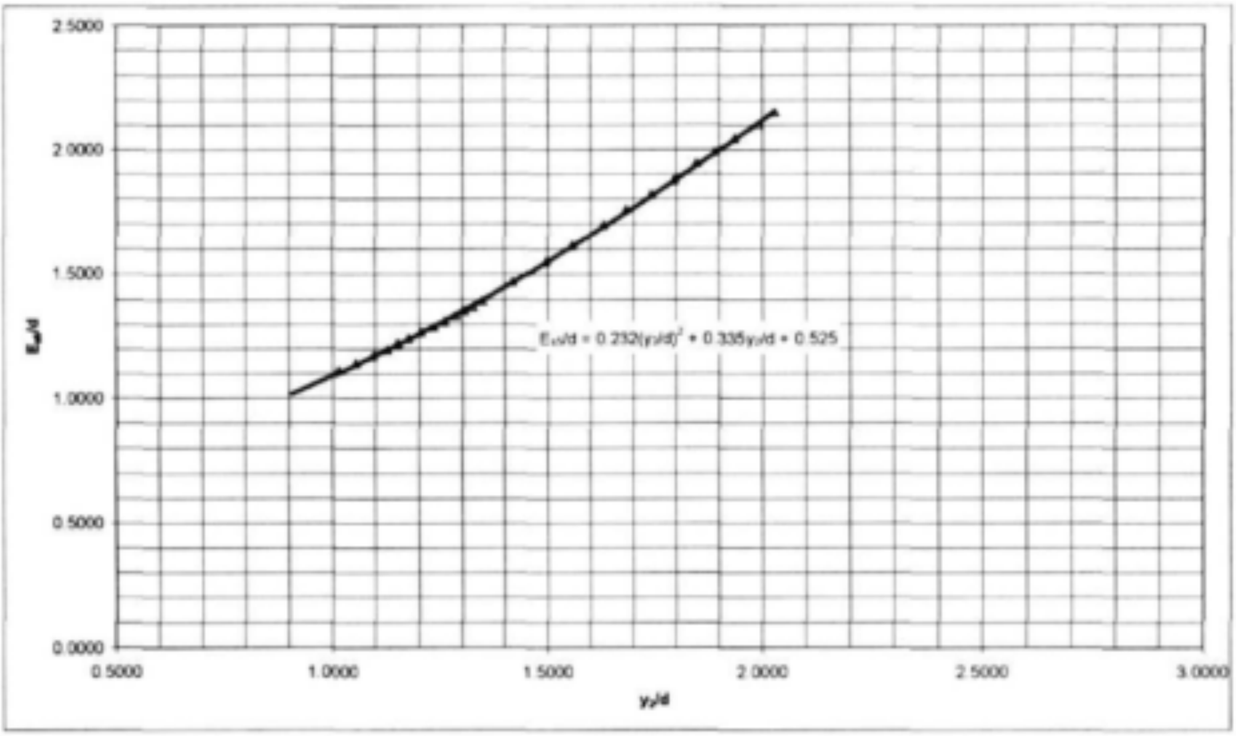

FIGURE 9.17: Relationship between stage (y_2) and energy level in pool (Es_5) for d/b=1.0 with sharp-crested weir

A curve was fitted through the data as follows:

$$Es_5/d = 0.525 + 0.335(y_2/d) + 0.232(y_2/d)^2 \quad \text{for} \quad 0.9 < y_2/d < 2.0$$

9.7.4 Construction of calibration curves

The equations in sections 9.7.2 and 9.7.3 above, provide all the information required to be able to calculate the discharge through the flume for modular flow conditions if the stage is measured at the recommended position. It also provides the energy level in the pool upstream of the adjoining weirs for calculating the flow over the weirs. An example of the construction of a calibration curve for a sluicing flume in combination with a adjoining weir, is given in section 11.6. The calibration curve calculated from the equations given above, are compared with the recorded calibration curve, in Figure 9.18.

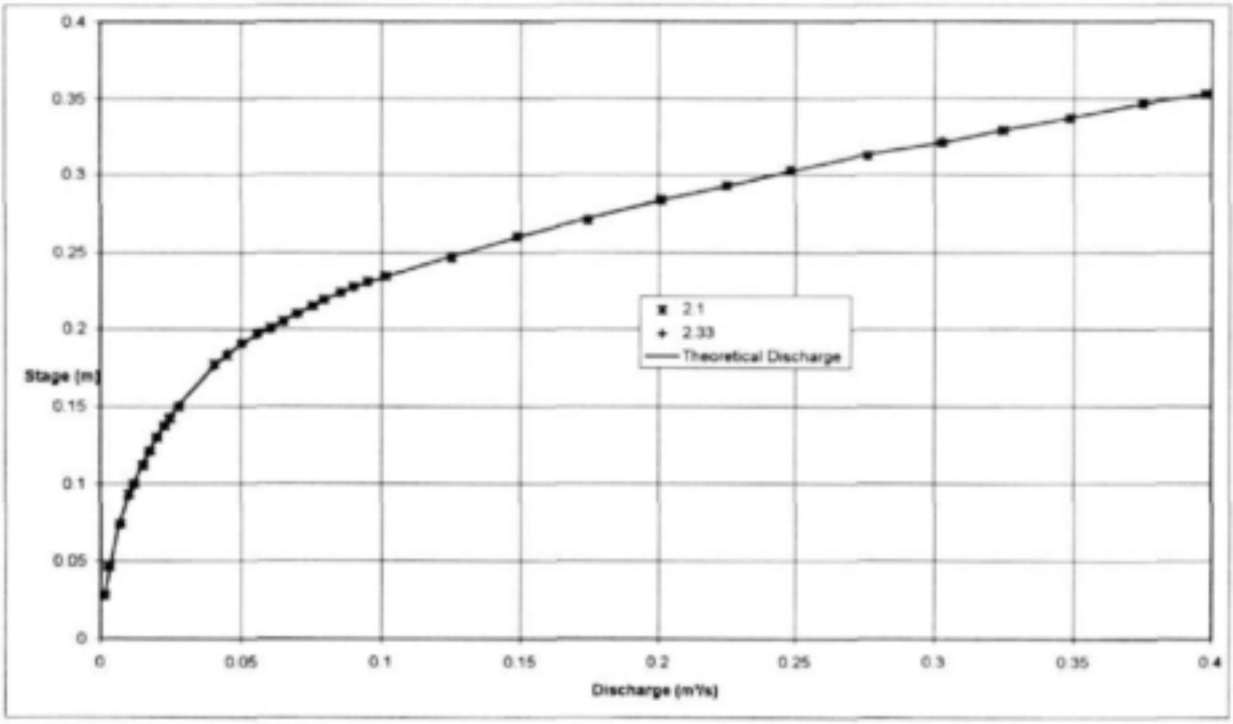

FIGURE 9.18: Calibration curve for flume with d/b=1.0 with sharp-crested weir as tested in model

As can be seen the fit of the data to the theoretically obtained curve, is excellent.

9.7.5 Accuracy of discharge calculated from the stage

The differences between the recorded and calculated discharge for a given stage, are summarised in Figure 9.19.

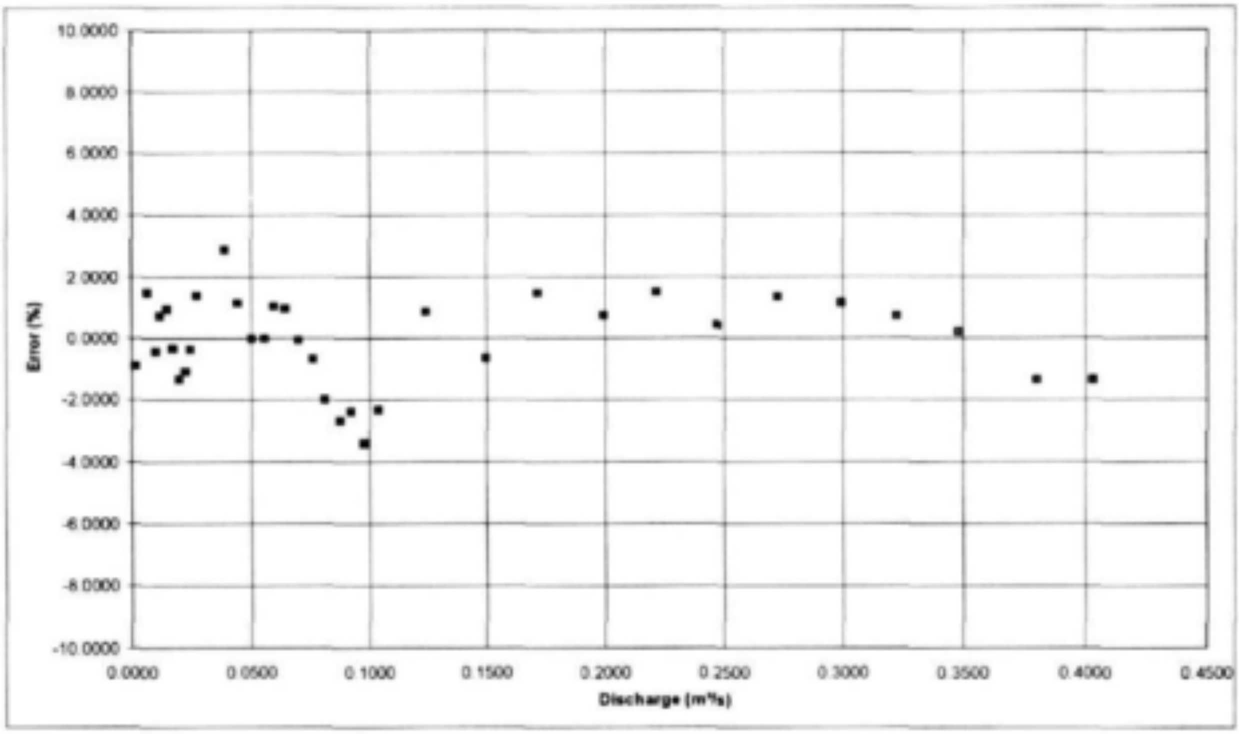

FIGURE 9.19: Error in derived discharge relative to measured discharge for flume with d/b=1.0 with sharp-crested weir

As can be seen on this figure, the maximum errors are less than 4% over the entire range of flows tested.

9.8 Results for sluicing flume with d/b = 0.25 in combination with a sharp crested weir

9.8.1 Lay-out

The dimensions of the recommended flume and the lay-out as tested in the model, are shown in Figure 9.20.

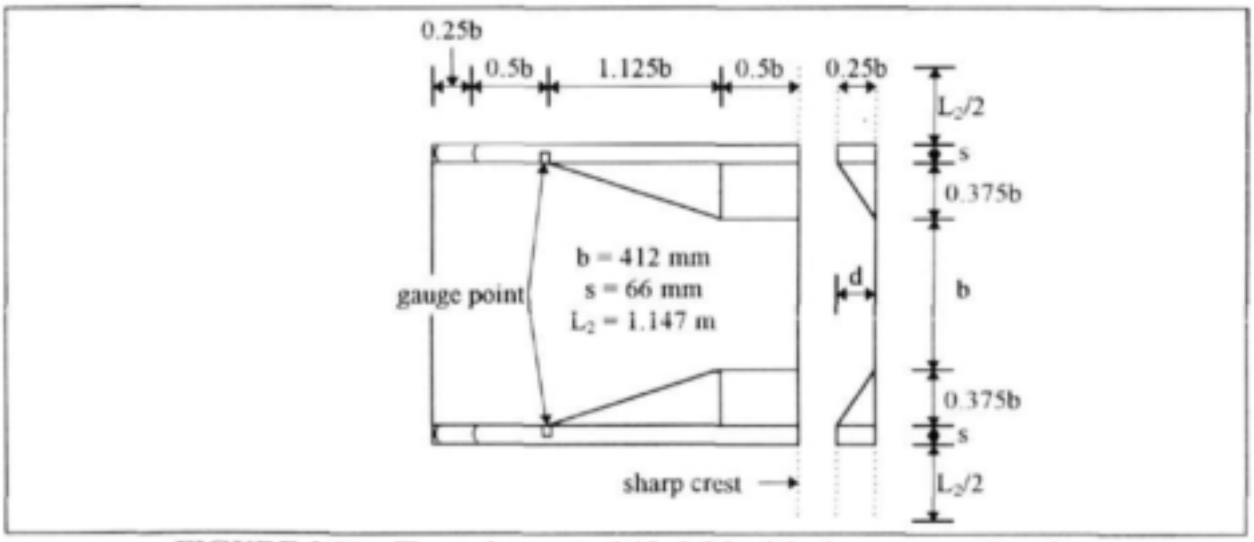

FIGURE 9.20: Flume lay-out - b/d=0.25 with sharp-crested weir

The positions where water levels were recorded are shown in Figure 9.1 . A complete record of the water levels associated with each discharge as recorded in the model, is contained in Appendix 9.1. A summary of this information is given in Table 9.4 below.

9.8.2 Estimates of discharge coefficients C_{d2} and C_{d5}

The discharge coefficients C_{d2} and C_{d5}, as derived from these tests, are summarised in Table 9.4. The analyses of the data can be found in Appendix 9.2.

TABLE 9.4: Recorded water levels and estimated discharge coefficients for flume with d/b=0.25 in combination with sharp-crested weir.

	Q (m^3/s)	2.11	2.33	Ave. (m)	4	5	6	Ave. (m)	C_{d2}	C_{d5}
1	0.0059	3.55	3.55	0.0355	3.85	3.85	3.85	0.0385	1.02	-
2	0.0107	5.25	5.30	0.0528	5.90	5.90	5.85	0.0588	0.99	-
2.1	0.0126	5.90	5.90	0.0590	6.65	6.65	6.65	0.0665	0.97	-
3	0.0147	6.40	6.40	0.0640	7.25	7.25	7.25	0.0725	0.98	-
3.1	0.0176	7.05	7.05	0.0705	8.00	8.00	8.00	0.0800	0.99	-
4	0.0200	7.50	7.55	0.0753	8.60	8.65	8.60	0.0862	1.00	-
5	0.0270	8.90	8.85	0.0888	10.45	10.45	10.45	0.1045	-	0.89
6	0.0302	9.10	9.05	0.0908	10.80	10.80	10.80	0.1080	-	0.92
7.1	0.0403	11.10	11.05	0.1108	12.00	12.00	12.00	0.1200	-	0.91
8	0.0455	11.70	11.70	0.1170	12.50	12.50	12.50	0.1250	-	0.91
10	0.0502	12.35	12.30	0.1233	12.95	12.95	12.95	0.1295	-	0.91
11	0.0555	12.80	12.75	0.1278	13.40	13.40	13.35	0.1338	-	0.92
11.1	0.0606	13.25	13.25	0.1325	13.75	13.75	13.70	0.1373	-	0.93
12	0.0648	13.70	13.65	0.1368	14.10	14.10	14.05	0.1408	-	0.92
13	0.0698	14.15	14.15	0.1415	14.50	14.50	14.50	0.1450	-	0.91
14	0.0750	14.50	14.45	0.1448	14.80	14.80	14.75	0.1478	-	0.93
14.1	0.0794	14.85	14.80	0.1483	15.10	15.10	15.10	0.1510	-	0.92
15	0.0859	15.25	15.25	0.1525	15.50	15.50	15.50	0.1550	-	0.93
16	0.0904	15.65	15.60	0.1563	15.85	15.85	15.85	0.1585	-	0.91
17	0.0946	15.80	15.80	0.1580	16.05	16.10	16.05	0.1607	-	0.92
18	0.1252	17.50	17.50	0.1750	17.70	17.70	17.70	0.1770	-	0.94
19	0.1530	18.75	18.75	0.1875	18.95	19.00	18.95	0.1897	-	0.97
20	0.1757	19.70	19.70	0.1970	19.90	19.90	19.85	0.1988	-	0.99
21	0.2028	20.70	20.75	0.2073	20.90	20.90	20.90	0.2090	-	1.02
22	0.2754	23.55	23.50	0.2353	23.65	23.70	23.65	0.2367	-	1.03
23	0.3000	24.45	24.50	0.2448	24.60	24.60	24.60	0.2460	-	1.02
24	0.2296	21.95	21.95	0.2195	22.10	22.10	22.10	0.2200	-	1.02
25	0.3259	25.25	25.30	0.2528	25.45	25.45	25.45	0.2545	-	1.03
26	0.3778	26.95	26.95	0.2695	27.10	27.10	27.05	0.2708	-	1.04
27	0.4025	27.65	27.80	0.2773	27.90	27.90	27.85	0.2788	-	1.03
28	0.4288	28.35	28.45	0.2840	28.60	28.60	28.60	0.2860	-	1.04
29	0.4522	29.10	29.05	0.2908	29.30	29.30	29.35	0.2932	-	1.04
30	0.2510	22.75	22.75	0.2275	22.95	22.95	22.90	0.2293	-	1.01
31	0.3550	26.20	26.25	0.2623	26.40	26.40	26.45	0.2642	-	1.03

The tests covered a range of y_2/d values from 0.3 to 2.8. A graph of C_{d2} and C_{d5} vs. y_2/d is shown in Figure 9.21.

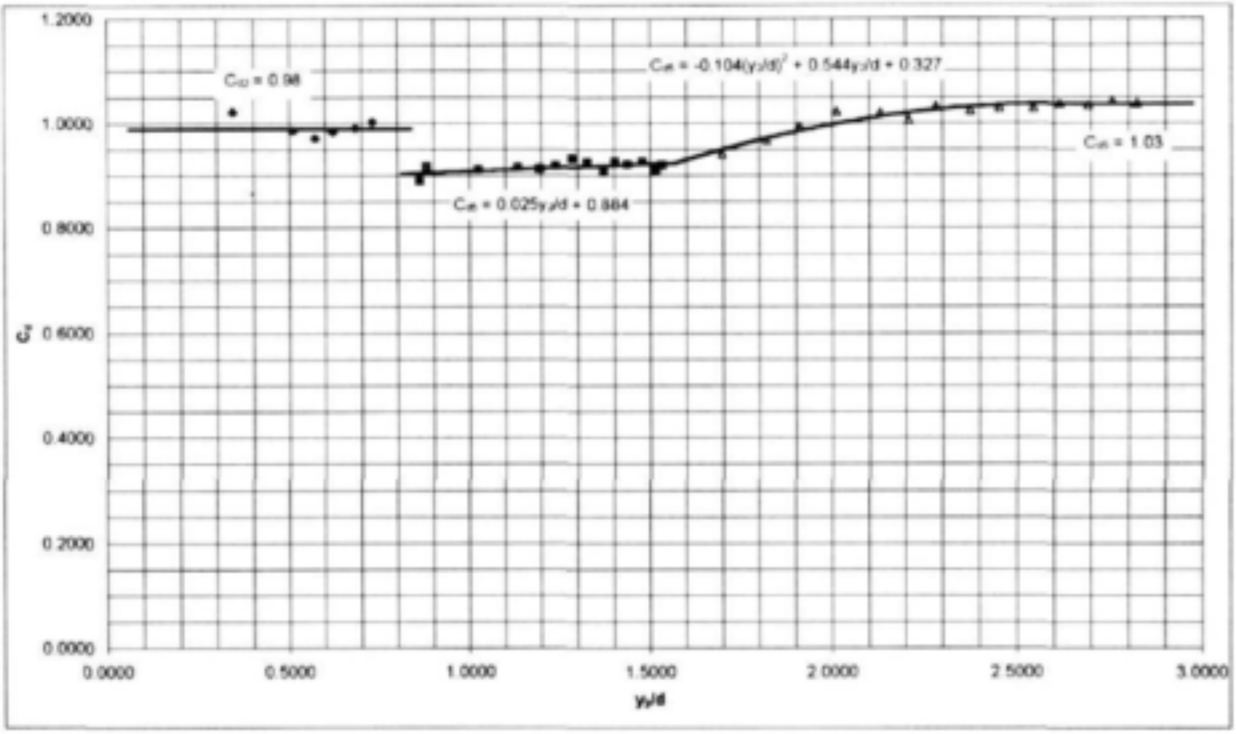

FIGURE 9.21: Discharge coefficients for flume with b/d=0.25 in combination with a sharp-crested weir

A curve was fitted to the data as follows:

When the flow is contained in the flume

$$C_{d2} = 0.98 \qquad \text{for} \qquad 0 < y_2/d < 0.85$$

When the sidewalls of the flume are overtopped:

$$C_{d5} = 0.884 + 0.025y_2/d \qquad \text{for} \qquad 0.85 < y_2/d < 1.55$$

and $$C_{d5} = 0.327 + 0.544y_2/d - 0.104(y_2/d)^2 \qquad \text{for} \qquad 1.55 < y_2/d < 2.5$$

and $$C_{d5} = 1.03 \qquad \text{for} \qquad 2.5 < y_2/d < 3.0$$

9.8.3 Converting stage(y_2) to upstream water level (y_5) and upstream energy (E_{s5})

In Figure 9.22 a graph of y_2/d versus y_2/y_5 is shown.

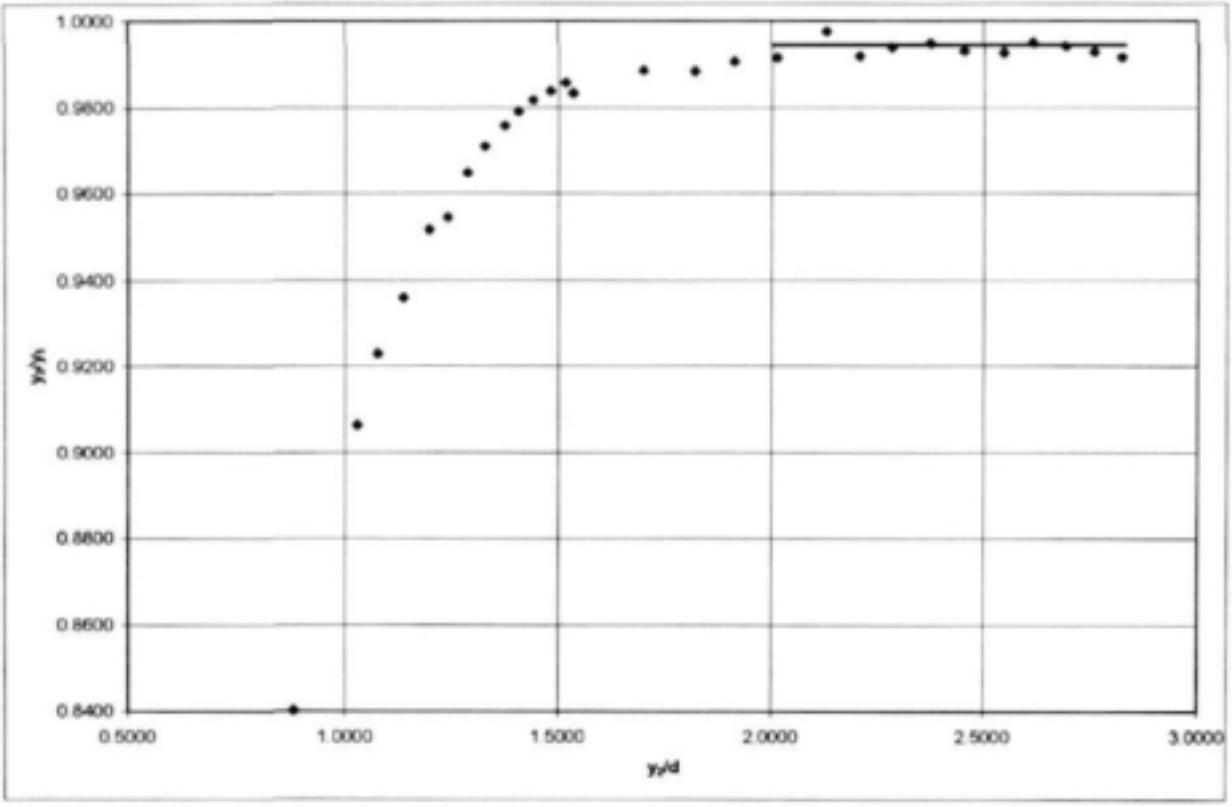

FIGURE 9.22: Relationship between stage (y_2) and water level in pool (y_5) for d/b=0.25 with sharp-crested weir

For y_2/d exceeding 2.0, y_2/y_5 reaches a constant value of 0.995. At high flow rates the water level at the recording position therefore approximates the water level in the upstream pool. This information can be used to extrapolate the records to higher flows than were recorded during the tests.

A graph of E_{s5}/d vs. y_2/d is shown in Figure 9.23.

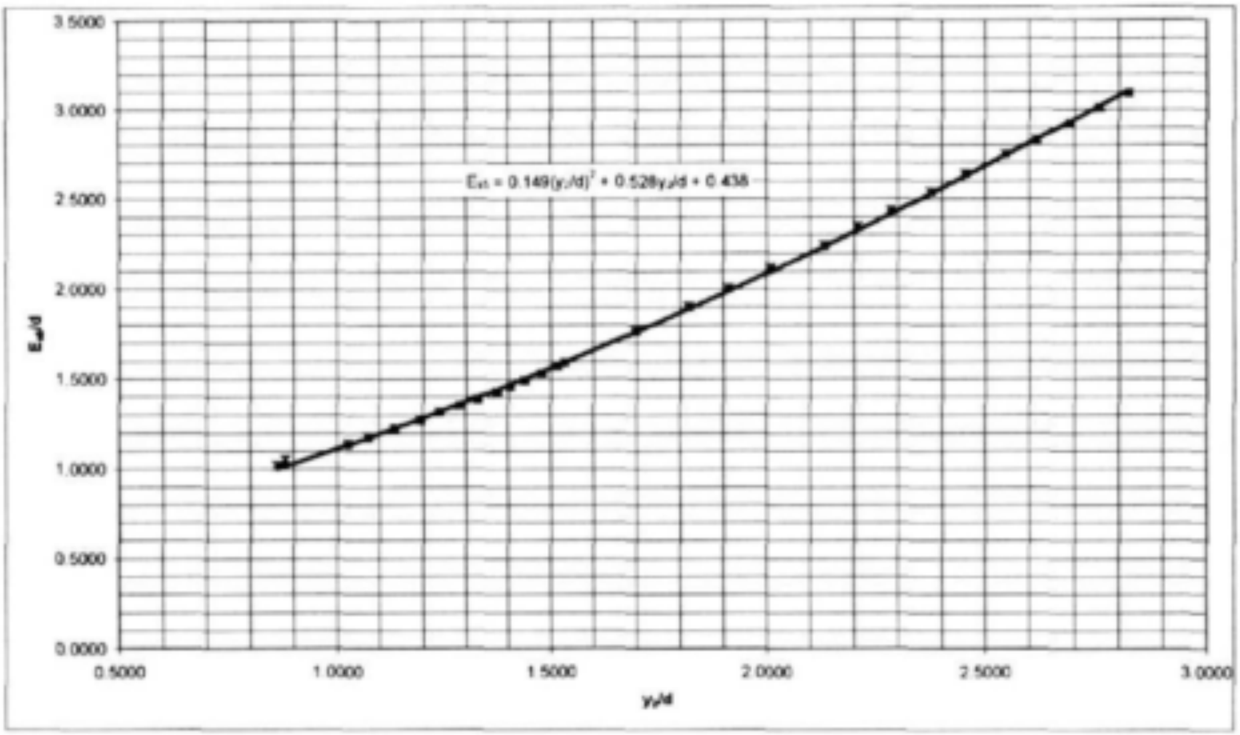

FIGURE 9.23: Relationship between stage (y_2) and energy level in pool (Es_5) for d/b=0.25 with sharp-crested weir

A curve was fitted through the data as follows:

$$E_{s5}/d = 0.438 + 0.528y_2/d + 0.149(\,y_2/d)^2 \quad \text{for} \qquad 0.85 < y_2/d < 3.0$$

9.8.4 Construction of calibration curves

The equations in sections 9.8.2 and 9.8.3 above, provide all the information required to be able to calculate the discharge through the flume for modular flow conditions if the stage is measured at the recommended position. It also provides the energy level in the pool upstream of the adjoining weirs for calculating the flow over the weirs. An example of the construction of a calibration curve for a sluicing flume in combination with a adjoining weir, is given in section 11.6 . The calibration curve calculated from the equations given above, are compared with the recorded calibration curve, in Figure 9.24.

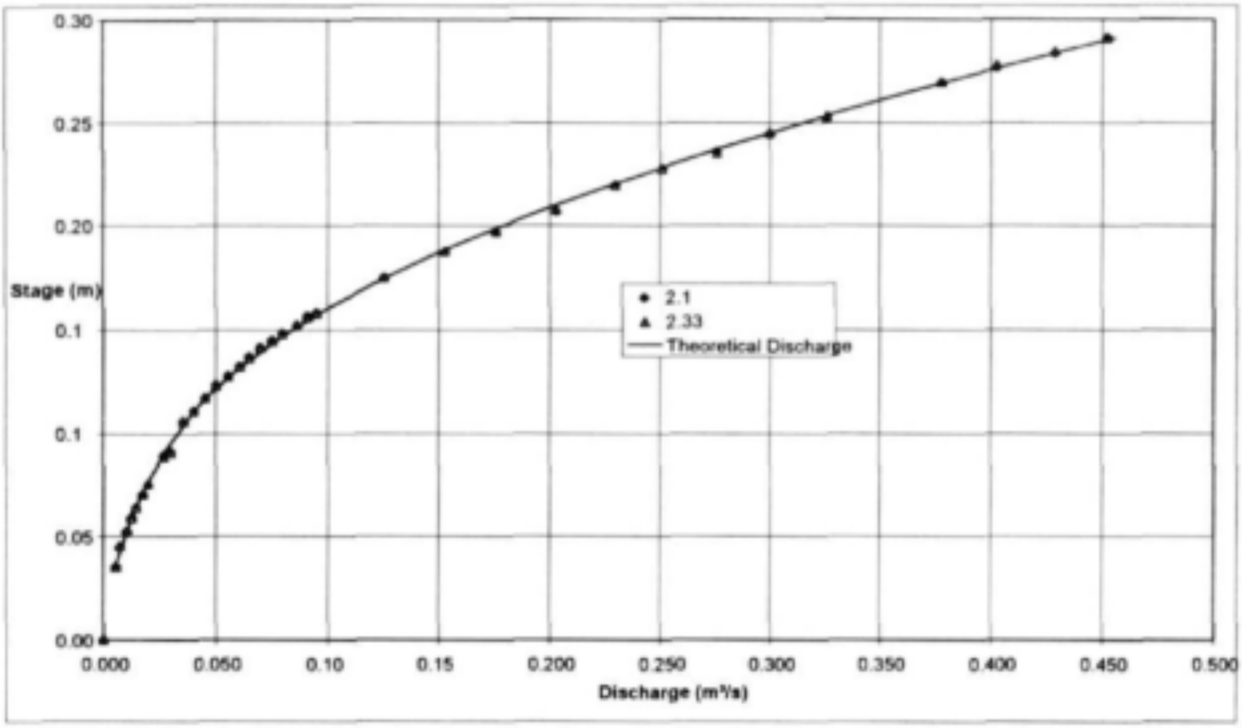

FIGURE 9.24: Calibration curve for flume with d/b=0.25 with sharp-crested weir as tested in model

As can be seen the fit of the data to the theoretically obtained curve, is good.

9.8.5 Accuracy of discharge calculated from the stage

The differences between the recorded and calculated discharge for a given stage, are summarised in Figure 9.25.

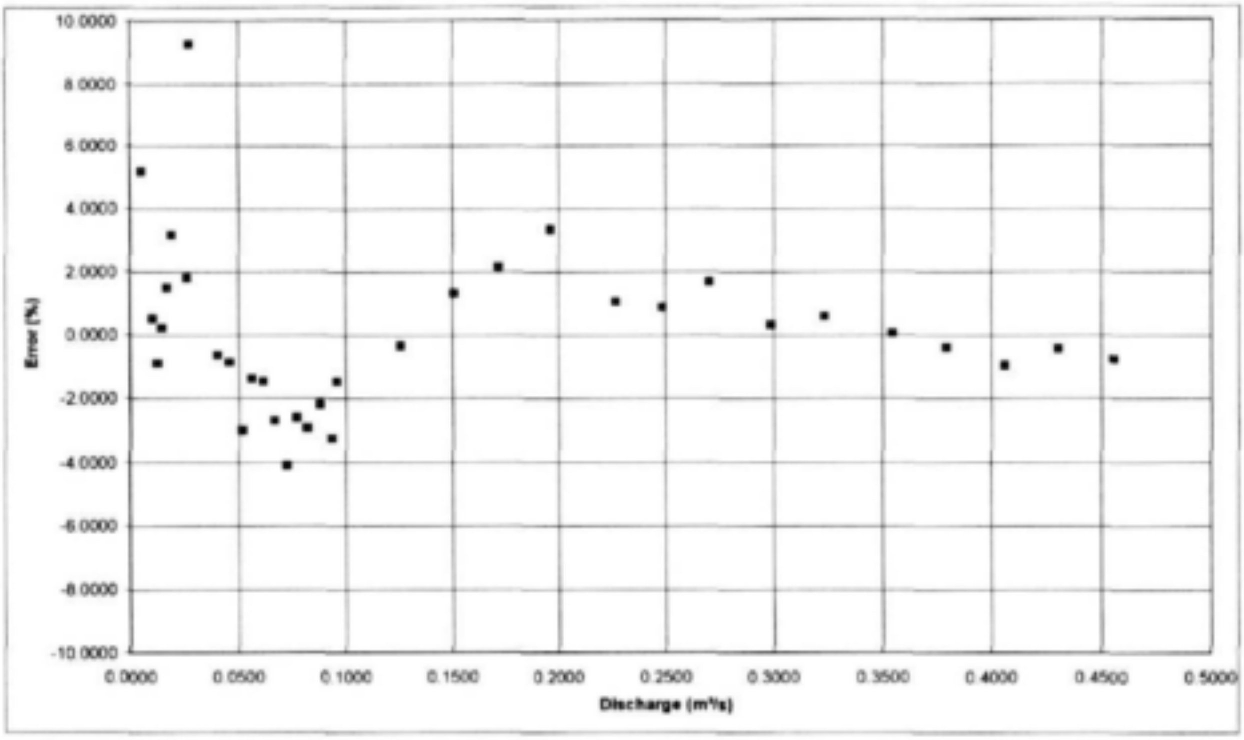

FIGURE 9.25: Error in derived discharge relative to measured discharge for flume with d/b=0.25 with sharp-crested weir

As can be seen on this figure, the maximum error is 9.5% and the errors are less than 4% in all but 3 of the tests over the entire range of flows tested. Maximum errors again occur soon after the flume abutment walls start to overtop.

9.9 Conclusion

In general the results obtained for the four flume-weir combinations tested are very satisfactory. The discharge coefficient C_{d5} determined in each case, does not only allow for losses, but also incorporates all deviations from the ideal flow conditions assumed when developing the theory. These include cross flow over the flume wall and at the flume end of the adjoining weir structures. This is the reason for the C_{d5} values reaching values exceeding 1.0 .

The accuracies obtained in the tests are an indication of the accuracy with which the curves were fitted to the C_d and E_{s5} values. It therefore represents the stability of the calibration data rather than the absolute accuracy of the calibration. It is estimated that the error in the flow measurement in the model, never exceeded 2% and that the errors only occured at the extreme low and high flows. The overall accuracy of the calibration will therefore be slightly worse than indicated in this chapter. Errors larger than 5% in discharge through the flume, will normally not occur.

CHAPTER

TEN

SUBMERGENCE TESTS ON RECOMMENDED STRUCTURES

10.1 Introduction

A series of tests were performed to determine the discharge characteristics of the recommended structures under conditions of high downstream water levels. These tests are an extension of the tests described in Chapter 7. In these tests on the finally recommended structures, however, considerably higher flow rates were tested. It can be expected that submerged flow will only occur during conditions of high discharge. For that reason the analysis will concentrate on the tests with the higher discharges.

All the measurements of the stage in these tests will be related to the preferred location inside the cavities in the flume walls. A series of tests were also performed to study the submerged flow performance of the flumes on their own, i.e. without adjoining weirs. The purpose of these tests was to try and overcome the difficulty of separating the behaviour of the flumes from the adjoining weirs, described in Chapter 7. If these flows could be treated separately, the results could be applied to a wider range of flume-weir combinations than those tested in this study.

To enable the reader to follow this section without referring to the previous tests, some definitions and test procedures are repeated here.

10.2 Definitions

In these tests the modular limits of the structures were determined. The modular limit is the ratio of downstream level to upstream level where the upstream level starts to be influenced by the downstream level. At downstream levels lower than the modular limit, a unique relationship exists between the upstream water level (stage) and the discharge. This flow is described as modular flow. Under modular flow conditions only the upstream water level needs to be recorded to be able to estimate the discharge. When the downstream level starts to influence the upstream level, the flow condition is described as drowned, submerged or non-modular. Under these circumstances the flow depth upstream and downstream of the gauging structure is required to be able to estimate the discharge.

10.3 Lay-outs tested

10.3.1 Flumes without adjoining weirs

Tests were done for the three flume geometries (i.e. with b/d ratios of 0.25, 0.5 and 1.0), in which the side weirs were blocked off as shown in Figure 10.1.

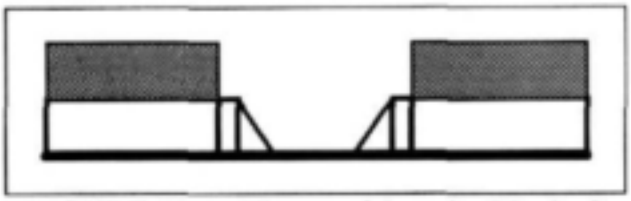

FIGURE 10.1: Flume with weirs blocked

The purpose of these tests was to establish the non-modular behaviour of the flumes on their own, without side weirs. If techniques can be developed in which the flow through the flume and over the weirs under non-modular conditions can be treated separately, it will be possible to estimate discharge for the flumes in combination with a variety of weir structures.

10.3.2 Flumes combined with sharp-crested weirs

The recommended flumes were also tested with the adjoining sharp crested weirs, to establish the non modular behaviour of the flumes in combination with adjoining weirs. The lay-outs tested were identical to those calibrated for modular flow as described in the previous chapter (see Figures 9.2, 9.14 & 9.20).

10.3.3 Flumes combined with a Crump weir.

A series of tests with the flume with a d/b ratio of 0.5 in combination with a Crump weir, as illustrated in Figure 9.8, were also conducted.

10.4 Range of test conditions

In Table 10.1, the range of test conditions that were used in studying the non-modular behaviour of the flumes are summarised.

TABLE 10.1: Submergence tests on recommended structures

d/b	weir	d	b	L_1	L_2	y_2 (modular)	L_2/L_1	y_2/d
0.5	sharp	132	264	528	1340	329	2.54	2.5
1.0	sharp	174	174	348	1520	322	4.37	1.9
0.25	sharp	103	412	721	1147	291	1.59	2.8
0.5	Crump	132	264	528	1340	316	2.54	2.4

The tests on the flumes in combination with sharp-crested weirs therefore covered the following ranges as seen in Table 10.2.

TABLE 10.2: Range of test for flumes in combination with sharp crested weirs.

	d/b	y_2/d	L_2/L_1
from	0.25	0.2	1.6
up too	1.0	2.8	4.4

10.5 Test Procedures

The procedure that was followed in all the tests was as follows:

- A given discharge was established in the model and the downstream water level was adjusted to ensure modular flow conditions
- Water levels were recorded at the positions indicated in Figure 9.1.
- The downstream level was increased without changing the discharge and the a new set of water levels were recorded.
- This process was repeated until the downstream water levels relative to the flume bottom were approaching the water depth in the flume (at the gauging position).
- The discharge was then adjusted and the process was repeated for the new discharge.

10.6 Data analysis

The data were analysed as follows:

- The water level in the pool (y_5) was calculated as the average of the water levels recorded at positions 4, 5 and 6. For modular flow the upstream level y_5 was termed the un-submerged pool depth h_{p0} and for submerged flow y_5 was termed the submerged pool depth, h_{pv} (see Figure 10.2 below). The level in the pool will not be recorded in the prototype, but will be used here to establish a relationship between the recorded stage and the pool level.
- The stage at the recording position (y_2) was taken as the average of the of the level recorded at positions 2.11 and 2.33. For modular flow this depth was termed the un-submerged flow depth h_0 and for submerged flow, the submerged flow depth h_v
- The downstream water level (y_{10}) was calculated as the mean water level recorded at positions 10, 11 and 12. This water level was termed the downstream depth, t.

All water levels were recorded relative to the level of the flume bottom.

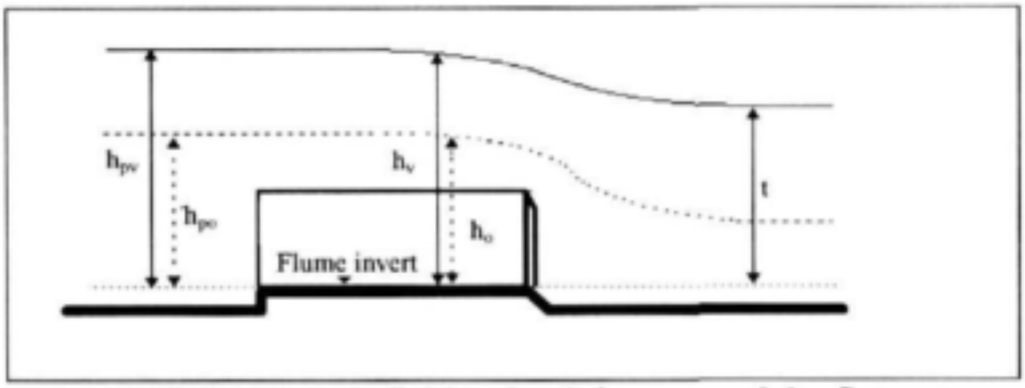

FIGURE 10.2: Definition sketch for non-modular flow

The data were analysed to relate the degree of submergence of the flume $S = t/h_v$ to the ratio of the unsubmerged depth to the submerged depth h_0/h_v. This is illustrated in the Figure 10.3 below:

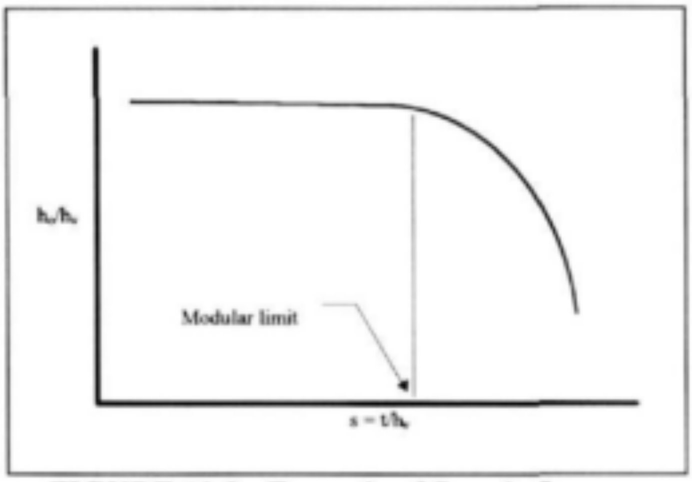

FIGURE 10.3: Example of S vs. h_0/h_v curve

From the graph of S versus h_v/h_0 the modular flow depth could be calculated if h_v and t is recorded. The modular flow depth derived in this way could then be used to calculate the discharge.

10.7 Results for the flumes isolated from adjacent weirs

The detailed results for each test are given in Appendix 10.1 and the analysis in Appendix 10.2. The results of the tests on all three the flumes for a variety of discharges are shown in Figure 10.4.

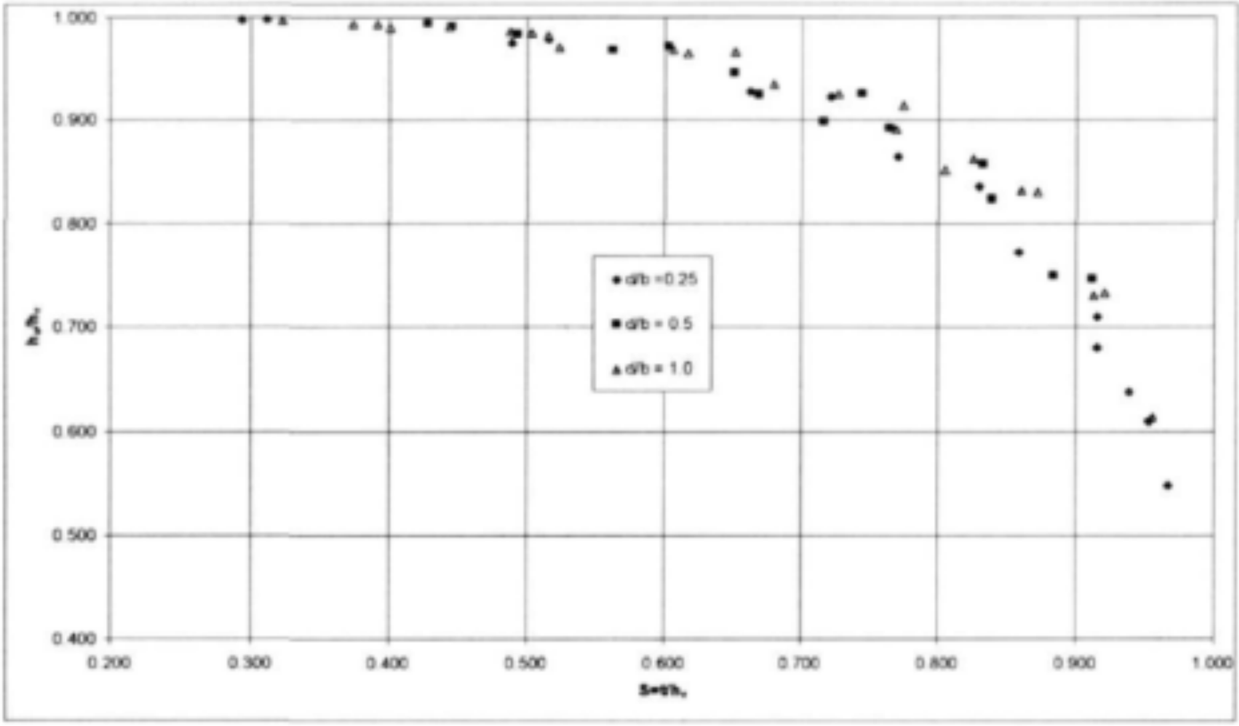

Figure 10.4: S vs. h_0/h_v curves for Flumes with weirs blocked off

Only discharges where the modular flow depth in the flume exceeded the flume depth by more than 50%, i.e. $h_0/d>1.5$, are shown on the figure. It is assumed that if the flume is constructed at a suitable level, non-modular conditions will not occur for h_0/d smaller than 1.5.

The main purpose of the submergence tests on the flume isolated from the adjacent weirs was to try and separate the submergence performance of the flume from the performance of the adjacent weirs under drowned conditions. It was hoped that by separating the analyses for the flume and the adjacent weirs, the basis for the analysis of any a flume-weir combination could be established. Efforts to do this was not very successful. The main reason for this is thought to be the somewhat artificial cut off walls that were used adjacent to the flume when the flume was tested on its own. These cut-off wall caused flow contractions that is very different to the case where the flume are combined with adjacent weirs. In the latter case the flume-weir combination allows a large degree of cross flow at the point of separation. This cross flow could not be simulated when the structures were isolated. It was therefore decided to test the flumes in combination with adjacent weirs and to develop a method of estimating discharge for non-modular flow of the combined structures.

10.8 Flumes in combination with sharp crested weirs

The detailed results for each test are given in Appendix 10.3 and the analysis in Appendix 10.4. The results of the tests on all three the flumes for a variety of discharges are shown in Figure 10.5.

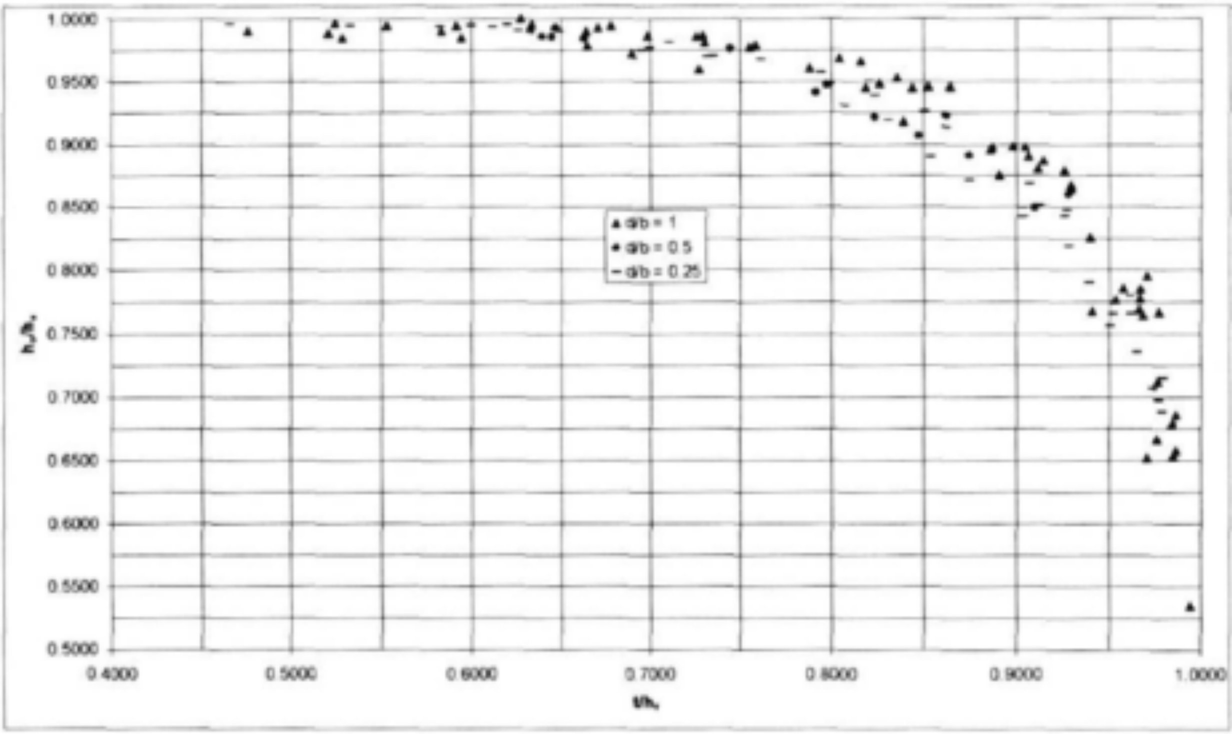

Figure 10.5: S vs. h_0/h_v curves for Flumes combined with sharp-crested weirs

Once again only discharges where the modular flow depth in the flume exceeded the flume depth by more than 50%, i.e. $h_0/d>1.5$, are shown on the figure. It is assumed that if the flume is constructed at a suitable level, non-modular conditions will not occur for h_0/d smaller than 1.5.

As can be seen on Figure 10.5, the non-modular behaviour of the three flume-weir combinations as tested under conditions of high flow, is similar. It is therefore possible to construct one S vs. h_0/h_v diagram to represent a the range of d/b from 0.25 to 1, and L_2/L_1 from 1.6 to 4.4, for y_2/d under modular conditions in the range of 1.5 to 2.8. This insensitivity of the non-modular behaviour of the flume-weir combinations to the variation in the dimensions of these combinations, makes it possible to use this curve for most combinations of flume and sharp-crested weirs that will be found in prototype.

In the calibration tests described in Chapter 9, it was found that for the flumes in combination with sharp-crested weirs, the water level recorded in the flume (y_2), becomes approximately equal to the water level in the upstream pool during high flows (see section 9). This tendency is obviously more pronounced in the case of non-modular flow. This is illustrated in Figure 10.6 for the three flumes considered here.

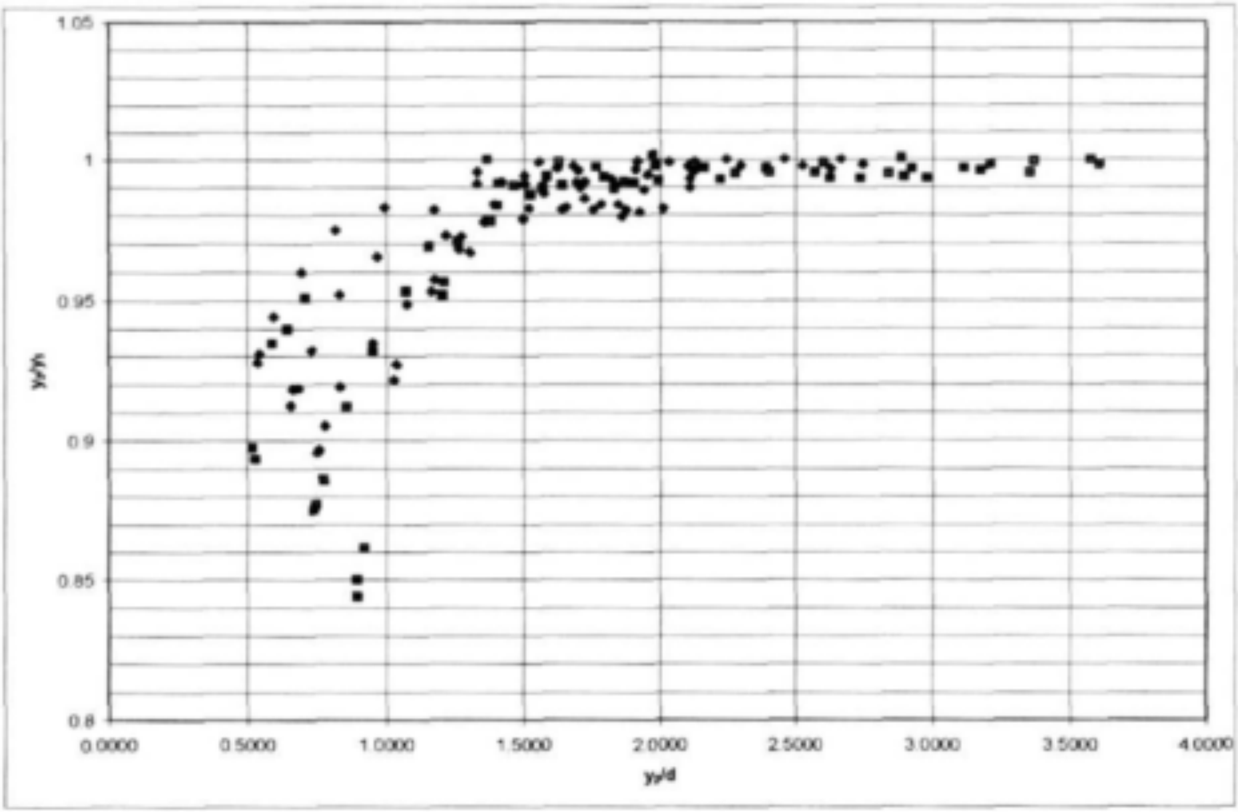

Figure 10.6: Relationship between water level in flume (y_2) and water level in pool (y_5) under non-modular conditions for flume combined with sharp-crested weirs.

This leads to the conclusion that the recorded water level in the flume represents the pool water level for all cases of submerged flow for the flume in combination with sharp-crested weirs tested in this study with y_2/d exceeding 1.5. The recorded stage can therefore be used directly to represent the water level upstream of any additional weirs in a multi-weir compound structure.

10.9 Flume with d/b = 0.5 in combination with Crump weir

The detailed results of tests on the flume with a depth to width ratio of 0.5 in combination with a Crump weir, are given in Appendix 10.5 and the analysis in Appendix 10.6. The results of the tests are summarised in Figure 10.7 for all the cases where the modular flow depth (y_2) exceeds the flume depth by 50%.

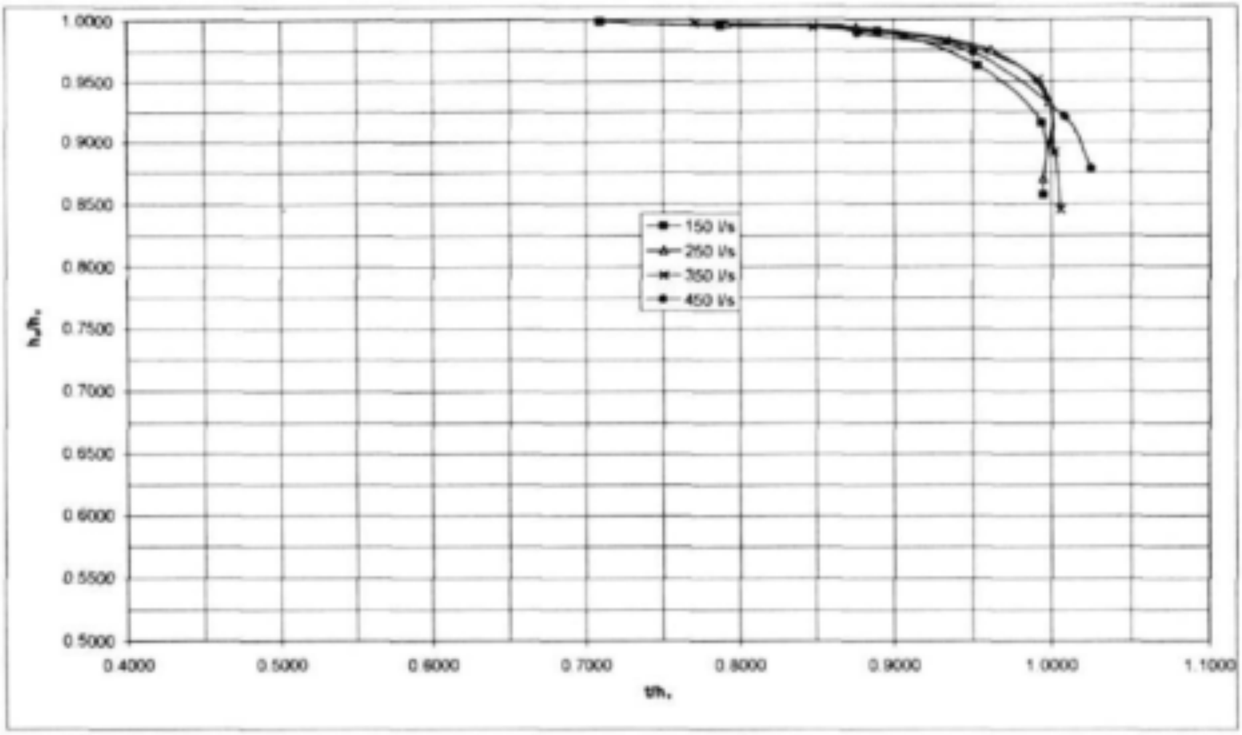

Figure 10.7: S vs. h_0/h_1 curves for flume with d/b = 0.5 combined with a Crump weir

The relationship between the water level in the pool relative to the water level in the flume is illustrated in Figure 10.8.

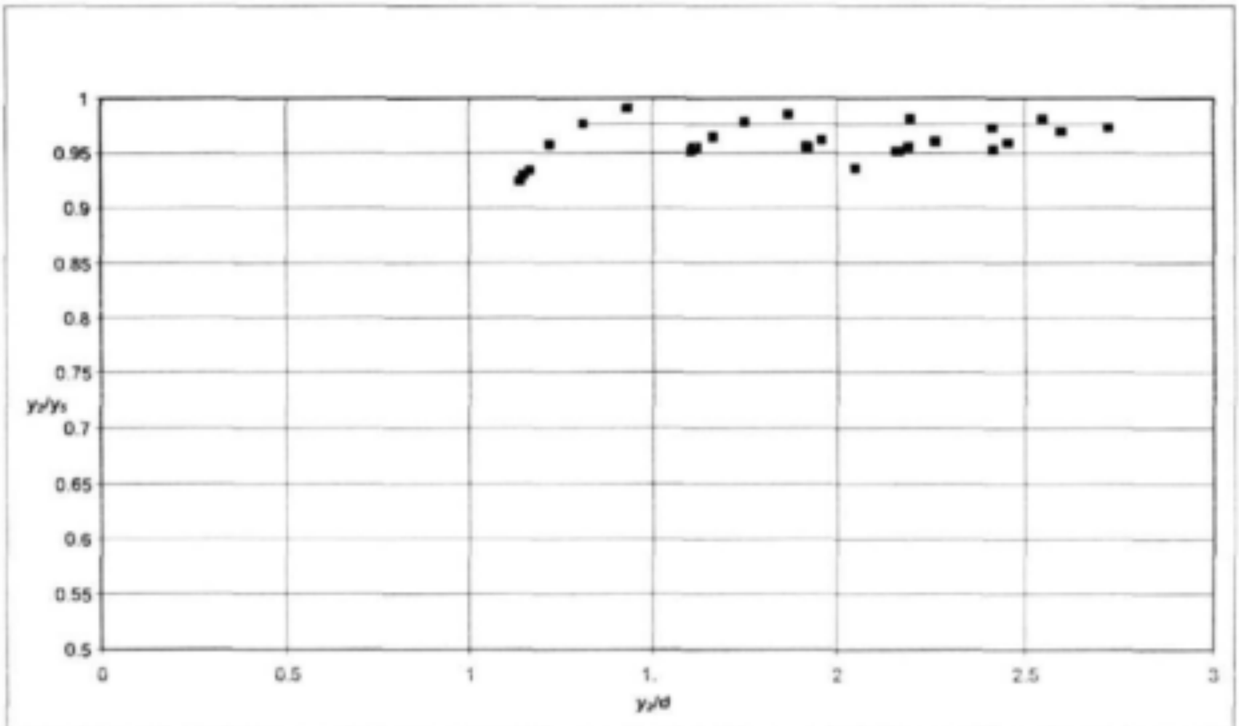

Figure 10.8: Relationship between water level in flume (y_2) and water level in pool (y_5) under non-modular conditions for flume combined with a Crump weir (d/b = 0.5).

From Figure 10.8 it is clear that for y_2/d values exceeding 1.5, the water level in the flume remains slightly lower than the level in the pool. Values vary from 0.95 to 0.99. The reason for the failure of the y_2 value to become equal to the y_5 value at high flow rates can be found in the position where y_2 is recorded relative to the crest of the adjoining Crump weir. The recording position is very close to the crest of the adjoining weir (see Figure 9.8) and therefore in the drawdown curve of the water flowing over the Crump weirs. This results in the lower levels recorded at the stage recording position, y_2. This is also the reason for the seemingly insensitivity of this combination of flume and weir to downstream water levels, illustrated in Figure 10.7. For high flows where the modular flow depth in the flume exceeds the flume depth by more than 50%, i.e. $y_2/d>1.5$, this flume-weir combination has a modular limit of 0.8 and at 95% drowning, i.e. at a t/h_v value of 0.95, the increase in the stage is only 2%. The drawdown at the recording position caused by the nearby crests of the Crump weirs, compensates for the increase in water level due to drowning. The errors in the estimated discharge that will be introduced if modular flow is assumed up to 95% drowning, will be less than 5% for the range of conditions tested in the model.

10.10 Estimating discharge under non-modular flow conditions

The method proposed for estimating the discharge under non-modular flow conditions, is as flows:

- The water levels at position 2 and position 10 must be recorded in the prototype. These levels are denoted as h_v and t respectively
- The ratio $S = t/h_v$ is therefore known
- Read the value of h_0/h_v corresponding to this S value from the appropriate diagram such as Figure 10.5
- With h_0 known, the discharge through the flume and weir combination can be calculated from the calibration curve for this combination.
- The water level in the pool upstream of the structure can be determined from the appropriate figures such as Figure 10.6.
- With the water level in the pool known, the discharge over the additional weirs can be estimated.

10.11 Conclusion

The three flume lay-outs with b/d = 0.25, 0.5 and 1.0 combined with sharp crested weirs, show similar non-modular flow behaviour. The curves shown in Figures 10.5 and 10.6 can be used to calculate flows under non-modular conditions for similar structures for the range of conditions listed in Table 10.2 . Errors in discharge of less than 10% is expected up to 95% of drowning, if this approach is used.

The flume with d/b = 0.5 in combination with a Crump weir, is very insensitive to high tailwater levels. The curves of Figure 10.7 and 10.8 can be used to calculate discharge under non-modular flow conditions. Errors in discharge of less than 5% can be expected up to 95% of drowning.

The approach to separate the non-modular behaviour of the flume from that of the adjoining weirs was not successful. This aspect will be further investigated in a separate study on flow measurement under high flow conditions that will start at the University of Stellenbosch in 1998.

CHAPTER

ELEVEN

RECOMMENDED PROCEDURES FOR IMPLEMENTING THE RESULTS OF THIS STUDY

11.1 Introduction

The main purpose of this chapter is to provide a quick reference for the reader to be able to implement the results of the tests on the recommended structures. Examples of the implementation of the results are also given.

11.2 Summary of results for recommended structures

The figures and tables containing the final results of the tests on the recommended structures are summarised in Table 11.1

Table 11.1 Summary of Figures and tables containing final results of recommended structures

d/b	Weir	Lay-out	C_d	y_2 @ y_s	y_2 @ E_{ss}	Calibration	Submergence
0.5	Sharp	Fig 9.2	Fig 9.3	Fig 9.4	Fig 9.5	Table 9.1 Figure 9.6	Figure 10.5
0.5	Crump	Fig 9.8	Fig 9.9	Fig 9.10	Fig 9.11	Table 9.2 Figure 9.12	Figure 10.7
1.0	Sharp	Fig 9.14	Fig 9.15	Fig 9.16	Fig 9.17	Table 9.3 Figure 9.18	Figure 10.5
0.25	Sharp	Fig 9.20	Fig 9.21	Fig 9.22	Fig 9.23	Table 9.4 Figure 9.24	Figure 10.5

If for example a flume with a depth to width ratio of 0.5 in combination with a Crump weir is considered, the lay-out is given in Figure 9.8, the discharge coefficients in Figure 9.9, etc..

11.3 Rating curves for structures exactly scaled-up from the tested structures

If the selected structure is a precise scaled-up version of any of the four flume-weir combinations summarised in Table 9.1, the rating curve for the structure can be obtained directly from standard Froude scale relationships. In this case it is important that all the dimensions, including the length of the adjacent weirs, should be scaled up by the same factor.

If for example a flume with a depth to width ratio d/b=0.5 combined with a sharp-crested weir is selected, the following procedure is suggested:

- select a suitable dimension for the flume depth say d=1.0 m. The scale is therefore $n_l = n_p/n_m = 1.00/0.132 = 7.57$. All the structure dimensions must now be multiplied by this factor i.e. $b = 0.264 \times 7.57 = 2.00$m $s = 0.066 \times 7.57 = 0.50$m $L_2 = 1.34 \times 7.57 = 10.15$m, etc.

- the stage discharge relationship for this structure can now be obtained directly from Table 9.1. The stage in this table must be multiplied with the length scale $n_l = 7.57$ and the discharge with the discharge scale $n_Q = n_l^{5/2} = 7.57^{2.5}$. The model discharge of 0.02470 cumec at a stage of 0.112m will therefore convert to a discharge of 3.902 cumec at a stage of 0.848m. The stage-discharge relationship for the flume-weir combination can therefore be obtained directly from Table 9.1, without making use of the discharge coefficients of Figure 9.3.

- if the flume-weir combination is constructed as part of a compound weir structure, it will be necessary to obtain the energy level in the upstream pool for cases where the additional weirs are overflowing. In this case the energy level can be obtained by scaling the y_2 and E_{s5} values in Table 9.1 directly according to the length scale.

- For cases where y_2/d exceeds the values that were tested in the model, the procedures described in section 11.4 below are recommended to extend the results to high flow conditions.

11.4 General procedure for construction of rating curves

If the flume-weir combination selected for the prototype differ from the configurations listed in Table 9.1, the rating curve can be constructed using the techniques described in Section 5.6. The discharge coefficients and the conversions from stage (y_2) to upstream energy (E_{s5}) required in the process must be selected from the appropriate relationships as listed in Table 9.1. If the conversion to upstream energy exceeds the range covered by the model tests, the stage must be converted to an upstream water level (y_5), using the appropriate factors as indicated in Table 9.1.

An example of the construction of a rating curve, using this procedure, is given in Section 11.6.

11.5 Submerged conditions

11.5.1 Flumes combined with sharp crested weirs

If the sluicing flumes are designed to ensure that modular flow will occur until y_2/d exceeds 1.5, Figure 10.5 (as listed in Table 9.1) can be used to estimate discharge under submerged flow conditions. This would mean that the water level downstream of the flume (relative to the flume floor) must not exceed 70% of the level in the flume (y_2) before a y_2/d value of 1.5 is reached. The curve shown in Figure 10.5 should strictly only be applied to scaled-up versions of the tested flume-weir combinations. The differences between the curves for the various combinations tested are however sufficiently small to allow their application to any flume weir combination with L_2/L_1 ratios between 1.6 and 4.4 (see Table 10.1).

The water level in the pool upstream of the flume can be taken as equal to the level in the flume under conditions of severe drowning with $y_2/d > 1.5$ (see Figure 10.6)

11.5.2 Flume with d/b=0.5 in combination with a Crump weir

The curve shown in Figure 10.7 can be used to estimate discharge under conditions of high tailwater levels for a flume-weir combination with a L_2/L_1 ratio of 2.54 as tested in the model. This is the preferred structure to be used if submerged flow conditions are expected to be a problem since the combination of the flume with a Crump weir shows far superior qualities under submerged flow conditions than the flume in combination with sharp-crested weirs.

11.6 Example of general procedure for constructing a rating curve

An example of the construction of a rating curve for a flume with a depth to width ratio of 0.5 in combination with a sharp-crested weir is given below. The necessary dimensions are listed in Table 11.2 and are defined in Figure 9.2

Table 11.2: Dimensions of flume d/b = 0.5

b	d	s	p	L_2
0.264	0.132	0.066	0.025	1.340

b_2 = width at point 2 = b + 2d = 0.528 m

11.6.1 Flow in flume only

Select

$$
\begin{aligned}
y_c &= 0{,}080\,\text{m} \\
A_c &= b \times y_c + y_c^2 = 0{,}0275 \quad \text{m}^2 \\
B_c &= b + 2y_c = 0{,}4240 \quad \text{m} \\
Q_T &= \left(\tfrac{gA_c^3}{B_c}\right)^{1/2} = 0{,}0220 \quad \text{m}^3/\text{s} \\
E_{sc} &= y_c + \tfrac{A_c}{2B_c} = 0{,}1125 \quad \text{m}
\end{aligned}
$$

The method whereby a flow depth at point (y_2) is found, works on a iterative basis. As a first estimation the theoretical flow (Q_T) can be used.

$$
\begin{aligned}
E_{s2} &= E_{sc} = y_2 + \left(\tfrac{Q}{b_2 y_2}\right)^2 / 2g = y_2 + \left(\tfrac{0{,}0220}{0{,}528 y_2}\right)^2 / 2g = 0{,}1125 \text{ m} \\
y_2 &= 0{,}1044\,\text{m} \\
y_2/d &= 0.79, \text{ which is between } 0.6 \text{ and } 0.9.
\end{aligned}
$$

From Section 9.5.2, $C_{d2} = 0.517(y_2/d)^2 + 0.479\,(y_2/d) + 1.031$, for $0.6 < y_2/d < 0.9$.

$$C_{d2} = 0.976$$

$$Q_R = C_{d2} \times Q_T = 0.976 \times 0.022 = 0.0215 \text{ m}^3/\text{s}$$

This flow can now be used for a better estimation of y_2. The process is repeat until the difference between two Q_R's becomes negligible.

With a set of y_2-values and the corresponding Q_R-values the first part of the rating curve can be constructed, where $y_2 < 0.9d$.

11.6.2 Flow over flume walls with $y_c < d$

$$
\begin{aligned}
\text{Select } y_c &= 0{,}130 \text{ m} \\
A_c &= by_c + y_c^2 = 0{,}0512 \text{ m}^2 \\
B_c &= b + 2_{yc} = 0{,}5240 \text{ m} \\
Q_T &= \left(\tfrac{gA_c^3}{B_c}\right)^{1/2} = 0{,}0471 \text{ m}^3/\text{s} \\
E_{sc} &= y_c + \tfrac{A_c}{2B_c} = 0{,}1789 \text{ m} \\
E_{s5} &= E_{sc} = 0{,}1789\,\text{m}
\end{aligned}
$$

By using the relationship between E_{s5}/d and y_2/d in Section 9.5.3, y_2/d can be found.

$$E_{s5}/d = 0.315 + 0.630(\, y_2/d) + 0.125(\, y_2/d)^2 \qquad \text{for} \qquad 0.9 < y_2/d < 2.5$$

$$E_{s5}/d = 0.1789/0.132 = 1.3553$$

$$\therefore y_2/d = 1.3103$$

Flow through flume = $Q_R = C_{d5} \times Q_T$. The value of C_{d5} for $0.9 < y_2/d < 1.5$ can be found in Section 9.5.2.

$$C_{d5} = -0.0267 y_2/d + 0.899$$

$$= -0.0267 \times 1.3103 + 0.899$$

$$= 0.86$$

$$\therefore Q_R = 0.86 \times 0.0471$$

$$= 0.0405 \text{ m}^3/\text{s}$$

The flow over the sharp-crest weir:

$$\begin{aligned}
\therefore \quad Q_w &= \left(0.627 + 0.018 \tfrac{H}{P}\right) \tfrac{2}{3} \sqrt{2g}\, L_s\, H^{3/2} \\
H &= E_{s5} - d = 0.1789 - 0.132 = 0.0469 \text{ m} \\
P &= d + p = 0.132 + 0,025 = 0,157 \text{ m} \\
\therefore \quad Q_w &= \left(0.627 + 0.018 \tfrac{0.0469}{0.157}\right) + \tfrac{2}{3} \sqrt{2g} \times 1.340 \times (0.0469)^{3/2} = 0.0254 \text{ m}^3/\text{s}
\end{aligned}$$

The total flow = $Q_{tot} = Q_R + Q_w = 0.0405 + 0.0254 = 0.0659$ m³/s, when $y_2 = 1.3103 \times 0.132 = 0.172$ m.. With a set of y_2-values and corresponding Q_{tot}-values, the next part of the curve can be constructed, where $0.9d < y_c < d$.

11.6.3 Flow over flume walls with $y_c > d$

$$\begin{aligned}
\text{Select} \quad y_c &= 0.150 \text{ m} \\
\therefore \quad A_c &= b \cdot d + d^2 + B_c \times (y_c - d) \\
&= 0.264 \times 0.132 + 0.132^2 + (0.66) \times (0.150 - 0.132) \\
&= 0.0642 \text{ m}^2 \\
B_c &= 0.528 + 2 \times 0.066 = 0.660 \text{ m} \\
Q_{Tflume} &= \left(\tfrac{g A_c^3}{B_c}\right)^{1/2} = 0.0626 \text{ m}^3/\text{s} \\
E_{sc} &= y_c + \tfrac{A_c}{2B_c} = 0.150 + \tfrac{0.0626}{2 \times 0.660} = 0.1986 \text{ m} \\
E_{s5} &= E_{sc}
\end{aligned}$$

By using the relationship between E_{s5}/d and y_2/d in Section 9.5.3, y_2/d can be found.

$E_{s5}/d = 0.315 + 0.630(y_2/d) + 0.125(y_2/d)^2$ for $0.9 < y_2/d < 2.5$

$E_{s5}/d = 0.1986/0.132 = 1.5045$

$\therefore y_2/d = 1.4631$

Flow through flume = $Q_R = C_{d5} \times Q_T$. The value of C_{d5} for $0.9 < y_2/d < 1.5$ can be found in Section 9.5.2.

$$C_{d5} = -0.0267 y_2/d + 0.899$$

$= -0.0267\times1.3103+0.899$

$= 0.86$

$\therefore Q_R = 0.86\times0.0626$

$= 0.0538\ m^3/s$

The flow over the sharp-crest weir:

$$
\begin{aligned}
\therefore\quad Q_w &= \left(0.627+0.018\tfrac{H}{P}\right)\tfrac{2}{3}\sqrt{2g}\,L_2\,H^{3/2}\\
H &= E_{s5}-d = 0.1986-0.132 = 0.0666\ \text{m}\\
P &= d+p = 0.132+0.025 = 0.157\ \text{m}\\
\therefore\quad Q_w &= \left(0.627+0.018\tfrac{0.0666}{0.157}\right)+\tfrac{2}{3}\sqrt{2g}\times1.340\times(0.0666)^{3/2} = 0.0432\,\text{m}^3/\text{s}
\end{aligned}
$$

The total flow = $Q_{tot} = Q_R + Q_w = 0.0538 + 0.0432 = 0.0970$ m³/s, when $y_2 = 1.4631\times0.132 = 0.193$ m. With a set of y_2-values and corresponding Q_{tot}-values, the last part of the curve can be constructed, where $y_c > d$.

CHAPTER
TWELVE

CONCLUSIONS

A series of sluicing flumes have been developed which can be used for flow gauging in sediment laden South African rivers. The main characteristics of the sluicing flumes are as follows.

- *All three different flume layouts possess stable calibration characteristics that are not affected by adjacent weir structures.* This will allow combination of the flumes with a wide variety of adjacent sharp-crested and Crump weir configurations, without the need for laboratory calibration in each case.

- *A gauging position inside the flume is used.* During low flows when the flow is contained within the flume, the gauged water level can be converted directly to a rate of flow by using standard theory and is therefore unaffected by siltation in the pool. During higher flows when the abutment walls of the flume are overtopped, the recorded level can be translated to an energy level in the upstream pool. This conversion should lead to a better estimate of the energy level in the pool than when the water level in the pool is recorded directly in cases where the silted depth of the pool is unknown. It was however proven that the empirical relationships between stage at the gauge point and stage in the upstream pool, can also be used for the accurate iterative calculation of energy in the upstream pool, which is required to calculate discharge through the structure.

- *The flumes have good characteristics with respect to the handling of severe sediment loads.* Sedimetation of the flume will still occur during the falling stage of a flood if sediment levels in the pool are higher than the invert of the flume. These sediment deposits will however be removed quickly during the rising phase of the next flood.

- *The gauging position remains largely sediment free and the control section of the flume stays totally sediment free.* The flume will give accurate calibration results even if sediment deposition occurs in the flume, for as long as the control at the trapezoidal end section of the flume remains predominant.

- *The flume shows good modular behaviour.* The modular limit for all three flume configurations tested is 0.8, and accurate flow gauging for the flume as such is possible up to 95% submergence.

Extensive model tests in the hydraulics laboratory of the University of Stellenbosch were used to develop the flume configuration. Inputs received from DWAF personnel were received throughout the study and these inputs were incorporated in the model tests. The end results are three flume configurations which were recommended in Chapter 8. Calibration curves for any flume and weir combination can be derived analytically from the procedures described in Chapter 11. The procedures followed have sound theoretical bases and it is expected that flow measurement to an accuracy of better than 95 % will be possible over a wide range of flow conditions.

CHAPTER

THIRTEEN

RECOMMENDATIONS

(i) The use of the flume layout 2R, as shown in Figure 8.1, is recommended for use with compound weir structures in rivers where sediment problems are experienced in the pools upstream of weirs.

(ii) For new structures in cases where serious sediment problems are expected, the sluicing flume should be combined with Crump weirs. The calibration of such a combined structure will be unaffected by sedimentation in the pool and will also provide superior performance under conditions of submergence.

(iii) If depth to width ratios other than $d/b = 0.5$ are required for the flume, the layouts 1R and 3R, as shown in Figures 8.2 and 8.3, may be considered.

(iv) The flume bed should be installed at a minimum elevation that will ensure that maximum discharge can be measured without exceeding the modular limits of the flume or the adjoining weirs. Accuracy of flow measurement will be affected by excessive submergence.

(v) More than one flume should be installed in a wide river channel and water level gauging should ideally be undertaken in each flume.

(vi) If it is important to gauge flow under submerged conditions with flume-weir combinations very different from those tested in the model, further model tests and analyses on submerged conditions will be required.

(vii) If sluicing flumes are installed as part of compound weir structures, in situations which are very different from those tested in the model, careful monitoring and experimentation will be advisable. The installation of one or more gauging points in the pool in very wide rivers, will provide useful information about the representativeness of the gauging point in the flume under these extreme conditions.

(viii) This study brings to conclusion comprehensive research which has been performed for modular and near modular flow conditions at weirs. High flows i.e. flows which are beyond the capacity of traditional flow measurement structures, remains problematic. It is recommended that further research be conducted on measurement of high flows.

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APPENDIX

PLEASE NOTE:

THIS "CHAPTER" CONSISTS OF APPENDICES 4.1, 5.1, 6.1, 7.1, 9.1, 9.2, 10.1, 10.2, 10.3, 10.4, 10.5 and 10.6.

THE DATA IN THESE APPENDICES ARE AVAILABLE IN ELECTRONIC FORMAT, AND ARE OBTAINABLE FROM THE

WATER RESEARCH COMMISSION
PO BOX 824
PRETORIA, 0001

REFERENCE NO: WRC 442/3/98

APPENDIX

4.1

RESULTS OF CALIBRATION TESTS

CALIBRATION OF FLUME AND COMPOUND WEIR SETUP
Results of model tests

Model 1 Setup 1
Layout 2, with long flume abutment walls, in 3 m channel with sharp-crested weir length = 2,34 m.
(all stage measurements relative to bottom of flume)

W =	3	m
L2/2 =	1.17	m
s =	0.066	m
b =	0.264	m
d =	0.132	m
L1 =	0.528	m

H mano (m)	Q mano (l/s)	H orifice (m)	Q orifice (l/s)	% Difference	Gauge point 1 (mm)	Gauge point 2.1 (mm)	Gauge point 2.2 (mm)	Gauge point 2.3 (mm)	Gauge point 3 (mm)	Gauge point 4 (mm)	Gauge point 5 (mm)	Gauge point 6 (mm)
0.0073	9.369	0.033	8.921	4.777	69		66		69	68.5	69	68.5
0.0136	12.787	0.041	12.262	4.105	85		79.5		85	84.5	84.5	84.5
0.02	15.507	0.047	14.995	3.303	94		88.5		95	94.5	95	94.5
0.031	19.306	0.0555	19.173	0.690	109		100		109	109	110	109.5
0.05	24.519	0.065	24.240	1.138	123.5		113		124	123.5	123.5	124
0.074	29.828	0.0745	29.698	0.436	135.5		122.5		136	136	136	136.5
0.143	41.465	0.093	41.368	0.235	147		139.5		147.5	147	147.5	147
0.204	49.526	0.105	49.623	-0.196	154		149.5		154	153	154	153.5
0.267	56.659	0.115	56.890	-0.407	158.5		155		158.5	158	158.5	158.5
0.368	66.518	0.1275	66.448	0.106	163.5		161		164.5	163.5	164	164.5
0.555	81.689	0.1465	81.940	-0.308	172		170.5		173.5	172	173	173
0.915	104.888	0.172	104.462	0.406	183.5		182.5		184.5	183	183	183.5
1.855	149.344	0.217	148.713	0.422	201		201		202.5	201.5	202	202.5

CALIBRATION OF FLUME AND COMPOUND WEIR SETUP
Results of model tests

Model 1 Setup 2
Layout 2, with long flume abutment walls, in 3 m channel with sharp-crested weir length = 0,8 m.
(all stage measurements relative to bottom of flume)

W =	3	m
L2/2 =	0.4	m
s =	0.066	m
b =	0.264	m
d =	0.132	m
L1 =	0.528	m

H mano (m)	Q mano (l/s)	H orifice (m)	Q orifice (l/s)	% Difference	Gauge point 1 (mm)	Gauge point 2.1 (mm)	Gauge point 2.2 (mm)	Gauge point 2.3 (mm)	Gauge point 3 (mm)	Gauge point 4 (mm)	Gauge point 5 (mm)	Gauge point 6 (mm)
0.009	10.402	0.035	9.723	6.536	76.5	70	72.2	72.4	76.9	76.2	77.5	77
0.017	14.297	0.0449	14.017	1.954	91.7	84	85.2	84.4	91.7	91.7	92	92.5
0.027	18.018	0.053	17.908	0.607	106.5	98.5	99.7	97.7	107.7	106.7	108.5	108
0.032	19.615	0.056	19.429	0.946	111.5	100.5	102.7	100.2	112.2	111.7	112	112.5
0.049	24.272	0.065	24.240	0.134	124.5	111.5	113.2	109.2	124.5	124.2	125	125
0.062	27.303	0.07	27.066	0.870	133.5	119	119.2	116.2	132.7	132.2	133.5	133.5
0.075	30.029	0.075	29.996	0.111	138.5	124.5	125.2	121.2	139.2	138.2	139.5	139
0.092	33.259	0.0795	32.720	1.619	143.5	131.5	132.2	129.2	142.7	143.2	144	144
0.11	36.367	0.084	35.525	2.316	149	141.5	141.2	139.2	149.2	148.2	149	149.5
0.241	53.830	0.1095	52.850	1.820	170.5	167.5	167.7	167.2	169.2	170.2	171	170.5
0.359	65.699	0.1265	65.664	0.054	183.5	182	182.2	182.2	184.7	183.7	185	184.5
0.574	83.075	0.1475	82.786	0.348	200.5	198.5	198.7	198.7	200.7	200.2	201.5	201
0.94	106.311	0.174	106.309	0.002	219.5	217.5	217.2	217.2	218.7	219.2	220	220.5
1.835	148.536	0.216	147.670	0.583	249	246.5	246.7	246.2	249.2	248.7	249.5	250.5

CALIBRATION OF FLUME AND COMPOUND WEIR COMBINATION
Results of model tests

Model 1 Setup 3
Layout 2, with long flume abutment walls, in 2 m channel with sharp-crested weir length = 1,34
(all measurements relative to flume bed)

W =	2	m
L2/2 =	0.67	m
s =	0.066	m
b =	0.264	m
d =	0.132	m
L1 =	0.528	m

H mano (m)	Q mano (l/s)	H (V-notch) (m)	Q (V-notch) (l/s)	% Difference	Gauge point 1 (mm)	Gauge point 2.1 (mm)	Gauge point 2.2 (mm)	Gauge point 2.3 (mm)	Gauge point 3 (mm)	Gauge point 4 (mm)	Gauge point 5 (mm)	Gauge point 6 (mm)
0.018	7.777	0.122	7.246	6.829	65	61	61	61	66	65.5	66	66
0.053	13.345	0.154	12.972	2.796	90.5	83	83.5	82.5	91	91	90.5	90.5
0.129	20.820	0.182	19.696	5.398	115.5	105	105	104.5	116	116	115.5	116
0.235	28.101	0.208	27.502	2.132	137	125	125	124.5	137.5	137	137	138
0.466	39.571				153	146	147.5	146	154	153.5	153.5	154
0.585	44.336				157	151	152.5	151.5	158	157	157	158
0.766	50.734				163.5	160	160	160.5	164	163.5	163.5	164
0.857	53.663				166	163.5	163	163.5	167	167	166.5	166
1.114	61.182				172	170	170	170	173	172	172.5	172.5
1.4	68.588				178	176	176	176	179	178.5	178.5	178.5
1.523	71.537				180	178	178	178	180.5	181	181	181
1.843	78.695				185	183.5	183.5	183.5	185.5	185.5	186	186
2.024	82.468				187	186	186	186	188	188	188.5	188.5
2.244	86.835				191	189	189	189.5	191	191	191	191.5
2.72	95.602				197	196	195.5	195.5	197.5	197	197.5	198

CALIBRATION OF FLUME AND COMPOUND WEIR SETUP
Results of model tests

Model 2 Setup 1
Layout 2, with long narrow flume abutment walls, in 2 m channel with sharp-crested weir length = 1.426 m.
(all stage measurements relative to flume bed)

W =	2	m
L2/2 =	0.713	m
s =	0.023	m
b =	0.264	m
d =	0.132	m
L1 =	0.528	m

H mano (m)	Q mano (l/s)	H (V- notch) (m)	Q (V-notch) (l/s)	% Difference	Gauge point 1 (mm)	Gauge point 2.1 (mm)	Gauge point 2.2 (mm)	Gauge point 2.3 (mm)	Gauge point 3 (mm)	Gauge point 4 (mm)	Gauge point 5 (mm)	Gauge point 6 (mm)
0.008	5.185	0.105	4.979	3.961	53	45.5	46.5	47.5	54.5	52	52	53.8
0.02	8.198				67	57.5	57.5	59	68	66	66	67.5
0.042	11.880	0.147	11.548	2.795	86	73.5	74	74.5	87.5	85	85	86.5
0.049	12.832				88.5	75	76	76.5	90	87.5	87	89
0.0775	16.137	0.168	16.124	0.083	100.5	84.5	85.5	86	101.5	99.3	99	100.5
0.095	17.867				108.5	90	92	91.5	110	107.5	107	108.5
0.12	20.080	0.181	19.427	3.256	117	97	98.5	98.5	118.5	116.3	116	117.5
0.202	26.053				134.5	109	110.5	110.5	136	133	133	134.5
0.22	27.189				136.5	112	112.8	113.5	138	135.5	135	137
0.563	43.495				156.5	150.5	150.5	152	157.5	155	155	156
1.36	67.601				176.5	173	173	174	178	175	175	176.5
1.7	75.580				181.5	178	178.5	179.5	182.5	180.5	180.5	181.5
2.516	91.947				190.5	187	187.5	188.5	191.5	189.5	189.5	190.5
	102.402				199.5	196	196	197.5	200	199.3	199.5	200
	114.546				206.5	203.3	203.5	204.8	207.5	205	205.5	206.5
1.81	147.521				216.3	213.5	214.5	215	217.5	214.8	215	216.8
	164.560				227.5	224.5	225.5	226.5	228.8	226.5	226	228
	211.037				247.5	245.5	246	247	249.5	247	247	249

CALIBRATION OF FLUME AND COMPOUND WEIR COMBINATION
Results of model tests

Model 2 Setup 2
Layout 2, with long thick flume abutment walls, in 2 m channel with sharp-crested weir length = 1,262 m.
(all stage measurements relative to flume bed)

W =	2	m
L2/2 =	0.631	m
s =	0.105	m
b =	0.264	m
d =	0.132	m
L1 =	0.528	m

H mano (m)	Q mano (l/s)	H (V-notch) (m)	Q (V-notch) (l/s)	% Difference	Gauge point 1 (mm)	Gauge point 2.1 (mm)	Gauge point 2.2 (mm)	Gauge point 2.3 (mm)	Gauge point 3 (mm)	Gauge point 4 (mm)	Gauge point 5 (mm)	Gauge point 6 (mm)
0.009	5.499	0.1045	4.920	10.528	52.5	48	48.5	49.5	54.5	52	52	53
0.042	11.880	0.1455	11.255	5.256	84.5	77	77.8	78.5	85	83.5	83	85
0.078	16.189	0.169	16.365	-1.085	101.5	93	93.5	93.5	103	100.5	100	102
0.122	20.247	0.183	19.968	1.380	115.5	104.5	105.5	106	117	114.5	114	116
0.233	27.981				140	126.5	127.5	128.5	141	138.5	137.5	140
0.515	41.599				155.5	147.5	148.5	149	157	154	154	155.5
	68.802				177	173.5	174	175	179	176	176	177.5
	87.272				190.5	187	187.8	189	192	189	189	191
	118.529				206.5	203.5	204	205	208	206.5	206	207.5
	159.518				226.5	223.5	224	225	228	226.3	226	227.5

CALIBRATION OF FLUME AND COMPOUND WEIR COMBINATION
Results of model tests

Model 2 Setup 3
Layout 2, with long thick abutment walls, in 2 m channel with Crump weir length = 1,262 m.
(all stage measurements relative to flume bed)

W =	2	m
L2/2 =	0.631	m
s =	0.105	m
b =	0.264	m
d =	0.132	m
L1 =	0.528	m

H mano (m)	Q mano (l/s)	H (V-notch) (m)	Q (V-notch) (l/s)	% Difference	Gauge point 1 (mm)	Gauge point 2.1 (mm)	Gauge point 2.2 (mm)	Gauge point 2.3 (mm)	Gauge point 3 (mm)	Gauge point 4 (mm)	Gauge point 5 (mm)	Gauge point 6 (mm)
0.009	5.499	0.117	6.526	-18.676	53.5	48.5	49.4	49.5	55	52.5	52.5	53.5
0.048	12.700	0.154	12.972	-2.141	88	81	81.5	81.5	90	87	87	88.5
0.076	15.980	0.164	15.181	5.001	100.5	91.5	92.5	92.5	102.5	99.5	99	100.5
0.126	20.576				116.5	105.5	106	106.5	117.5	115	114.5	116
0.236	28.160				136.5	124	125	125.5	139.3	136	135	137.3
0.58	44.146				158.5	153	153.5	153.5	160	157.5	157	159
1.3464	67.262				177.5	173.5	174	175	179	176.5	177	178
	86.809				190.3	187	187.5	189	192	189	189.5	191
	117.448				208	205.5	205.5	206.5	210	207	207	208.5
	148.470				223.5	220	220.5	221.5	225	222	223	224.5
	170.124				233	230	230.5	231.5	235	232	233	234
	211.037				250.5	248	248	249.5	252	250	251	252

CALIBRATION OF FLUME AND COMPOUND WEIR COMBINATION
Results of model studies

Model 3 Setup 1
Layout 1, with long flume abutment walls, in 2 m channel witjh sharp-crested weir length = 1,52 m.
(all stage measurements relative to flume bed)

W =	2	m
L2/2 =	0.76	m
s =	0.066	m
b =	0.174	m
d =	0.174	m
L1 =	0.348	m

H mano (m)	Q mano (l/s)	H (V-notch) (m)	Q (V-notch) (l/s)	% Difference	Gauge point 1 (mm)	Gauge point 2.1 (mm)	Gauge point 2.2 (mm)	Gauge point 2.3 (mm)	Gauge point 3 (mm)	Gauge point 4 (mm)	Gauge point 5 (mm)	Gauge point 6 (mm)
0.018	7.777	0.12	6.953	10.601	85.5	80.5	80.5	81	86	84.5	85.5	85.5
0.064	14.665	0.16	14.273	2.674	124.5	116.5	116	116	125.5	126	125.5	126
0.179	24.525	0.197	24.009	2.106	166	151	151	151.5	166.5	166	166	166.5
0.265	29.840				180.5	166	166	166	181	180.5	180.5	180.5
0.566	43.610				198	189.5	192.5	192.5	198.5	198	198	198.5
0.83	52.811				206.5	203	203.5	203	207	206.5	206.5	206.5
1.258	65.016				216.5	214.5	214.5	214.5	216.5	216.5	216.5	217
1.612	73.598				223	221.5	221.5	221.5	223.5	223	223.5	223.5
2.0672	83.344				230.5	229.5	229.5	229.5	231	230.5	231	231
2.788	96.790				240	239	239	239	240.4	240	240.5	240.5

CALIBRATION OF FLUME AND COMPOUND WEIR COMBINATION
Results of model studies

Model 4 Setup 1
Layout 3, with long flume abutment walls, in 2 m channel with sharp-crested weir length = 1,146 m.
(all stage measurements relative to bottom of flume)

W =	2	m
L2/2 =	0.573	m
s =	0.066	m
b =	0.412	m
d =	0.103	m
L1 =	0.722	m

H mano (m)	Q mano (l/s)	H (V-notch) (m)	Q (V-notch) (l/s)	% Difference	Gauge point 1 (mm)	Gauge point 2.1 (mm)	Gauge point 2.2 (mm)	Gauge point 2.3 (mm)	Gauge point 3 (mm)	Gauge point 4 (mm)	Gauge point 5 (mm)	Gauge point 6 (mm)
0.019	7.990	0.123	7.395	7.444	51	47	47.5	47	51	51	51	52
0.043	12.020	0.145	11.159	7.167	65	59	60	59	65	65	65	65
0.067	15.004	0.16	14.273	4.878	74	67	68	67	74	74	74	74.5
0.118	19.912	0.18	19.159	3.782	88	76.5	79.5	76	88	88	87.5	88
0.197	25.729	0.197	24.009	6.685	101	87.5	89	87.5	101	101	100	101
0.232	27.921	0.205	26.521	5.014	105	91	93	90	105	105	104.5	105
0.315	32.534				112	101.5	103	101.5	112	112	111.5	112.5
0.484	40.328				122.5	116	117	116	123	122.5	122	122.5
0.782	51.261				132.5	129	129	128.5	133	132.5	132.5	133
1.047	59.314				138	135	135	135	139	138.5	138.5	138.5
1.36	67.601				144	142	142	142	144.5	144.5	145	145
1.7	75.580				150	148	148	148	151	150.5	151	151
2.026	82.509				154.5	152.5	152.5	152.5	155	155	155.5	155.5
2.421	90.194				159.5	157.5	157.5	158	160.5	160	160.5	160.5
2.774	96.546				163.5	162	161.5	162	164	164	164	164.5

CALIBRATION OF FLUME AND COMPOUND WEIR COMBINATION
Results of model tests

Model 5 Setup 1
Layout 2, with flume abutment walls shortened to where contraction starts, in 2 m channel with sharp-crested weir length = 1,34 m
(all measurements relative to flume bed)

W =	2	m
L2/2 =	0.67	m
s =	0.066	m
b =	0.264	m
d =	0.132	m
L1 =	0.528	m

H mano (m)	Q mano (l/s)	H (V-notch) (m)	Q (V-notch) (l/s)	% Difference	Gauge point 1 (mm)	Gauge point 2.1 (mm)	Gauge point 2.2 (mm)	Gauge point 2.3 (mm)	Gauge point 3 (mm)	Gauge point 4 (mm)	Gauge point 5 (mm)	Gauge point 6 (mm)
0.013	6.609	0.115	6.251	5.422	57.5	53.5	53.5	53.5	58.5	56.5	57	57
0.038	11.300	0.144	10.967	2.942	80.5	73	74	73	80.5	78.5	79	79.5
0.098	18.147	0.175	17.856	1.599	106	95	97	96	106.5	104	104.5	105
0.156	22.895	0.192	22.514	1.665	121	109	109.5	109	121	119	119	120
0.238	28.279	0.209	27.833	1.577	135.5	120	121.5	121	136.5	134	134	135
0.408	37.026				147.5	134	134	133	147.5	145.5	145.5	146
0.589	44.488				156.5	143	144.5	143	157	154	154.5	155
0.945	56.351				168	158	157.5	158	168	166	166	167
1.238	64.497				174	164.5	164	164.5	174.5	172	172	173
1.673	74.977				182	173.5	173	173.5	182.5	180	180	181
2.23	86.563				190	182.5	182	183	191	188.5	188.5	189.5
2.652	94.399				196	188.5	188	188.5	196.5	194	194.5	195.5

CALIBRATION OF FLUME AND COMPOUND WEIR COMBINATION
Results of model tests

Model 6 Setup 1
Layout 2, with flume abutment walls shortened and wall heads bevelled at 45 degrees, in 2 m channel with sharp-crested weir length = 1,34 m
(all measurements relative to flume bed)

W =	2	m
L2 /2 =	0.67	m
s =	0.066	m
b =	0.264	m
d =	0.132	m
L1 =	0.528	m

H mano (m)	Q mano (l/s)	H (V-notch) (m)	Q (V-notch) (l/s)	% Difference	Gauge point 1 (mm)	Gauge point 2 11 (mm)	Gauge point 2 2 from top (mm)	Gauge point 2 2 with pipe (mm)	Gauge point 2 31 (mm)	Gauge point 3 (mm)	Gauge point 4 (mm)	Gauge point 5 (mm)	Gauge point 6 (mm)
0.015	7.100	0.118	6.667	6.097	60	55.5	56	54	54.5	61	59	59	59
0.058	13.960	0.156	13.397	4.034	91.5	82	83	81.5	82	92	90	90.5	90.5
0.142	21.844	0.187	21.077	3.511	119	104	105.5	105	103	119	117.5	118	118
0.258	29.444	0.212	28.843	2.040	138	118	122	120	118	138.5	136.5	137	137
0.435	38.232				153	142	141.5	140	142	153.5	151	151	151
0.802	51.912				164.5	155	155.5	153	155	165	162.5	162.5	162.5
1.136	61.783				172	164	164.5	162	164	172	170	170	170
1.51	71.231				179	173	172	170	173	179.5	177.5	178	178
1.986	81.691	H mano	Q mano	Q total	187	182	180.5	178	181	187	185	185	185.5
2.57	92.928	(m)	(l/s)	(l/s)	194	189.5	188.5	186	189	195	193	193	193.5
0.592	44.601	0.721	49.221	93.822	196.5	190	191	189	191	197	195	195	195.5
0.775	51.031	0.938	56.141	107.172	205	197	198.5	196.5	199.5	205	203	203.5	203.5
1.108	61.017	1.333	66.926	127.944	215.5	209	209.5	207.5	211	216	214	214.5	214.5
1.754	76.771	2.081	83.622	160.393	230.5	224.5	224.5	222.5	226	231	229.5	230	230

CALIBRATION OF FLUME AND COMPOUND WEIR COMBINATION
Results of model tests

Model 6 Setup 2
Layout 2, with flume abutment walls shortened and wall heads bevelled at 45 degrees, in 2 m channel with sharp-crested weir length = 1.34 m
Sharp-crested weir now at new position at end of trapezoidal section
(all measurements relative to flume bed)

W =	2	m
L2/2 =	0.67	m
s =	0.066	m
b =	0.264	m
d =	0.132	m
L1 =	0.528	m

H mano (m)	Q mano (l/s)	H (V-notch) (m)	Q (V-notch) (l/s)	% Difference	Gauge point 1 (mm)	Gauge point 2.11 (mm)	Gauge point 2.2 from top (mm)	Gauge point 2.2 with pipe (mm)	Gauge point 2.31 (mm)	Gauge point 3 (mm)	Gauge point 4 (mm)	Gauge point 5 (mm)	Gauge point 6 (mm)
0.021	8.400	0.124	7.547	10.161	62.5	59	58	57.5	58.5	63.5	62	62	62.5
0.091	17.486	0.170	16.608	5.023	106.5	95	96.5	94.5	95	107	105.5	105.5	106
0.177	24.388	0.195	23.404	4.034	126	111.5	113.5	112.5	111	128.5	127.5	127.5	126
0.262	29.671	0.213	29.184	1.640	138.5	121.5	123.5	123	120.5	139.5	138	138	138.5
0.495	40.784				153	144.5	144.5	143	144.5	153.5	152	152.5	153
0.854	53.569				165.5	160	160.5	158	160	167	164.5	165	165
1.183	63.048				172.5	169	168.5	166.5	169	173.5	172	172.5	172.5
1.578	72.817				180.5	177.5	176.5	175.5	177.5	181.5	179.5	180	180
2.081	83.622				187.5	185.5	184.5	182.5	185.5	188.5	187	187.5	188
2.625	93.918				194	192	191	189.5	192	195.5	193.5	194	194

CALIBRATION OF FLUME AND COMPOUND WEIR COMBINATION
Results of model tests

Model 6 Setup 3
Layout 2, with flume abutment walls shortened and wall heads bevelled at 45 degrees, in 2 m channel with sharp-crested weir length = 0.67 m
Sharp-crested weir now at new position at end of trapezoidal section and unsymmetrical, with one side completely blocked off
(all measurements relative to flume bed)

W =	2	m
L2/2 =	0.67	m
s =	0.066	m
b =	0.264	m
d =	0.132	m
L1 =	0.528	m

H mano (m)	Q mano (l/s)	H (V-notch) (m)	Q (V-notch) (l/s)	% Difference	Gauge point 1 (mm)	Gauge point 2.11 (mm)	Gauge point 2.2 from top (mm)	Gauge point 2.2 with pipe (mm)	Gauge point 2.31 (mm)	Gauge point 3 (mm)	Gauge point 4 (mm)	Gauge point 5 (mm)	Gauge point 6 (mm)
0.02	8.198	0.122	7.246	11.610	67.5	62.5	63	61	62.5	68.5	67	67	67
0.119	19.997	0.179	18.894	5.512	113.5	100.5	102	100.5	100	114.5	112.5	113	113
0.295	31.484	0.218	30.927	1.769	143	126	129.5	128	126.5	143.5	142	142	142.5
0.59	44.525				163	156.5	157	156	157.5	163.5	162	162.5	163
0.945	56.351				177.5	172	173	171	174	178	176.5	176.5	176.5
1.394	68.441				190	186.5	186	184	187	189.5	189	189	189
1.809	77.965				199	195.5	195.5	193.5	196	199	198	198	198
2.264	87.221				207	203.5	203.5	201	204	206	206	206	206
2.638	94.150				213	209	209	207	209.5	212	212	212	211.5

CALIBRATION OF FLUME AND COMPOUND WEIR COMBINATION
Results of model tests

Model 7 Setup 1
Layout 1, with flume abutment walls shortened and wall heads bevelled at 45 degrees, in 2 m channel with sharp crested weir length = 1,52 m
Sharp-crested weir now at new position at end of trapezoidal section
(all measurements relative to flume bed)

W =	2	m
L2/2 =	0 76	m
s =	0 066	m
b =	0 174	m
d =	0 174	m
L1 =	0 348	m

H mano (m)	Q mano (l/s)	H (V-notch) (m)	Q (V-notch) (l/s)	% Difference	Gauge point 1 (mm)	Gauge point 2 11 (mm)	Gauge point 2 2 from top (mm)	Gauge point 2 2 with pipe (mm)	Gauge point 2 31 (mm)	Gauge point 3 (mm)	Gauge point 4 (mm)	Gauge point 5 (mm)	Gauge point 6 (mm)
0 012	6 350	0 112	5 851	7 855	74 5	70	69	68	69 5	75 5	73 5	74	74
0 034	10 689	0 139	10 040	6 068	102 5	94 5	93 5	92 5	93 5	103	101 5	101 5	101 5
0 097	18 054	0 171	16 854	6 648	139	126 5	125 5	124 5	126	139 5	138 5	138 5	139
0 166	23 618	0 192	22 514	4 673	162 5	144 5	141 5	140 5	144 5	163 5	161 5	161 5	162
0 236	28 160	0 208	27 502	2 339	177 5	157	150 5	148 5	156 5	178 5	176 5	177	177 5
0 415	37 343				190	175 5	173 5	171 5	174 5	190 5	188 5	189	189 5
0 68	47 801				201 5	192 5	193 5	191 5	192 5	202 5	200 5	201	201
0 986	57 560				210 5	203	204 5	202 5	202 5	210 5	209	209 5	209 5
1 394	68 441				219	214	214 5	212 5	213 5	219 5	218	218 5	218 5
1 938	80 697				228	224	223 5	221	223 5	228 5	227	227	227 5
2 611	93 667				236 5	233 5	233	231	232 5	237	235 5	235 5	236

CALIBRATION OF FLUME AND COMPOUND WEIR COMBINATION
Results of model tests

Model 8 Setup 1
Layout 3, with flume abutment walls shortened and wall heads bevelled at 45 degrees, in 2 m channel with sharp-crested weir length = 1,146 m
Sharp-crested weir now at new position at end of trapezoidal section
(all measurements relative to flume bed)

W =	2	m
L2/2 =	0.573	m
s =	0.066	m
b =	0.412	m
d =	0.103	m
L1 =	0.722	m

H mano (m)	Q mano (l/s)	H (V-notch) (m)	Q (V-notch) (l/s)	% Difference	Gauge point 1 (mm)	Gauge point 2.11 (mm)	Gauge point 2.2 from top (mm)	Gauge point 2.2 with pipe (mm)	Gauge point 2.31 (mm)	Gauge point 3 (mm)	Gauge point 4 (mm)	Gauge point 5 (mm)	Gauge point 6 (mm)
0.0205	8.300	0.126	7.855	5.362	52	46.5	48	47	46	53	51.5	52	52
0.066	14.892	0.161	14.497	2.656	73.5	62	66.5	65	62	74.5	72.5	72.5	73
0.116	19.743	0.180	19.159	2.956	89.5	74.5	80	79	73.5	90	88.5	88.5	89
0.204	26.182	0.203	25.879	1.158	101	83	89.5	88.5	81	102	100	100	100.5
0.31	32.275				111	93	100	99	92.5	111.5	110	110	110.5
0.453	39.015				119	108	110.5	109.5	107	119.5	117.5	117.5	118
0.726	49.391				128.5	122	122	121	121.5	129	127.5	127.5	128
1.047	59.314				136.5	132	131.5	130	132	138	135.5	136	136
1.462	70.090				144.5	141	140	139	141	145.5	144	144	145
2.026	82.509				153	150	149	147.5	150	154	152.5	152.5	153
2.679	94.879				160	158	157	155	157.5	161.5	160	160	160.5

APPENDIX
5.1

ANALYSIS OF CALIBRATION RESULTS

CALIBRATION OF FLUME AND COMPOUND WEIR SETUP
Analysis of test results

Model 1 Setup 1
Layout 2, with long flume abutment walls, in 3 m channel with sharp-crested weir length = 2,34 m
(all stage measurements relative to bottom of flume)

W =	3	m
L2/2 =	1.17	m
s =	0.066	m
b =	0.264	m
d =	0.132	m
L1 =	0.528	m

Y2 (m)	Es2 / Es5 (m)	Es min (m)	H (m)	Yc (m)	Bc (m)	Ac (m2)	Q flume th (m3/s)	Q flume real (m3/s)	Cd	Q weir (m3/s)	Q total (m3/s)	Q mano (m3/s)	% Difference	Delta Es (m)
0.066	0.0697	0.0697		0.0486	0.3613	0.0152	0.0098	0.0094	0.959		0.0094	0.0094	0.258	-5.97E-10
0.0795	0.0842	0.0842		0.0592	0.3824	0.0191	0.0134	0.0128	0.954		0.0129	0.0128	0.794	1.307E-10
0.0885	0.0941	0.0941		0.0665	0.3969	0.0220	0.0162	0.0155	0.959		0.0156	0.0155	0.281	3.496E-10
0.1	0.1068	0.1068		0.0758	0.4156	0.0258	0.0201	0.0193	0.961		0.0193	0.0193	0.040	2.738E-09
0.113	0.1216	0.1216		0.0868	0.4376	0.0305	0.0252	0.0245	0.974		0.0242	0.0245	-1.347	2.02E-09
0.1225	0.1364	0.1364	0.004	0.0979	0.4598	0.0354	0.0308	0.0285	0.927	0.0013	0.0300	0.0298	0.475	1.047E-08
0.1395	0.1476	0.1476	0.016	0.1063	0.4766	0.0394	0.0354	0.0330	0.931	0.0085	0.0415	0.0415	0.047	-2.06E-08
0.1495	0.1541	0.1541	0.022	0.1112	0.4864	0.0417	0.0383	0.0352	0.921	0.0143	0.0499	0.0495	0.818	-1.33E-08
0.155	0.1591	0.1591	0.027	0.1150	0.4939	0.0436	0.0405	0.0373	0.920	0.0194	0.0571	0.0567	0.833	-5.92E-08
0.161	0.1649	0.1649	0.033	0.1194	0.5028	0.0458	0.0433	0.0404	0.935	0.0261	0.0664	0.0665	-0.228	-7.55E-08
0.1705	0.1739	0.1739	0.042	0.1336	0.6600	0.0533	0.0474	0.0441	0.931	0.0375	0.0817	0.0817	0.036	-1.1E-08
0.1825	0.1850	0.1850	0.053	0.1409	0.6600	0.0582	0.0541	0.0514	0.950	0.0535	0.1039	0.1049	-0.956	-3.96E-08
0.201	0.2051	0.2051	0.073	0.1543	0.6600	0.0670	0.0669	0.0624	0.933	0.0870	0.1493	0.1493	-0.061	1.943E-16

Cd2 =	0.961
Cd5 =	0.931

CALIBRATION OF FLUME AND COMPOUND WEIR SETUP
Analysis of test results

Model 1 Setup 2
Layout 2, with long flume abutment walls, in 3 m channel with sharp-crested weir length = 0.8 m
(all stage measurements relative to bottom of flume)

W =	3	m
L2/2 =	0.4	m
s =	0.066	m
b =	0.264	m
d =	0.132	m
L1 =	0.528	m

Y2 (m)	Es 2 / Es5 (m)	Es min (m)	H (m)	Yc (m)	Bc (m)	Ac (m2)	Q flume th (m3/s)	Q flume real (m3/s)	Cd	Q weir (m3/s)	Qtotal (m3/s)	Q mano (m3/s)	% Differenc	Delta Es
0.0715	0.0754	0.0754		0.0528	0.3696	0.0167	0.0111	0.0104	0.934		0.0106	0.0104	2.026	-3.69E-09
0.0845	0.0898	0.0898		0.0633	0.3905	0.0207	0.0149	0.0143	0.958		0.0142	0.0143	-0.504	-4.26E-09
0.0986	0.1047	0.1047		0.0743	0.4126	0.0251	0.0194	0.0180	0.928		0.0185	0.0180	2.719	-1.16E-10
0.1011	0.1080	0.1080		0.0767	0.4174	0.0261	0.0205	0.0196	0.958		0.0195	0.0196	-0.505	-7.74E-10
0.1113	0.1200	0.1200		0.0856	0.4352	0.0299	0.0246	0.0243	0.987		0.0234	0.0243	-3.493	1.21E-09
0.1181	0.1332	0.1332	0.0012	0.0955	0.4550	0.0343	0.0295	0.0272	0.922	0.0001	0.0265	0.0273	-3.0487	-1.24E-07
0.1236	0.1391	0.1391	0.0071	0.0999	0.4638	0.0364	0.0319	0.0291	0.914	0.0009	0.0294	0.0300	-2.1611	-2.96E-08
0.1310	0.1440	0.1440	0.0120	0.1036	0.4711	0.0381	0.0339	0.0313	0.924	0.0019	0.0322	0.0333	-3.0904	-1.25E-07
0.1406	0.1491	0.1491	0.0171	0.1075	0.4789	0.0399	0.0361	0.0330	0.915	0.0033	0.0356	0.0364	-2.0883	-3.01E-08
0.1675	0.1710	0.1710	0.0390	0.1240	0.5120	0.0481	0.0462	0.0423	0.916	0.0115	0.0528	0.0538	-1.9146	-9.11E-08
0.1821	0.1850	0.1850	0.0530	0.1409	0.6600	0.0581	0.0541	0.0474	0.878	0.0183	0.0666	0.0657	1.3441	8.33E-17
0.1986	0.2017	0.2017	0.0697	0.1520	0.6600	0.0655	0.0646	0.0554	0.858	0.0276	0.0854	0.0831	2.8230	-7.99E-15
0.2173	0.2210	0.2210	0.0890	0.1649	0.6600	0.0740	0.0776	0.0662	0.854	0.0401	0.1094	0.1063	2.9342	-2.47E-07
0.2465	0.2512	0.2512	0.1192	0.1851	0.6600	0.0873	0.0995	0.0860	0.864	0.0626	0.1515	0.1485	1.9680	1.93E-14

Cd2 =	0.953
Cd5 =	0.894

CALIBRATION OF FLUME AND COMPOUND WEIR COMBINATION
Analysis of test results

Model 1 Setup 3
Layout 2, with long flume abutment walls, in 2 m channel with sharp-crested weir length = 1,34
(all measurements relative to flume bed)

W =	2	m
L2/2 =	0.67	m
s =	0.066	m
b =	0.264	m
d =	0.132	m
L1 =	0.528	m

Y2 (m)	Es 2 / Es5 (m)	Es min (m)	H (m)	Yc (m)	Bc (m)	Ac (m2)	Q flume th. (m3/s)	Q flume real (m3/s)	Cd	Q weir (m3/s)	Q total (m3/s)	Q mano (m3/s)	% Difference	Delta Es (m)
0.0610	0.0640	0.0640		0.0445	0.3530	0.0137	0.0085	0.0078	0.917		0.0079	0.0078	1.466	4.49E-09
0.0835	0.0882	0.0882		0.0621	0.3882	0.0202	0.0145	0.0133	0.921		0.0135	0.0133	0.929	-3.63E-10
0.1050	0.1122	0.1122		0.0798	0.4236	0.0274	0.0219	0.0208	0.952		0.0203	0.0208	-2.311	-3.75E-09
0.1250	0.1377	0.1377	0.0057	0.0989	0.4617	0.0359	0.0313	0.0270	0.8629	0.0011	0.0271	0.0281	3.6290	1.2E-11
0.1475	0.1543	0.1543	0.0223	0.1114	0.4867	0.0418	0.0384	0.0313	0.8154	0.0083	0.0401	0.0396	-1.4553	2.09E-11
0.1525	0.1581	0.1581	0.0261	0.1142	0.4924	0.0432	0.0401	0.0338	0.8442	0.0105	0.0438	0.0443	1.2490	2.77E-11
0.1600	0.1646	0.1646	0.0326	0.1191	0.5023	0.0457	0.0431	0.0361	0.8364	0.0147	0.0505	0.0507	0.5100	3.53E-11
0.1630	0.1675	0.1675	0.0355	0.1214	0.5067	0.0468	0.0445	0.0370	0.8306	0.0167	0.0537	0.0537	0.0199	3.88E-11
0.1700	0.1736	0.1736	0.0416	0.1260	0.5159	0.0491	0.0475	0.0400	0.8427	0.0212	0.0606	0.0612	0.9606	5.03E-11
0.1760	0.1799	0.1799	0.0479	0.1308	0.5256	0.0516	0.0507	0.0423	0.8344	0.0263	0.0684	0.0686	0.2974	6.06E-11
0.1780	0.1825	0.1825	0.0505	0.1393	0.6600	0.0571	0.0526	0.0431	0.8195	0.0284	0.0721	0.0715	-0.7994	-2.78E-17
0.1835	0.1876	0.1876	0.0556	0.1427	0.6600	0.0593	0.0557	0.0458	0.8229	0.0329	0.0791	0.0787	-0.5313	5.09E-10
0.1860	0.1902	0.1902	0.0582	0.1444	0.6600	0.0605	0.0573	0.0472	0.8238	0.0352	0.0828	0.0825	-0.4588	-5.55E-17
0.1890	0.1932	0.1932	0.0612	0.1464	0.6600	0.0618	0.0592	0.0488	0.8247	0.0380	0.0872	0.0868	-0.3871	5.72E-10
0.1955	0.1999	0.1999	0.0679	0.1508	0.6600	0.0647	0.0635	0.0512	0.8070	0.0444	0.0971	0.0956	-1.5502	-8.33E-17

Cd2 =	0.9300
Cd5 =	0.8304

CALIBRATION OF FLUME AND COMPOUND WEIR SETUP
Analysis of test results

Model 2 Setup 1
Layout 2, with long narrow flume abutment walls, in 2 m channel with sharp-crested weir length = 1,426 m.
(all stage measurements relative to flume bed)

W =	2	m
L2/2 =	0.713	m
s =	0.023	m
b =	0.264	m
d =	0.132	m
L1 =	0.528	m

Y2 (m)	Es 2 / Es5 (m)	Es min (m)	H (m)	Yc (m)	Bc (m)	Ac (m)	Q flume th (m3/s)	Q flume real (m3/s)	Cd	Q weir (m3/s)	Q total (m3/s)	Q mano (m3/s)	% Difference	Delta Es (m)
0.0465	0.0488	0.0488		0.0337	0.3313	0.0100	0.0055	0.0052	0.950		0.0055	0.0052	6.945	-7.46E-09
0.0580	0.0617	0.0617		0.0429	0.3497	0.0131	0.0080	0.0082	1.027		0.0081	0.0082	-0.993	-7.94E-09
0.0740	0.0787	0.0787		0.0552	0.3744	0.0176	0.0120	0.0119	0.993		0.0122	0.0119	2.381	-6.22E-10
0.0758	0.0811	0.0811		0.0569	0.3778	0.0183	0.0126	0.0128	1.021		0.0128	0.0128	-0.413	-7.08E-09
0.0853	0.0919	0.0919		0.0648	0.3936	0.0213	0.0155	0.0161	1.039		0.0158	0.0161	-2.206	-9E-09
0.0912	0.0982	0.0982		0.0694	0.4029	0.0232	0.0174	0.0179	1.027		0.0177	0.0179	-1.083	2.162E-08
0.0980	0.1057	0.1057		0.0750	0.4140	0.0254	0.0197	0.0201	1.018		0.0200	0.0201	-0.169	-5.5E-10
0.1100	0.1203	0.1203		0.0858	0.4356	0.0300	0.0247	0.0261	1.056		0.0251	0.0261	-3.737	8.987E-10
0.1128	0.1363	0.1363	0.0043	0.0978	0.4597	0.0354	0.0308	0.0264	0.8590	0.0008	0.0273	0.0272	0.3511	-6.39E-08
0.1510	0.1563	0.1563	0.0243	0.1129	0.4898	0.0425	0.0393	0.0334	0.8508	0.0101	0.0439	0.0435	1.0209	-5.14E-08
0.1733	0.1774	0.1774	0.0454	0.1289	0.5217	0.0506	0.0494	0.0418	0.8465	0.0258	0.0684	0.0676	1.1408	-1.06E-07
0.1787	0.1831	0.1831	0.0511	0.1396	0.6600	0.0573	0.0529	0.0448	0.8465	0.0308	0.0764	0.0756	1.0930	1.36E-15
0.1877	0.1928	0.1928	0.0608	0.1461	0.6600	0.0616	0.0590	0.0518	0.8789	0.0401	0.0910	0.0919	-1.0769	-2.19E-07
0.1965	0.2030	0.2030	0.0710	0.1529	0.6600	0.0661	0.0655	0.0517	0.7901	0.0507	0.1071	0.1024	4.6020	-2.29E-07
0.2039	0.2096	0.2096	0.0776	0.1573	0.6600	0.0690	0.0699	0.0565	0.8084	0.0581	0.1183	0.1145	3.2791	-2.08E-15
0.2143	0.2215	0.2215	0.0895	0.1653	0.6600	0.0742	0.0780	0.0754	0.9677	0.0721	0.1393	0.1475	-5.5784	-4.86E-15
0.2255	0.2335	0.2335	0.1015	0.1733	0.6600	0.0795	0.0865	0.0772	0.8934	0.0873	0.1619	0.1646	-1.6443	-2.6E-07
0.2462	0.2569	0.2569	0.1249	0.1889	0.6600	0.0898	0.1038	0.0913	0.8798	0.1197	0.2092	0.2110	-0.8718	1.588E-14

Cd2 =	1.0163
Cd5 =	0.8621

CALIBRATION OF FLUME AND COMPOUND WEIR COMBINATION
Analysis of test results

Model 2 Setup 2
Layout 2, with long thick flume abutment walls, in 2 m channel with sharp-crested weir length = 1,262 m.
(all stage measurements relative to flume bed)

W =	2	m
L2/2 =	0.631	m
s =	0.105	m
b =	0.264	m
d =	0.132	m
L1 =	0.528	m

Y2 (m)	Es2 / Es5 (m)	Es min (m)	H (m)	Yc (m)	Bc (m)	Ac (m2)	Q flume th. (m)	Q flume real (m3/s)	Cd	Q weir (m3/s)	Q total (m3/s)	Q mano (m3/s)	% Difference	Delta Es (m)
0.0487	0.0510	0.0510		0.0352	0.3345	0.0105	0.0059	0.0055	0.938		0.0054	0.0055	-1.047	-5.42E-09
0.0778	0.0820	0.0820		0.0576	0.3792	0.0185	0.0128	0.0119	0.926		0.0119	0.0119	0.185	2.049E-09
0.0933	0.0988	0.0988		0.0699	0.4039	0.0233	0.0176	0.0162	0.921		0.0163	0.0162	0.798	-7.11E-10
0.1053	0.1121	0.1121		0.0797	0.4235	0.0274	0.0218	0.0202	0.927		0.0203	0.0202	0.081	-5.52E-10
0.1275	0.1392	0.1392	0.0072	0.1000	0.4639	0.0364	0.0319	0.0266	0.8320	0.0014	0.0300	0.0280	7.3012	-8.7E-08
0.1483	0.1554	0.1554	0.0234	0.1122	0.4884	0.0422	0.0389	0.0332	0.8536	0.0084	0.0432	0.0416	3.9656	-4.87E-08
0.1742	0.1784	0.1784	0.0464	0.1297	0.5233	0.0510	0.0499	0.0452	0.9049	0.0236	0.0684	0.0688	-0.6439	-1.08E-07
0.1879	0.1924	0.1924	0.0604	0.1458	0.6600	0.0614	0.0587	0.0522	0.8891	0.0351	0.0877	0.0873	0.4656	-8.33E-09
0.2042	0.2109	0.2109	0.0789	0.1582	0.6600	0.0695	0.0707	0.0659	0.9320	0.0526	0.1160	0.1185	-2.1442	-2.37E-07
0.2242	0.2329	0.2329	0.1009	0.1729	0.6600	0.0793	0.0860	0.0830	0.9646	0.0765	0.1536	0.1595	-3.6968	-2.59E-07

Cd2 =	0.9280
Cd5 =	0.8960

CALIBRATION OF FLUME AND COMPOUND WEIR COMBINATION
Analysis of test results

Model 2 Setup 3
Layout 2, with long thick abutment walls, in 2 m channel with Crump weir length = 1,262 m
(all stage measurements relative to flume bed)

W =	2	m
L2/2 =	0.631	m
s =	0.105	m
b =	0.264	m
d =	0.132	m
L1 =	0.528	m

Y2 (m)	Es 2 / Es 5 (m)	Es min (m)	H (m)	Yc (m)	Bc (m)	Ac (m2)	Q flume th (m3/s)	Q flume real (m3/s)	Cd	Q Crump (m3/s)	Q total (m3/s)	Q mano (m3/s)	% Difference	Delta Es (m)
0.0491	0.0514	0.0514		0.0355	0.3351	0.0106	0.0059	0.0055	0.925		0.0055	0.0055	0.012	-4.95E-09
0.0813	0.0858	0.0858		0.0603	0.3847	0.0196	0.0138	0.0127	0.918		0.0128	0.0127	0.778	-1.31E-09
0.0922	0.0977	0.0977		0.0691	0.4021	0.0230	0.0172	0.0160	0.927		0.0159	0.0160	-0.213	-2.11E-09
0.1060	0.1129	0.1129		0.0803	0.4246	0.0277	0.0221	0.0206	0.931		0.0205	0.0206	-0.567	-3.12E-09
0.1248	0.1366	0.1366	0.0046	0.0981	0.4601	0.0355	0.0309	0.0274	0.8884	0.0007	0.0276	0.0282	-2.0174	-5.76E-08
0.1533	0.1588	0.1588	0.0268	0.1148	0.4936	0.0435	0.0404	0.0333	0.8247	0.0108	0.0460	0.0441	4.1466	-5.86E-08
0.1742	0.1790	0.1790	0.0470	0.1301	0.5242	0.0513	0.0502	0.0420	0.8364	0.0253	0.0689	0.0673	2.5095	-1.09E-07
0.1878	0.1925	0.1925	0.0605	0.1459	0.6600	0.0615	0.0588	0.0499	0.8485	0.0370	0.0881	0.0868	1.4562	-2.19E-07
0.2058	0.2116	0.2116	0.0796	0.1587	0.6600	0.0699	0.0712	0.0616	0.8651	0.0559	0.1178	0.1174	0.2991	-2.38E-07
0.2207	0.2288	0.2288	0.0968	0.1701	0.6600	0.0774	0.0831	0.0735	0.8840	0.0750	0.1473	0.1485	-0.7844	-2.55E-07
0.2307	0.2398	0.2398	0.1078	0.1775	0.6600	0.0823	0.0910	0.0819	0.9005	0.0882	0.1673	0.1701	-1.6326	-7.44E-15
0.2485	0.2600	0.2600	0.1280	0.1909	0.6600	0.0912	0.1061	0.0968	0.9124	0.1142	0.2065	0.2110	-2.1332	-2.86E-07

Cd2 =	0.9255
Cd5 =	0.8700

CALIBRATION OF FLUME AND COMPOUND WEIR COMBINATION
Analysis of test results

Model 3 Setup 1
Layout 1, with long flume abutment walls, in 2 m channel witjh sharp-crested weir length = 1,52 m.
(all stage measurements relative to flume bed)

W =	2	m
L2/2 =	0.76	m
s =	0.066	m
b =	0.174	m
d =	0.174	m
L1 =	0.348	m

Y2 (m)	Es 2 / Es 5 (m)	Es min (m)	H (m)	Yc (m)	Bc (m)	Ac (m2)	Q flume th (m3/s)	Q flume real (m3/s)	Cd	Q weir (m3/s)	Q total (m3/s)	Q mano (m3/s)	% Difference	Delta Es (m)
0.0807	0.0846	0.0846		0.0589	0.2329	0.0120	0.0085	0.0078	0.9143		0.0079	0.0078	1.8871	-2.01E-10
0.1162	0.1229	0.1229		0.0867	0.2607	0.0189	0.0159	0.0147	0.9237		0.0148	0.0147	0.8512	-1.97E-09
0.1512	0.1622	0.1622		0.1159	0.2899	0.0269	0.0256	0.0245	0.9567		0.0239	0.0245	-2.6253	-7.04E-10
0.1660	0.1808	0.1808	0.0068	0.1297	0.3037	0.0310	0.0310	0.0283	0.9116	0.0016	0.0292	0.0298	-2.3086	-8.72E-09
0.1915	0.1987	0.1987	0.0247	0.1432	0.3172	0.0352	0.0367	0.0326	0.8888	0.0110	0.0436	0.0436	0.0540	-6.65E-09
0.2032	0.2072	0.2072	0.0332	0.1496	0.3236	0.0372	0.0396	0.0356	0.8995	0.0172	0.0524	0.0528	-0.7527	-6.85E-09
0.2145	0.2176	0.2176	0.0436	0.1575	0.3315	0.0398	0.0432	0.0389	0.9008	0.0261	0.0645	0.0650	-0.7597	-5.7E-09
0.2215	0.2245	0.2245	0.0505	0.1627	0.3367	0.0416	0.0457	0.0410	0.8972	0.0326	0.0732	0.0736	-0.4865	-5.17E-08
0.2295	0.2322	0.2322	0.0582	0.1686	0.3426	0.0436	0.0486	0.0429	0.8816	0.0405	0.0837	0.0833	0.4578	-2.42E-08
0.2390	0.2420	0.2420	0.0680	0.1878	0.4800	0.0520	0.0537	0.0454	0.8464	0.0514	0.0991	0.0968	2.3867	-1.75E-08

Cd2 =	0.9316
Cd5 =	0.8894

CALIBRATION OF FLUME AND COMPOUND WEIR COMBINATION
Analysis of test results

Model 4 Setup 1
Layout 3, with long flume abutment walls, in 2 m channel with sharp-crested weir length = 1,146 m.
(all stage measurements relative to bottom of flume)

W =	2	m
L2/2 =	0.573	m
s =	0.066	m
b =	0.412	m
d =	0.103	m
L1 =	0.722	m

Y2 (m)	Es 2 / Es 5 (m)	Es min (m)	H (m)	Yc (m)	Bc (m)	Ac (m2)	Q flume th. (m3/s)	Q flume real (m3/s)	Cd	Q weir (m3/s)	Q total (m3/s)	Q mano (m3/s)	% Difference	Delta Es (m)
0.0472	0.0500	0.0500		0.0345	0.5154	0.0160	0.0088	0.0080	0.9062		0.0083	0.0080	4.1643	-6.25E-09
0.0593	0.0634	0.0634		0.0440	0.5441	0.0210	0.0130	0.0120	0.9274		0.0122	0.0120	1.7821	-5.56E-09
0.0673	0.0722	0.0722		0.0504	0.5632	0.0246	0.0161	0.0150	0.9335		0.0152	0.0150	1.1129	-4.76E-09
0.0773	0.0838	0.0838		0.0588	0.5885	0.0294	0.0206	0.0199	0.9660		0.0195	0.0199	-2.2887	-3.08E-09
0.0880	0.0964	0.0964		0.0680	0.6160	0.0350	0.0261	0.0257	0.9865		0.0246	0.0257	-4.3127	-2.39E-09
0.0913	0.1054	0.1054	0.0024	0.0747	0.6360	0.0391	0.0304	0.0277	0.9103	0.0003	0.0269	0.0279	-3.8186	-2.57E-08
0.1020	0.1127	0.1127	0.0097	0.0801	0.6522	0.0426	0.0341	0.0305	0.8943	0.0020	0.0319	0.0325	-2.0012	-3.99E-11
0.1163	0.1233	0.1233	0.0203	0.0879	0.6757	0.0478	0.0398	0.0342	0.8578	0.0062	0.0410	0.0403	1.7248	5.741E-09
0.1288	0.1340	0.1340	0.0310	0.0959	0.6997	0.0533	0.0461	0.0396	0.8589	0.0117	0.0520	0.0513	1.4714	3.975E-10
0.1350	0.1402	0.1402	0.0372	0.1050	0.8530	0.0600	0.0499	0.0440	0.8814	0.0153	0.0590	0.0593	-0.5216	1.018E-07
0.1420	0.1469	0.1469	0.0439	0.1094	0.8530	0.0638	0.0547	0.0479	0.8762	0.0197	0.0676	0.0676	-0.0744	-9.27E-15
0.1480	0.1532	0.1532	0.0502	0.1137	0.8530	0.0674	0.0594	0.0515	0.8664	0.0241	0.0761	0.0756	0.6992	-1.7E-07
0.1525	0.1580	0.1580	0.0550	0.1169	0.8530	0.0702	0.0630	0.0548	0.8693	0.0277	0.0829	0.0825	0.4580	-1.75E-07
0.1577	0.1634	0.1634	0.0604	0.1204	0.8530	0.0732	0.0672	0.0583	0.8678	0.0319	0.0907	0.0902	0.5512	1.665E-16
0.1618	0.1675	0.1675	0.0645	0.1232	0.8530	0.0756	0.0705	0.0613	0.8701	0.0352	0.0969	0.0965	0.3779	-6E-15

Cd2 =	0.9439
Cd5 =	0.8752

CALIBRATION OF FLUME AND COMPOUND WEIR COMBINATION
Analysis of test results

Model 5 Setup 1
Layout 2, with flume abutment walls shortened to where contraction starts, in 2 m channel with sharp-crested weir length = 1,34 m.
(all measurements relative to flume bed)

W =	2	m
L2/2 =	0.67	m
s =	0.066	m
b =	0.264	m
d =	0.132	m
L1 =	0.528	m

Y2 (m)	Es 2 / Es 5 (m)	Es min (m)	H (m)	Yc (m)	Bc (m)	Ac (m2)	Q flume th (m3/s)	Q flume real (m3/s)	Cd	Q weir (m3/s)	Q total (m3/s)	Q mano (m3/s)	% Difference	Delta Es (m)
0.0535	0.0563	0.0563		0.0390	0.3420	0.0118	0.0069	0.0066	0.960		0.0066	0.0066	-0.163	4.33E-09
0.0740	0.0783	0.0783		0.0549	0.3737	0.0175	0.0119	0.0113	0.953		0.0114	0.0113	0.567	5.95E-09
0.0970	0.1034	0.1034		0.0733	0.4106	0.0247	0.0190	0.0181	0.955		0.0182	0.0181	0.378	-3.38E-09
0.1095	0.1175	0.1175		0.0837	0.4315	0.0291	0.0237	0.0229	0.966		0.0227	0.0229	-0.771	-5.72E-09
0.1215	0.1347	0.1347	0.0027	0.0966	0.4573	0.0348	0.0301	0.0279	0.9268	0.0004	0.0275	0.0283	2.5921	-5.47E-10
0.1340	0.1463	0.1463	0.0143	0.1053	0.4746	0.0389	0.0349	0.0328	0.9405	0.0042	0.0357	0.0370	3.5798	1.08E-08
0.1445	0.1553	0.1553	0.0233	0.1121	0.4882	0.0422	0.0388	0.0356	0.9183	0.0089	0.0439	0.0445	1.3817	4.9E-09
0.1575	0.1674	0.1674	0.0354	0.1213	0.5066	0.0467	0.0445	0.0397	0.8926	0.0167	0.0568	0.0564	-0.7767	1.48E-12
0.1640	0.1737	0.1737	0.0417	0.1261	0.5161	0.0492	0.0475	0.0432	0.9091	0.0213	0.0642	0.0645	0.4893	-6.37E-12
0.1730	0.1820	0.1820	0.0500	0.1390	0.6600	0.0569	0.0523	0.0470	0.8983	0.0280	0.0752	0.0750	-0.2905	-9.82E-09
0.1820	0.1909	0.1909	0.0589	0.1449	0.6600	0.0608	0.0578	0.0507	0.8777	0.0359	0.0880	0.0866	-1.6511	3.68E-08
0.1880	0.1970	0.1970	0.0650	0.1489	0.6600	0.0635	0.0616	0.0528	0.8564	0.0416	0.0972	0.0944	-3.0078	-9.41E-09

Cd2 =	0.9587
Cd5 =	0.9024

CALIBRATION OF FLUME AND COMPOUND WEIR COMBINATION
Analysis of test results

Model 6 Setup 1
Layout 2, with flume abutment walls shortened and wall heads bevelled at 45 degrees, in 2 m channel with sharp-crested weir length = 1,34 m.
(all measurements relative to flume bed)

W =	2	m
L2/2 =	0.67	m
s =	0.066	m
b =	0.264	m
d =	0.132	m
L1 =	0.528	m

Y2 (m)	Es2 / Es 5 (m)	Es min (m)	H (m)	Yc (m)	Bc (m)	Ac (m2)	Q flume th. (m3/s)	Q flume real (m3/s)	Cd	Q weir (m3/s)	Q total (m3/s)	Q mano (m3/s)	% Differenc	Delta Es (m)
0.0550	0.0580	0.0580		0.0403	0.3445	0.0123	0.0072	0.0071	0.981		0.0072	0.0071	0.857	-3.69E-10
0.0820	0.0873	0.0873		0.0615	0.3869	0.0200	0.0142	0.0140	0.980		0.0141	0.0140	0.950	-1.96E-09
0.1035	0.1116	0.1116		0.0794	0.4228	0.0273	0.0217	0.0218	1.007		0.0215	0.0218	-1.760	-1E-08
0.1180	0.1373	0.1373	0.0053	0.0985	0.4610	0.0357	0.0311	0.0285	0.9153	0.0009	0.0282	0.0294	4.2093	-3.76E-10
0.1420	0.1516	0.1516	0.0196	0.1093	0.4826	0.0408	0.0372	0.0314	0.8447	0.0068	0.0394	0.0382	-2.9896	-2.52E-10
0.1550	0.1635	0.1635	0.0315	0.1183	0.5006	0.0452	0.0426	0.0380	0.8919	0.0139	0.0512	0.0519	1.3497	-1.89E-10
0.1640	0.1713	0.1713	0.0393	0.1242	0.5124	0.0482	0.0463	0.0423	0.9135	0.0195	0.0600	0.0618	2.8533	-1.21E-08
0.1730	0.1794	0.1794	0.0474	0.1304	0.5246	0.0514	0.0504	0.0454	0.9003	0.0258	0.0700	0.0712	1.7588	-7.83E-09
0.1815	0.1871	0.1871	0.0551	0.1423	0.6600	0.0591	0.0554	0.0493	0.8900	0.0324	0.0809	0.0817	0.9869	-9.1E-09
0.1893	0.1955	0.1955	0.0635	0.1479	0.6600	0.0628	0.0606	0.0528	0.8705	0.0401	0.0932	0.0929	-0.3258	-1.34E-08
0.1905	0.1975	0.1975	0.0655	0.1493	0.6600	0.0637	0.0619	0.0518	0.8357	0.0421	0.0963	0.0938	-2.6219	2.14E-15
0.1983	0.2061	0.2061	0.0741	0.1550	0.6600	0.0675	0.0676	0.0564	0.8349	0.0508	0.1099	0.1072	-2.5604	-2.33E-07
0.2100	0.2180	0.2180	0.0860	0.1629	0.6600	0.0727	0.0755	0.0644	0.8528	0.0635	0.1297	0.1279	-1.3393	-1.39E-16
0.2253	0.2349	0.2349	0.1029	0.1742	0.6600	0.0801	0.0874	0.0770	0.8805	0.0834	0.1600	0.1604	0.2758	-2.61E-07

Cd2 =	0.9895
Cd5 =	0.8755

CALIBRATION OF FLUME AND COMPOUND WEIR COMBINATION
Analysis of test results

Model 6 Setup 2
Layout 2, with flume abutment walls shortened and wall heads bevelled at 45 degrees, in 2 m channel with sharp-crested weir length = 1,34 m.
Sharp-crested weir now at new position at end of trapezoidal section
(all measurements relative to flume bed)

W =	2	m
L2/2 =	0.67	m
s =	0.066	m
b =	0.264	m
d =	0.132	m
L1 =	0.528	m

Y2 (m)	Es 2 / Es 5 (m)	Es min (m)	H (m)	Yc (m)	Bc (m)	Ac (m2)	Q flume th. (m3/s)	Q flume real (m3/s)	Cd	Q weir (m3/s)	Q total (m3/s)	Q mano (m3/s)	% Differenc	Delta Es (m)
0.0588	0.0625	0.0625		0.0435	0.3509	0.0134	0.0082	0.0084	1.029		0.0081	0.0084	-3.606	-3.03E-09
0.0950	0.1012	0.1012		0.0717	0.4073	0.0241	0.0183	0.0175	0.955		0.0182	0.0175	3.850	-3.06E-10
0.1113	0.1200	0.1200		0.0856	0.4353	0.0299	0.0246	0.0244	0.991		0.0244	0.0244	0.034	-6.72E-09
0.1210	0.1386	0.1386	0.0066	0.0995	0.4630	0.0362	0.0317	0.0283	0.8948	0.0013	0.0291	0.0297	2.0159	-7.25E-10
0.1445	0.1532	0.1532	0.0212	0.1105	0.4850	0.0414	0.0379	0.0331	0.8744	0.0077	0.0408	0.0408	-0.1411	-8.46E-10
0.1600	0.1658	0.1658	0.0338	0.1201	0.5042	0.0461	0.0437	0.0380	0.8700	0.0155	0.0538	0.0536	-0.4848	-1.5E-09
0.1690	0.1736	0.1736	0.0416	0.1260	0.5160	0.0491	0.0475	0.0418	0.8801	0.0212	0.0628	0.0630	0.3153	-1.39E-09
0.1775	0.1814	0.1814	0.0494	0.1320	0.5279	0.0522	0.0515	0.0453	0.8798	0.0275	0.0726	0.0728	0.2695	-1.02E-09
0.1855	0.1895	0.1895	0.0575	0.1439	0.6600	0.0601	0.0569	0.0491	0.8632	0.0345	0.0843	0.0836	-0.8659	-2.38E-09
0.1920	0.1962	0.1962	0.0642	0.1484	0.6600	0.0631	0.0611	0.0531	0.8693	0.0408	0.0943	0.0939	-0.4346	2.78E-17

Cd2 =	0.9918
Cd5 =	0.8760

CALIBRATION OF FLUME AND COMPOUND WEIR COMBINATION
Analysis of test results

Model 6 Setup 3
Layout 2, with flume abutment walls shortened and wall heads bevelled at 45 degrees, in 2 m channel with sharp-crested weir length = 0,67 m.
Sharp-crested weir now at new position at end of trapezoidal section and unsymmetrical, with one side completely blocked off.
(all measurements relative to flume bed)

W =	2	m
L2/2 =	0.67	m
s =	0.066	m
b =	0.264	m
d =	0.132	m
L1 =	0.528	m

Y2 (m)	Es 2 / Es 5 (m)	Es min (m)	H (m)	Yc (m)	Bc (m)	Ac (m2)	Q flume th. (m3/s)	Q flume real (m3/s)	Cd	Q weir (m3/s)	Q total (m3/s)	Q mano (m3/s)	% Differenc	Delta Es (m)
0.0625	0.0656	0.0656		0.0457	0.3554	0.0142	0.0089	0.0082	0.9259		0.0085	0.0082	3.1344	-4.18E-10
0.1003	0.1075	0.1075		0.0763	0.4167	0.0260	0.0203	0.0200	0.9840		0.0194	0.0200	-2.9495	-4.52E-09
0.1263	0.1426	0.1426	0.0106	0.1026	0.4691	0.0376	0.0333	0.0301	0.9038	0.0014	0.0310	0.0315	1.4834	-7.95E-10
0.1570	0.1632	0.1632	0.0312	0.1181	0.5002	0.0451	0.0425	0.0376	0.8866	0.0069	0.0447	0.0445	-0.3061	8.06E-09
0.1730	0.1775	0.1775	0.0455	0.1359	0.6600	0.0549	0.0495	0.0442	0.8923	0.0121	0.0562	0.0564	0.2180	-5E-16
0.1868	0.1903	0.1903	0.0583	0.1445	0.6600	0.0605	0.0574	0.0508	0.8853	0.0177	0.0687	0.0684	-0.3833	-8.63E-09
0.1958	0.1996	0.1996	0.0676	0.1506	0.6600	0.0646	0.0633	0.0559	0.8838	0.0221	0.0783	0.0780	-0.4861	-7.27E-09
0.2038	0.2078	0.2078	0.0758	0.1561	0.6600	0.0682	0.0687	0.0610	0.8877	0.0263	0.0874	0.0872	-0.1671	-6.04E-09
0.2093	0.2138	0.2138	0.0818	0.1602	0.6600	0.0709	0.0727	0.0647	0.8892	0.0295	0.0942	0.0941	-0.0461	-2.68E-08

Cd2 =	0.9549
Cd5 =	0.8898

CALIBRATION OF FLUME AND COMPOUND WEIR COMBINATION
Analysis of test results

Model 7 Setup 1
Layout 1, with flume abutment walls shortened and wall heads bevelled at 45 degrees, in 2 m channel with sharp-crested weir length = 1,52 m.
Sharp-crested weir now at new position at end of trapezoidal section.
(all measurements relative to flume bed)

W =	2	m
L2/2 =	0.76	m
s =	0.066	m
b =	0.174	m
d =	0.174	m
L1 =	0.348	m

Y2 (m)	Es 2 / Es 5 (m)	Es min (m)	H (m)	Yc (m)	Bc (m)	Ac (m2)	Q flume th (m3/s)	Q flume real (m3/s)	Cd	Q weir (m3/s)	Q total (m3/s)	Q mano (m3/s)	% Differenc	Delta Es (m)
0.0698	0.0732	0.0732		0.0507	0.2247	0.0101	0.0067	0.0063	0.9448		0.0065	0.0063	2.2886	-5.88E-09
0.0940	0.0994	0.0994		0.0696	0.2436	0.0145	0.0111	0.0107	0.9612		0.0107	0.0107	0.5415	6.69E-09
0.1263	0.1349	0.1349		0.0955	0.2695	0.0212	0.0186	0.0181	0.9702		0.0180	0.0181	-0.3856	-2.47E-09
0.1445	0.1557	0.1557		0.1110	0.2850	0.0255	0.0239	0.0236	0.9895		0.0231	0.0236	-2.3331	-1.36E-08
0.1568	0.1772	0.1772	0.0032	0.1271	0.3011	0.0302	0.0299	0.0276	0.9229	0.0005	0.0284	0.0282	1.0252	-2.48E-10
0.1750	0.1894	0.1894	0.0154	0.1362	0.3102	0.0330	0.0337	0.0319	0.9481	0.0054	0.0368	0.0373	-1.4054	1.1E-08
0.1925	0.2014	0.2014	0.0274	0.1453	0.3193	0.0358	0.0376	0.0349	0.9278	0.0129	0.0480	0.0478	0.3681	1.44E-08
0.2028	0.2101	0.2101	0.0361	0.1519	0.3259	0.0380	0.0406	0.0380	0.9357	0.0196	0.0574	0.0576	-0.2234	1.12E-08
0.2138	0.2193	0.2193	0.0453	0.1589	0.3329	0.0403	0.0439	0.0408	0.9292	0.0277	0.0686	0.0684	0.2102	5.7E-09
0.2238	0.2285	0.2285	0.0545	0.1788	0.4800	0.0477	0.0471	0.0441	0.9362	0.0366	0.0805	0.0807	-0.2153	1.36E-08
0.2330	0.2373	0.2373	0.0633	0.1847	0.4800	0.0505	0.0514	0.0476	0.9277	0.0460	0.0939	0.0937	0.2653	5.55E-17

Cd2 =	0.9664
Cd5 =	0.9325

CALIBRATION OF FLUME AND COMPOUND WEIR COMBINATION
Analysis of test results

Model 8 Setup 1
Layout 3, with flume abutment walls shortened and wall heads bevelled at 45 degrees, in 2 m channel with sharp-crested weir length = 1,146 m.
Sharp-crested weir now at new position at end of trapezoidal section.
(all measurements relative to flume bed)

W =	2	m
L2/2 =	0.573	m
s =	0.066	m
b =	0.412	m
d =	0.103	m
L1 =	0.722	m

Y2 (m)	Es 2 / Es 5 (m)	Es min (m)	H (m)	Yc (m)	Bc (m)	Ac (m2)	Q flume th. (m3/s)	Q flume real (m3/s)	Cd	Q weir (m3/s)	Q total (m3/s)	Q mano (m3/s)	% Differenc	Delta Es (m)
0.0480	0.0509	0.0509		0.0351	0.5174	0.0163	0.0091	0.0083	0.9131		0.0085	0.0083	2.7380	-5.76E-10
0.0665	0.0714	0.0714		0.0498	0.5615	0.0242	0.0158	0.0149	0.9434		0.0148	0.0149	-0.5670	-1.19E-10
0.0800	0.0860	0.0860		0.0604	0.5932	0.0304	0.0215	0.0197	0.9182		0.0202	0.0197	2.1696	-2.45E-09
0.0895	0.0979	0.0979		0.0691	0.6194	0.0356	0.0268	0.0262	0.9777		0.0251	0.0262	-4.0476	-4.77E-09
0.1000	0.1109	0.1109	0.0079	0.0787	0.6481	0.0417	0.0332	0.0308	0.9285	0.0015	0.0325	0.0323	0.5844	-5.96E-11
0.1105	0.1186	0.1186	0.0156	0.0844	0.6653	0.0455	0.0372	0.0349	0.9359	0.0042	0.0390	0.0390	-0.1551	-2.27E-10
0.1220	0.1290	0.1290	0.0260	0.0922	0.6885	0.0507	0.0431	0.0404	0.9381	0.0089	0.0492	0.0494	-0.3364	-3.62E-10
0.1315	0.1376	0.1376	0.0346	0.0986	0.7077	0.0552	0.0483	0.0456	0.9441	0.0137	0.0588	0.0593	-0.8022	-1.71E-10
0.1400	0.1465	0.1465	0.0435	0.1092	0.8530	0.0636	0.0545	0.0506	0.9300	0.0194	0.0703	0.0701	0.3295	0
0.1490	0.1554	0.1554	0.0524	0.1151	0.8530	0.0687	0.0611	0.0567	0.9292	0.0258	0.0828	0.0825	0.3750	-1.52E-08
0.1570	0.1635	0.1635	0.0605	0.1205	0.8530	0.0733	0.0673	0.0629	0.9339	0.0320	0.0949	0.0949	0.0241	-1.67E-08

Cd2 =	0.9381
Cd5 =	0.9342

APPENDIX

6.1

RESULTS OF SIEVE ANALYSIS ON SAND USED FOR SEDIMENTATION TESTS

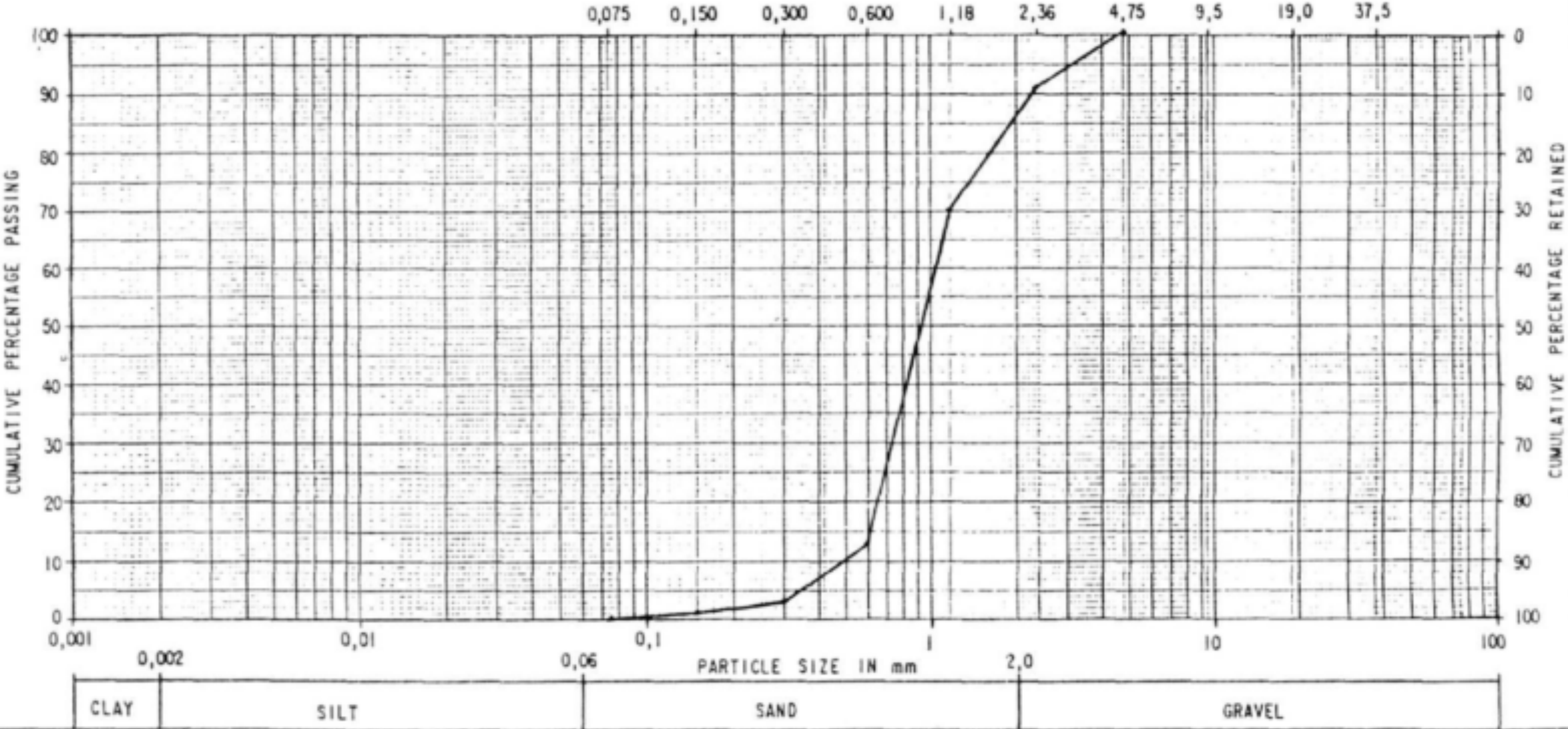
UNIVERSITEIT VAN STELLENBOSCH

Siviele Laboratorium

Projek .... Monster verskaf deur: .... Datum: ..29/11/96.....

Monsterbeskrywing		Sifanalise												Besinkingstoets						Atterberggrense		
		% wat deurgaan																				
Nr.	Sif Grootte mm	75	53	37,5	26,5	19	13,2	9,5	4,75	2,36	1,18	0,60	0,30	0,15	0,075					Vloeigrens	Plastisiteits-indeks	% Liniêre krimping
									100	91	70	13	3	1	0							

Sifopeninge in mm.



SAMPLE NUMBER	LOCATION	DEPTH m	ATTERBERG LIMITS			CLAY %	SILT %	SAND %	GRAVEL %	SCS DSP %	LABORATORY DESCRIPTION	CHECKED BY
			LL	PI	LS							REFERENCE

PROJ NO	PROJECT	TEST METHOD	DATE

NAAM _______________ DATUM 29/11/96

MONSTER NR _______________

TOTALE GEWIG 475,0 gm

SIF GROOTTE mm	AGTERBLYWENDE GEWIG gm	% OP SIF	% WAT DEURGAAN
75			
53			
37,5			
26,5			
19			
13,2			
9,5			
4,75			100
2,36	43,4	9,1	90,9
1,18	98,7	20,8	70,1
0,60	269,9	56,8	13,3
~~0,425~~ 0,30	48,1	10,1	3,2
0,15	9,3	2,0	1,2
0,075	4,3	0,9	0,3
<0,075	1,3	0,3	

APPENDIX

7.1

SUBMERGENCE TEST RESULTS & ANALYSIS

EFFECT OF SUBMERGENCE ON CALIBRATION OF FLUME
Submergence results

Model 2 Set-up 2
Layout 2, with long, thick flume abutment walls, in 2 m channel with sharp-crested weir length = 1,262m
(all stage measurements relative to flume bed)

W = 2 m
L2/2 = 0.631 m
s = 0.105 m
b = 0.264 m
d = 0.132 m
L1 = 0.528 m

Q mano (l/s)	h0 (mm)	hv (mm)	t1 (mm)	t2 (mm)	t3 (mm)	t average (mm)	t/hv	h0/hv (measured)	h0/hv (fitted curve)	h0 (fitted)	h0 difference %
5.5	49.4										
		51.5	36.5	35.5	36	36.0	0.699	0.959	not applicable	not applicable	not applicable
		53.5	45	44.5	44.5	44.7	0.835	0.923	0.9833	52.6	6.5
		65.5	61	59.5	61.5	60.7	0.926	0.754	0.8760	57.4	16.1
11.88	77.8										
		80	68.5	67.5	68.5	68.2	0.852	0.973	0.9764	78.1	0.4
		87.5	81.5	80.5	80.5	80.8	0.924	0.889	0.8810	77.1	-0.9
		91	85	84.5	84.5	84.7	0.930	0.855	0.8669	78.9	1.4
		100	96.5	96.5	96	96.3	0.963	0.778	0.7827	78.3	0.6
15.98	92.5										
		93.5	79	79	78.5	78.8	0.843	0.989	0.9808	91.7	-0.9
		96.5	83.5	83.5	84	83.7	0.867	0.959	0.9654	93.2	0.7
		106.5	100.5	101	99.5	100.3	0.942	0.869	0.8396	89.4	-3.3
		116.5	112	111	111	111.3	0.956	0.794	0.8043	93.7	1.3
20.25	105.5										
		106.5	79.5	79.5	78.5	79.2	0.743	0.991	not applicable	not applicable	not applicable
		113.5	102.5	103.5	102	102.7	0.905	0.930	0.9171	104.1	-1.3
		116.5	104.5	105.5	105	105.0	0.901	0.906	0.9225	107.5	1.9
		125.5	119	118	117	118.0	0.940	0.841	0.8441	105.9	0.4
41.599	149										
		150	71	69.5	69.5	70.0	0.467	0.993	not applicable	not applicable	not applicable
		152.5	127.5	128.5	127.5	127.8	0.838	0.977	0.9721	148.2	-0.5
		163	151.5	150.5	150.5	150.8	0.925	0.914	0.8894	145.0	-2.7
		177.5	171	171.5	170.5	171.0	0.963	0.839	0.8270	146.8	-1.5
		194	190.5	190.5	190	190.3	0.981	0.768	0.7925	153.7	3.2
87.272	187.8										
		189.5	148.5	147.5	148.5	148.2	0.782	0.991	not applicable	not applicable	not applicable
		202.5	182.5	179.5	181.5	181.2	0.895	0.927	0.9281	187.9	0.1
		209	193.5	192.5	192.5	192.8	0.923	0.899	0.8932	186.7	-0.6
		216.5	205.5	204.5	205.5	205.2	0.948	0.867	0.8547	185.1	-1.5
159.518	224										
		225	143	142.5	142.5	142.7	0.634	0.996	not applicable	not applicable	not applicable
		238.5	202.5	200.5	201.5	201.5	0.845	0.939	0.9687	231.0	3.1
		247.5	223.5	224.5	224.5	224.2	0.906	0.905	0.9153	226.5	1.1
		259.5	243	245	243	243.7	0.939	0.863	0.8689	225.5	0.7

EFFECT OF SUBMERGENCE ON CALIBRATION OF FLUME
Submergence results

Model 2 Set-up 3
Layout 2, with long, thick flume abutment walls, in 2 m channel with Crump weir length = 1.262m
(all stage measurements relative to flume bed)

W =	2
L2/2 =	0.631
s =	0.105
b =	0.264
d =	0.132
L1 =	0.528

Q mano (l/s)	h0 (mm)	hv (mm)	t1 (mm)	t2 (mm)	t3 (mm)	t average (mm)	t/hv	h0/hv (measured)	h0/hv (fitted curve)	h0 (fitted)	h0 difference %
5.5	49.4										
		51.5	36.5	35.5	36	36.0	0.699	0.959	not applicable	not applicable	not applicable
		53.5	45	44.5	44.5	44.7	0.835	0.923	0.9833	52.6	6.5
		65.5	61	59.5	61.5	60.7	0.926	0.754	0.8760	57.4	16.1
11.88	77.8										
		80	68.5	67.5	68.5	68.2	0.852	0.973	0.9764	78.1	0.4
		87.5	81.5	80.5	80.5	80.8	0.924	0.889	0.8810	77.1	-0.9
		91	85	84.5	84.5	84.7	0.930	0.855	0.8669	78.9	1.4
		100	96.5	96.5	96	96.3	0.963	0.778	0.7827	78.3	0.6
15.98	92.5										
		93.5	79	79	78.5	78.8	0.843	0.989	0.9808	91.7	-0.9
		96.5	83.5	83.5	84	83.7	0.867	0.959	0.9654	93.2	0.7
		106.5	100.5	101	99.5	100.3	0.942	0.869	0.8396	89.4	-3.3
		116.5	112	111	111	111.3	0.956	0.794	0.8043	93.7	1.3
20.25	105.5										
		106.5	79.5	79.5	78.5	79.2	0.743	0.991	not applicable	not applicable	not applicable
		113.5	102.5	103.5	102	102.7	0.905	0.930	0.9171	104.1	-1.3
		116.5	104.5	105.5	105	105.0	0.901	0.906	0.9225	107.5	1.9
		125.5	119	118	117	118.0	0.940	0.841	0.8441	105.9	0.4
28.1604	125										
		125	76.5	77.5	77.5	77.2	0.617	1.000	not applicable	not applicable	not applicable
		136	120	119.5	120	119.8	0.881	0.919	0.9640	131.1	4.9
		145	133.5	134	134	133.8	0.923	0.862	0.9616	139.4	11.5
		154.5	148.5	149	148.5	148.7	0.962	0.809	0.9295	143.6	14.9
44.146	153.5										
		154.5	113.5	111.5	112.5	112.5	0.728	0.994	not applicable	not applicable	not applicable
		160.5	143.5	143	142.5	143.0	0.891	0.956	0.9664	155.1	1.0
		168.5	162.5	161	162	161.8	0.960	0.911	0.9316	157.0	2.3
		173.5	171	170.5	170.5	170.7	0.984	0.885	0.8999	156.1	1.7
67.262	174										
		177	152.5	151.5	150.5	151.5	0.856	0.983	0.9498	168.1	-3.4
		181.5	169	167.5	168	168.2	0.927	0.959	0.9598	174.2	0.1
		187	180.5	181.5	181.5	181.2	0.969	0.930	0.9214	172.3	-1.0
		199	197	196.5	196.5	196.7	0.988	0.874	0.8924	177.6	2.1
117.448	205.5										
		206.5	152.5	150.5	151.5	151.5	0.734	0.995	not applicable	not applicable	not applicable
		213.5	204	202.5	203.5	203.3	0.952	0.963	0.9403	200.7	-2.3
		218	211.5	211.5	211.5	211.5	0.970	0.943	0.9196	200.5	-2.5
		227.5	224	223.5	222.5	223.3	0.982	0.903	0.9030	205.4	0.0
170.124	230.5										
		231.5	162.5	161.5	163.5	162.5	0.702	0.996	not applicable	not applicable	not applicable
		242	235	233.5	233.5	234.0	0.967	0.952	0.9238	223.6	-3.0
		251	245.5	245	245.5	245.3	0.977	0.918	0.9094	228.3	-1.0
		264.5	263.5	262.5	261.5	262.5	0.992	0.871	0.8853	234.2	1.6

EFFECT OF SUBMERGENCE ON CALIBRATION OF FLUME
Submergence results

Model 3 Set-up 1
Layout 1, with long flume abutment walls, in 2 m channel with sharp-crested weir lentgh = 1,52 m.
(all stage measurements relative to flume bed)

W =	2	m
L2/2 =	0.76	m
s =	0.066	m
b =	0.174	m
d =	0.174	m
L1 =	0.348	m

Qmano (l/s)	h0 (mm)	hv (mm)	t (mm)	t/hv	h0/hv (measured)	h0/hv (fitted curve)	h0 (fitted)	h0 difference %
10.5	94.5							
		95.5	80.5	0.843	0.990	0.9637	92.0	-2.6
		102.5	89	0.868	0.922	0.9344	95.8	1.4
		107.5	97.5	0.907	0.879	0.8750	94.1	-0.5
		114	106.5	0.934	0.829	0.8227	93.8	-0.8
		123	117.5	0.955	0.768	0.7761	95.5	1.0
		133	129.5	0.974	0.711	0.7312	97.3	2.9
		143.5	141.5	0.986	0.659	0.6987	100.3	6.1
27	155.5							
		157.5	74.5	0.473	0.987	not applicable	not applicable	not applicable
		158.5	98.5	0.621	0.981	0.8974	142.2	-8.5
		159.5	116.5	0.730	0.975	1.0024	159.9	2.8
		165.5	140.5	0.849	0.940	0.9575	158.5	1.9
		182.5	166.5	0.912	0.852	0.8654	157.9	1.6
		196	188.5	0.962	0.793	0.7608	149.1	-4.1
		206.5	201.5	0.976	0.753	0.7258	149.9	-3.6
		217.5	214.5	0.986	0.715	0.6983	151.9	-2.3
47.3	198.5							
		199.5	130.5	0.654	0.995	not applicable	not applicable	not applicable
		200	145.5	0.728	0.993	not applicable	not applicable	not applicable
		201.5	159.5	0.792	0.985	not applicable	not applicable	not applicable
		204	170.5	0.836	0.973	0.9778	199.5	0.5
		207.5	184.5	0.889	0.957	0.9488	196.9	-0.8
		215.5	198.5	0.921	0.921	0.9183	197.9	-0.3
		225	213.5	0.949	0.882	0.8731	196.5	-1.0
		235.5	226.5	0.962	0.843	0.8404	197.9	-0.3
		249.5	244	0.978	0.796	0.7780	194.1	-2.2
		263.5	260.5	0.989	0.753	0.7125	187.7	-5.4
67.3	217							
		218	172.5	0.791	0.995	not applicable	not applicable	not applicable
		220.5	185.5	0.841	0.984	0.9755	215.1	-0.9
		225.5	197	0.874	0.962	0.9592	216.3	-0.3
		231	205.5	0.890	0.939	0.9484	219.1	1.0
		240	221.5	0.923	0.904	0.9160	219.8	1.3
		249.5	234.5	0.940	0.870	0.8907	222.2	2.4
		262.5	252.5	0.962	0.827	0.8400	220.5	1.6
		276	269.5	0.976	0.786	0.7852	216.7	-0.1

EFFECT OF SUBMERGENCE ON CALIBRATION OF FLUME
Submergence results

Model 4 Set-up 1
Layout 3, with long flume abutment walls, in 2 m channel with sharp-crested weir lentgh = 1,146 m.
(all stage measurements relative to flume bed)

W =	2	m
L2/2 =	0.574	m
s =	0.066	m
b =	0.412	m
d =	0.103	m
L1 =	0.721	m

Qmano (l/s)	h0 (mm)	hv (mm)	t (mm)	t/hv	h0/hv (measured)	h0/hv (fitted curve)	h0 (fitted)	h0 difference %
10.8	56							
		57	46	0.807	0.982	0.950	54.2	-3.3
		58	50	0.862	0.966	0.937	54.4	-2.9
		61	54.5	0.893	0.918	0.924	56.4	0.7
		63	58.5	0.929	0.889	0.897	56.5	0.9
		66	62	0.939	0.848	0.883	58.3	4.1
		68.5	66.5	0.971	0.818	0.791	54.2	-3.2
		71.5	70	0.979	0.783	0.731	52.3	-6.7
		77	76	0.987	0.727	0.621	47.8	-14.6
19.6	78.5							
		79	53	0.671	0.994	not applicable	not applicable	not applicable
		80.5	61.5	0.764	0.975	not applicable	not applicable	not applicable
		82.5	71.5	0.867	0.952	0.936	77.2	-1.7
		87	79.5	0.914	0.902	0.911	79.3	1.0
		93	88	0.946	0.844	0.871	81.0	3.2
		100	97	0.970	0.785	0.796	79.6	1.4
		108	106	0.981	0.727	0.705	76.1	-3.0
		117	115	0.983	0.671	0.687	80.4	2.4
31	100							
		101	53	0.525	0.990	not applicable	not applicable	not applicable
		101.5	63	0.621	0.985	not applicable	not applicable	not applicable
		102	72	0.706	0.980	not applicable	not applicable	not applicable
		104.5	83	0.794	0.957	not applicable	not applicable	not applicable
		109	93.5	0.858	0.917	0.939	102.3	2.3
		113.5	104	0.916	0.881	0.909	103.2	3.2
		121	114	0.942	0.826	0.879	106.3	6.3
		128	122.5	0.957	0.781	0.846	108.3	8.3
		135	131	0.970	0.741	0.794	107.1	7.1
		142	138	0.972	0.704	0.785	111.5	11.5
		148.5	146	0.983	0.673	0.684	101.6	1.6
		163	161	0.988	0.613	0.606	98.8	-1.2
40	115							
		116	78	0.672	0.991	not applicable	not applicable	not applicable
		117	88.5	0.756	0.983	not applicable	not applicable	not applicable
		119	99	0.832	0.966	0.934	111.2	-3.3
		124.5	112	0.900	0.924	0.913	113.7	-1.1
		133	124	0.932	0.865	0.890	118.4	3.0
		143.5	136	0.948	0.801	0.872	125.1	8.8
		153	147.5	0.964	0.752	0.839	128.3	11.6
		163	159	0.975	0.706	0.799	130.2	13.2
		173	171	0.988	0.665	0.706	122.2	6.3
49.7	126							
		127	77	0.606	0.992	not applicable	not applicable	not applicable
		127.5	93.5	0.733	0.988	not applicable	not applicable	not applicable
		129	109	0.845	0.977	0.932	120.2	-4.6
		136	123	0.904	0.926	0.911	123.9	-1.7
		145.5	135	0.928	0.866	0.895	130.2	3.3
		158	151	0.956	0.797	0.858	135.6	7.6
		170.5	165.5	0.971	0.739	0.818	139.5	10.7
		184.5	181	0.981	0.683	0.768	141.8	12.5
		197.5	196	0.992	0.638	0.654	129.3	2.6
70.9	143.5							
		144.5	107	0.740	0.993	not applicable	not applicable	not applicable
		147	118	0.803	0.976	0.939	138.1	-3.8
		152	132	0.868	0.944	0.925	140.7	-2.0
		160	143.5	0.897	0.897	0.915	146.3	2.0
		170.5	159.5	0.935	0.842	0.887	151.3	5.4
		182.5	175	0.959	0.786	0.851	155.4	8.3
		195.5	191	0.977	0.734	0.791	154.7	7.8
		209	206	0.986	0.687	0.734	153.4	6.9
		221	219	0.991	0.649	0.676	149.3	4.1
94.4	161.5							
		162.5	107	0.658	0.994	not applicable	not applicable	not applicable
		164	120	0.732	0.985	not applicable	not applicable	not applicable
		168	137	0.815	0.961	0.937	157.4	-2.5
		175.5	153	0.872	0.920	0.924	162.2	0.4
		189	174	0.921	0.854	0.900	170.2	5.4
		203.5	194.5	0.956	0.794	0.858	174.6	8.1
		220	213	0.968	0.734	0.827	181.8	12.6
		239.5	234	0.977	0.674	0.791	189.4	17.3
		258	255	0.988	0.626	0.707	182.4	13.0
		277	275	0.993	0.583	0.648	179.6	11.2

EFFECT OF SUBMERGENCE ON CALIBRATION OF FLUME
Submergence results

Model 6 Set-up 1
Layout 2, with flume abutment walls shortened and sloped at 45 degrees, in 2 m channel with sharp-crested weir lentgh = 1,34 m.
(all stage measurements relative to flume bed)

W =	2	m
L2/2 =	0.67	m
s =	0.066	m
b =	0.264	m
d =	0.132	m
L1 =	0.528	m

Qmano (l/s)	h0 (mm)	hv (mm)	t (mm)	t/hv	h0/hv (measured)	h0/hv (curve fitted)	h0 (fitted)	h0 difference %
12.6	79.5							
		80.5	64	0.795	0.988	not applicable	not applicable	not applicable
		82.5	69.5	0.842	0.964	0.971	80.1	0.8
		84.5	73.5	0.870	0.941	0.949	80.2	0.9
		86.5	76.5	0.884	0.919	0.932	80.6	1.4
		90.5	82.5	0.912	0.878	0.889	80.5	1.2
		95	88.5	0.932	0.837	0.847	80.5	1.2
		100.5	96.5	0.960	0.791	0.769	77.3	-2.8
		107.5	103.5	0.963	0.740	0.761	81.8	2.9
		116.5	114.5	0.983	0.682	0.688	80.2	0.8
18.5	97							
		98	80.5	0.821	0.990	0.980	96.0	-1.0
		100	85.5	0.855	0.970	0.963	96.3	-0.8
		103	91.5	0.888	0.942	0.927	95.4	-1.6
		108	97	0.898	0.898	0.912	98.5	1.6
		113.5	106.5	0.938	0.855	0.831	94.3	-2.8
		119.5	113.5	0.950	0.812	0.800	95.6	-1.4
		128.5	124.5	0.969	0.755	0.740	95.2	-1.9
		136.5	133.5	0.978	0.711	0.707	96.5	-0.5
26.6	116.5							
		117.5	68.5	0.583	0.991	not applicable	not applicable	not applicable
		118	77.5	0.657	0.987	not applicable	not applicable	not applicable
		118.5	84.5	0.713	0.983	not applicable	not applicable	not applicable
		119	93	0.782	0.979	not applicable	not applicable	not applicable
		120.5	100.5	0.834	0.967	0.975	117.5	0.9
		123.5	109.5	0.887	0.943	0.929	114.7	-1.5
		129.5	118	0.911	0.900	0.890	115.2	-1.1
		138	128.5	0.931	0.844	0.848	117.1	0.5
		148	141	0.953	0.787	0.792	117.2	0.6
		157.5	151.5	0.962	0.740	0.764	120.3	3.3
		166	162.5	0.979	0.702	0.704	116.8	0.3
43.5	144.5							
		145.5	85.5	0.588	0.993	not applicable	not applicable	not applicable
		146	93	0.637	0.990	not applicable	not applicable	not applicable
		146.5	110	0.751	0.986	not applicable	not applicable	not applicable
		147.5	119	0.807	0.980	0.973	143.5	-0.7
		150	127.5	0.850	0.963	0.956	143.3	-0.8
		156	141	0.904	0.926	0.895	139.7	-3.3
		164.5	152	0.924	0.878	0.860	141.5	-2.0
		172.5	162	0.939	0.838	0.829	143.0	-1.0
		181.5	172.5	0.950	0.796	0.802	145.6	0.8
		192.5	186.5	0.969	0.751	0.752	144.7	0.1
		204	199.5	0.978	0.708	0.723	147.5	2.1
68.3	169							
		170	111	0.653	0.994	not applicable	not applicable	not applicable
		171.5	120	0.700	0.985	not applicable	not applicable	not applicable
		172.5	133.5	0.774	0.980	not applicable	not applicable	not applicable
		174.5	145.5	0.834	0.968	0.965	168.4	-0.4
		179.5	155.5	0.866	0.942	0.942	169.1	0.1
		190	168.5	0.887	0.889	0.919	174.7	3.4
		202.5	188.5	0.931	0.835	0.847	171.5	1.5
		215.5	206	0.956	0.784	0.788	169.8	0.5
		232	226.5	0.976	0.728	0.728	169.0	0.0
91.7	187.5							
		188.5	147.5	0.782	0.995	not applicable	not applicable	not applicable
		193.5	159.5	0.824	0.969	0.969	187.5	0.0
		198.5	169	0.851	0.945	0.955	189.5	1.1
		204	177.5	0.870	0.919	0.938	191.4	2.1
		214	196	0.916	0.876	0.875	187.4	-0.1
		223	209.5	0.939	0.841	0.828	184.7	-1.5
		234	223	0.953	0.801	0.796	186.2	-0.7

EFFECT OF SUBMERGENCE ON CALIBRATION OF FLUME
Submergence results

Model 7 Set-up 1
Layout 1, with flume abutment walls shortened and sloped at 45 degrees, in 2 m channel with sharp-crested weir lenigh = 1,52 m.
(all stage measurements relative to flume bed)

W =	2	m
L2/2 =	0.76	m
s =	0.066	m
b =	0.174	m
d =	0.174	m
L1 =	0.348	m

Qmano (l/s)	h0 (mm)	hv (mm)	T (mm)	T/hv	h0/hv (measured)	h0/hv (curve fitted)	h0 (fitted)	h0 difference %
7.1	74.5							
		75.5	64.5	0.854	0.987	0.990	74.8	0.4
		76.5	68.5	0.895	0.974	0.969	74.2	-0.5
		78.5	72.5	0.924	0.949	0.930	73.0	-2.0
		81.5	76	0.933	0.914	0.913	74.4	-0.1
		84	80	0.952	0.887	0.870	73.1	-1.9
		87	83.5	0.960	0.856	0.852	74.1	-0.6
		89.5	87	0.972	0.832	0.819	73.3	-1.7
		93.5	92.5	0.989	0.797	0.767	71.7	-3.7
14.7	111							
		112	95.5	0.853	0.991	0.990	110.9	-0.1
		112.5	99	0.880	0.987	0.983	110.5	-0.4
		115	102.5	0.891	0.965	0.973	111.9	0.9
		118.5	108.5	0.916	0.937	0.943	111.7	0.7
		122	114	0.934	0.910	0.909	110.9	-0.1
		126	119.5	0.948	0.881	0.879	110.8	-0.2
		130	125	0.962	0.854	0.847	110.1	-0.8
		133.5	130.5	0.978	0.831	0.803	107.2	-3.4
		138	135.5	0.982	0.804	0.790	109.0	-1.8
		143.5	142	0.990	0.774	0.766	110.0	-0.9
22.8	140.5							
		142	118.5	0.835	0.989	0.983	139.6	-0.6
		143.5	123	0.857	0.979	0.990	142.1	1.2
		144	127.5	0.885	0.976	0.979	140.9	0.3
		146	133.5	0.914	0.962	0.945	137.9	-1.8
		150	138	0.920	0.937	0.936	140.4	-0.1
		154.5	143.5	0.929	0.909	0.920	142.2	1.2
		157.5	148.5	0.943	0.892	0.892	140.4	0.0
		161.5	156	0.966	0.870	0.835	134.9	-4.0
		168.5	163.5	0.970	0.834	0.823	138.8	-1.2
		177.5	170.5	0.961	0.792	0.850	150.8	7.3
		184.5	179.5	0.973	0.762	0.816	150.6	7.2
		192.5	188.5	0.979	0.730	0.798	153.6	9.3
42.4	185.5							
		187.5	120.5	0.643	0.989	not applicable	not applicable	not applicable
		190	128	0.674	0.976	not applicable	not applicable	not applicable
		190.5	135.5	0.711	0.974	not applicable	not applicable	not applicable
		191.5	147.5	0.770	0.969	not applicable	not applicable	not applicable
		193.5	158.5	0.819	0.959	0.966	187.0	0.8
		197	170	0.863	0.942	0.944	186.0	0.3
		201.5	180.5	0.896	0.921	0.920	185.3	-0.1
		207	189.5	0.915	0.896	0.899	186.2	0.4
		214	199.5	0.932	0.867	0.877	187.7	1.2
		220.5	210.5	0.955	0.841	0.836	184.4	-0.6
		228.5	220.5	0.965	0.812	0.811	185.2	-0.2
		236.5	230.5	0.975	0.784	0.781	184.6	-0.5
		245	240.5	0.982	0.757	0.754	184.8	-0.4
		253	250	0.988	0.733	0.725	183.4	-1.1
63.1	209.5							
		211	138	0.654	0.993	not applicable	not applicable	not applicable
		211.5	149.5	0.707	0.991	not applicable	not applicable	not applicable
		212	159.5	0.752	0.988	not applicable	not applicable	not applicable
		214	171.5	0.801	0.979	0.973	208.2	-0.6
		216.5	183.5	0.848	0.968	0.953	206.3	-1.5
		221	191.5	0.867	0.948	0.942	208.1	-0.7
		229	205.5	0.897	0.915	0.918	210.2	0.4
		236	220.5	0.934	0.888	0.874	206.3	-1.5
		248.5	235.5	0.948	0.843	0.851	211.4	0.9
		260.5	253	0.971	0.804	0.792	206.3	-1.5
		278	274	0.986	0.754	0.737	204.9	-2.2
82.4	225.5							
		227	156	0.687	0.993	not applicable	not applicable	not applicable
		227.5	167.5	0.736	0.991	not applicable	not applicable	not applicable
		229.5	178.5	0.778	0.983	not applicable	not applicable	not applicable
		232.5	189.5	0.815	0.970	0.968	225.0	-0.2
		237	199.5	0.842	0.951	0.956	226.5	0.5
		243.5	213	0.875	0.926	0.936	228.0	1.1
		250.5	227.5	0.908	0.900	0.907	227.3	0.8
		259	240.5	0.929	0.871	0.883	228.6	1.4
		267.5	255.5	0.955	0.843	0.835	223.4	-0.9
		281	271.5	0.966	0.802	0.807	226.8	0.6
		298.5	292	0.978	0.755	0.768	229.2	1.6
		317	313.5	0.989	0.711	0.721	228.5	1.3

EFFECT OF SUBMERGENCE ON CALIBRATION OF FLUME
Submergence results

Model 8 Set-up 1
Layout 3, with flume abutment walls shortened and sloped at 45 degrees, in 2 m channel with sharp-crested weir length = 1.146 m.
Sharp-crested weir now at new position at end of trapezoidal section
(all stage measurements relative to flume bed)

W =	2	m
L2/2 =	0.574	m
s =	0.066	m
b =	0.412	m
d =	0.103	m
L1 =	0.721	m

Qmano (l/s)	h0 (mm)	hv (mm)	t (mm)	t/hv	h0/hv (measured)	h0/hv (curve fitted)	h0 (fitted)	h0 difference %
13	60							
		61	48.5	0.795	0.984	not applicable	not applicable	not applicable
		61.5	52.5	0.854	0.976	0.970	59.7	-0.6
		62.5	56	0.896	0.960	0.961	60.1	0.1
		64.5	60.5	0.938	0.930	0.923	59.5	-0.8
		67.5	64.5	0.956	0.889	0.883	59.6	-0.7
		72	70	0.972	0.833	0.807	58.1	-3.1
		76	75	0.987	0.789	0.660	50.2	-16.4
20.6	78							
		79	58	0.734	0.987	not applicable	not applicable	not applicable
		79.5	62	0.780	0.981	not applicable	not applicable	not applicable
		80	66.5	0.831	0.975	0.970	77.6	-0.6
		81.5	72	0.883	0.957	0.966	78.7	0.9
		84	79	0.940	0.929	0.919	77.2	-1.1
		89	85	0.955	0.876	0.884	78.7	0.9
		93	90	0.968	0.839	0.833	77.5	-0.6
		98	96	0.980	0.796	0.749	73.4	-5.9
26.9	90							
		91	70	0.769	0.989	not applicable	not applicable	not applicable
		92	77	0.837	0.978	0.970	89.2	-0.9
		94	82	0.872	0.957	0.968	91.0	1.1
		96	89	0.927	0.938	0.938	90.1	0.1
		102	96	0.941	0.882	0.917	93.6	4.0
		107	101.5	0.949	0.841	0.902	96.5	7.2
		113.5	110.5	0.974	0.793	0.798	90.6	0.7
		121	118	0.975	0.744	0.786	95.2	5.7
		129	127	0.984	0.698	0.694	89.5	-0.5
45.1	117.5							
		119.5	82	0.686	0.983	not applicable	not applicable	not applicable
		120	90	0.750	0.979	not applicable	not applicable	not applicable
		122	98	0.803	0.963	0.961	117.2	-0.2
		125	107	0.856	0.940	0.932	116.5	-0.9
		129	115	0.891	0.911	0.896	115.6	-1.7
		134.5	122	0.907	0.874	0.875	117.7	0.2
		141	132	0.936	0.833	0.828	116.8	-0.6
		149.5	143	0.957	0.786	0.788	117.8	0.3
		159	154.5	0.972	0.739	0.754	119.8	2.0
		167	165.5	0.991	0.704	0.703	117.3	-0.2
68.8	139.5							
		141	101	0.716	0.989	not applicable	not applicable	not applicable
		144	111	0.771	0.969	not applicable	not applicable	not applicable
		147	124	0.844	0.949	0.941	138.3	-0.8
		152	131	0.862	0.918	0.927	140.9	1.0
		157	139	0.885	0.889	0.903	141.8	1.6
		164	152	0.927	0.851	0.845	138.5	-0.7
		172.5	164	0.951	0.809	0.800	138.1	-1.0
		181	175	0.967	0.771	0.765	138.5	-0.7
		191	187	0.979	0.730	0.735	140.4	0.6
91.2	155							
		156	112.5	0.721	0.994	not applicable	not applicable	not applicable
		159.5	121	0.759	0.972	not applicable	not applicable	not applicable
		162	131	0.809	0.957	0.959	155.4	0.2
		165	139	0.842	0.939	0.942	155.4	0.3
		170	148	0.871	0.912	0.919	156.2	0.8
		176	158	0.898	0.881	0.888	156.3	0.8
		183	169.5	0.926	0.847	0.846	154.8	-0.1
		191	181	0.948	0.812	0.807	154.1	-0.6
		200	192	0.960	0.775	0.781	156.1	0.7
		211	207	0.981	0.735	0.730	154.0	-0.6

APPENDIX

9.1

RESULTS OF CALIBRATION TESTS (FINALLY RECOMMENDED STRUCTURES)

CALIBRATION OF FLUME AND COMPOUND WEIR SETUP

Results of model tests

Model 9, Setup 1: Lay-out 2R with sharp-crested weir

	Q (m^3/s)	2.1	2.2	2.3	2.11	2.22	2.33	4	5	6	7	8
1	0.0123	8.05	8.05	8.05	7.95	7.87	7.95	8.65	8.65	8.65	8.80	8.90
2	0.0198	10.15	10.25	10.10	10.10	10.05	10.00	11.20	11.30	11.30	11.30	11.40
3	0.0058	5.15	5.15	5.15	5.10	4.95	5.05	5.40	5.40	5.40	5.45	5.50
4	0.0093	6.80	6.85	6.85	6.80	6.65	6.75	7.30	7.30	7.30	7.35	7.45
5	0.0131	8.25	8.30	8.25	8.20	8.10	8.15	8.90	8.90	8.95	9.00	9.05
6	0.0159	9.15	9.15	9.10	9.05	9.00	9.05	10.00	10.00	10.05	10.05	10.15
7	0.0211	10.50	10.60	10.45	10.40	10.40	10.35	11.65	11.65	11.70	11.75	11.85
8	0.0247	11.30	11.45	11.25	11.20	11.30	11.20	12.75	12.75	12.75	12.85	12.95
9	0.0344	13.30	13.50	13.30	13.35	13.30	13.35	14.50	14.50	14.55	14.55	14.65
10	0.0389	14.15	14.30	14.15	14.25	14.10	14.25	15.05	15.05	15.10	15.15	15.25
11	0.0429	14.75	14.85	14.75	14.85	14.65	14.80	15.50	15.50	15.55	15.55	15.65
12	0.0481	15.50	15.50	15.55	15.50	15.35	15.50	16.05	16.05	16.10	16.10	16.25
13	0.0511	15.85	15.80	15.85	15.80	15.65	15.80	16.25	16.30	16.30	16.35	16.45
14	0.0932	19.10	19.10	19.10	19.15	18.95	19.05	19.35	19.35	19.45	19.40	19.50
15	0.0683	17.30	17.30	17.35	17.35	17.10	17.35	17.65	17.65	17.70	17.70	17.80
16	0.0573	16.35	16.35	16.35	16.35	16.15	16.35	16.70	16.75	16.80	16.80	16.95
17	0.0784	18.10	18.10	18.10	18.15	17.90	18.15	18.35	18.35	18.45	18.40	18.55
18	0.0855	18.55	18.55	18.55	18.60	18.40	18.60	18.80	18.85	18.85	18.85	19.05
19	0.1538	22.00	22.00	22.05	22.15	21.80	22.15	22.35	22.35	22.40	22.30	22.45
20	0.2009	24.00	24.00	24.00	24.20	24.00	24.20	24.40	24.45	24.45	24.35	24.50
21	0.2510	26.00	25.95	26.00	26.40	26.00	26.40	26.45	26.50	26.50	26.35	26.45
22	0.3013	27.60	27.60	27.65	28.10	27.65	28.10	28.15	28.15	28.20	28.10	28.25
23	0.3513	29.40	29.35	29.40	29.85	29.35	29.90	30.00	30.00	30.05	29.95	30.10
24	0.3961	30.70	30.60	30.60	31.25	30.65	31.25	31.35	31.40	31.35	31.25	31.35
25	0.4507	32.10	32.10	32.10	32.80	32.15	32.90	32.85	32.90	32.90	32.80	32.95
26	0.4810	32.95	33.05	33.00	33.70	32.95	33.75	33.85	33.90	33.90	33.65	33.85
27	0.0544	16.15	16.10	16.15	16.15	16.20	16.20	16.55	16.55	16.60	16.65	16.75
28	0.0735	17.85	17.85	17.85	18.00	17.95	18.00	18.10	18.15	18.15	18.25	18.35
29	0.1052	19.85	19.85	19.85	19.95	19.95	20.00	20.05	20.05	20.15	20.15	20.25
30	0.1273	20.95	20.95	20.95	21.20	21.00	21.20	21.25	21.25	21.30	21.25	21.40
31	0.1504	22.05	22.00	22.05	22.35	22.10	22.30	22.35	22.35	22.40	22.35	22.50
32	0.1735	23.05	23.05	23.05	23.30	23.05	23.25	23.35	23.35	23.35	23.40	23.50
33	0.0852	18.60	18.60	18.60	18.75	18.70	18.80	18.85	18.85	18.95	18.95	19.10
34	0.0904	18.95	18.95	18.95	19.15	19.05	19.10	19.20	19.25	19.25	19.25	19.35
35	0.0961	19.35	19.30	19.30	19.50	19.40	19.50	19.55	19.55	19.60	19.65	19.75

CALIBRATION OF FLUME AND COMPOUND WEIR SETUP
Results of model tests

Model 9, Setup 2: Lay-out 2R with Crump weir

	Q (m^3/s)	2.1	2.2	2.3	2.11	2.22	2.33	4	5	6	7	8
1	0.0063	5.25	5.25	5.25	5.35	5.40	5.40	5.80	5.80	5.80	not applicable	
2	0.0154	8.75	8.90	8.75	8.90	8.90	8.90	9.95	9.95	9.95	not applicable	
3	0.0243	10.80	11.25	10.85	11.05	11.35	11.05	12.80	12.80	12.80	not applicable	
4	0.0503	14.15	14.75	14.05	14.90	14.85	15.00	16.20	16.20	16.15	16.05	15.95
5	0.0753	16.75	16.60	16.75	16.75	16.65	16.85	18.00	18.00	18.00	17.90	17.90
6	0.0960	18.00	17.85	18.00	18.20	17.95	18.25	19.35	19.35	19.35	19.10	19.15
7	0.1496	20.55	20.55	20.55	21.15	20.55	21.15	22.15	22.20	22.20	21.70	21.70
8	0.1977	22.50	22.45	22.50	23.15	22.40	23.25	24.35	24.35	24.30	23.60	23.50
9	0.2510	24.50	24.45	24.45	25.20	24.35	25.25	26.45	26.45	26.45	25.60	25.50
10	0.3013	26.20	26.15	26.20	26.95	27.00	27.00	28.35	28.40	28.40	27.25	27.30
11	0.3469	27.65	27.55	27.65	28.40	27.35	28.45	29.95	29.95	29.95	28.75	28.65
12	0.4025	29.25	29.15	29.20	30.15	28.85	30.25	31.75	31.75	31.75	30.30	30.40
13	0.4536	30.65	30.60	30.65	31.50	30.15	31.60	33.20	33.25	33.25	31.65	31.75
14	0.4877	31.55	31.45	31.55	32.45	31.00	32.55	34.25	34.25	34.20	32.50	32.60

CALIBRATION OF FLUME AND COMPOUND WEIR SETUP
Results of model tests

Model 10, Setup 1: Lay-out 1R with sharp-crested weir

	Q (m^3/s)	2.1	2.2	2.3	2.11	2.22	2.33	4	5	6	7	8
1	0.0013	2.70	2.70	2.70	2.80	2.80	2.80	2.90	2.95	2.90	2.90	2.90
2	0.0030	4.50	4.50	4.50	4.60	4.55	4.55	4.80	4.85	4.80	4.85	4.80
3	0.0069	7.30	7.25	7.35	7.40	7.25	7.35	7.90	7.95	7.90	7.90	7.90
4	0.0102	9.15	9.05	9.20	9.30	9.10	9.20	9.95	10.00	9.95	10.00	10.00
5	0.0120	9.90	9.80	9.90	10.00	9.80	9.95	10.85	10.85	10.85	10.85	10.85
6	0.0151	11.20	11.10	11.20	11.20	11.10	11.20	12.35	12.35	12.35	12.35	12.35
7	0.0174	11.95	11.95	12.00	12.10	11.85	12.05	13.35	13.40	13.35	13.35	13.35
8	0.0200	12.85	12.85	12.85	13.00	12.80	13.00	14.50	14.55	14.50	14.55	14.55
9	0.0225	13.60	13.50	13.55	13.75	13.60	13.75	15.50	15.55	15.50	15.55	15.50
10	0.0245	14.10	13.75	14.10	14.25	14.10	14.30	16.25	16.30	16.25	16.30	16.25
11	0.0277	14.80	14.25	14.70	15.00	14.90	15.05	17.30	17.30	17.30	17.30	17.25
13	0.0402	17.30	17.35	17.35	17.70	17.55	17.60	19.30	19.35	19.30	19.35	19.30
14	0.0448	18.30	18.10	18.40	18.30	18.30	18.40	19.80	19.80	19.80	19.85	19.80
15	0.0503	19.10	18.90	19.10	19.05	19.00	19.05	20.30	20.35	20.30	20.35	20.35
16	0.0556	19.65	19.55	19.55	19.65	19.55	19.60	20.75	20.75	20.75	20.75	20.75
17	0.0603	19.90	20.10	19.90	20.05	20.05	20.00	21.15	21.20	21.15	21.15	21.15
18	0.0650	20.65	20.65	20.65	20.50	20.50	20.45	21.50	21.55	21.50	21.55	21.50
19	0.0699	21.20	21.10	21.10	21.00	20.95	20.95	21.90	21.90	21.90	21.95	21.90
20	0.0757	21.60	21.60	21.60	21.50	21.45	21.50	22.30	22.35	22.30	22.35	22.30
21	0.0796	21.95	21.95	21.90	21.90	21.85	21.90	22.65	22.65	22.65	22.65	22.65
22	0.0854	22.40	22.35	22.40	22.40	22.25	22.35	23.00	23.05	23.00	23.05	23.05
23	0.0899	22.70	22.70	22.70	22.75	22.60	22.70	23.35	23.40	23.35	23.35	23.35
24	0.0948	23.10	23.05	23.10	23.10	22.95	23.05	23.65	23.70	23.65	23.70	23.70
25	0.1014	23.45	23.45	23.45	23.45	23.30	23.45	24.00	24.05	24.05	24.10	24.05
26	0.1252	24.65	24.60	24.65	24.65	24.65	24.70	25.25	25.30	25.25	25.25	25.20
27	0.1487	26.00	25.90	26.00	26.05	25.90	26.05	26.60	26.60	26.60	26.60	26.60
28	0.1742	27.00	27.00	27.05	27.10	27.10	27.15	27.65	27.70	27.65	27.70	27.70
29	0.2009	28.25	28.20	28.25	28.40	28.15	28.35	28.95	28.95	28.95	28.95	28.95
30	0.2251	29.10	29.05	29.10	29.30	29.15	29.30	29.95	29.95	29.95	29.85	29.90
31	0.2484	30.10	30.05	30.10	30.30	30.00	30.30	30.90	30.95	30.90	30.90	30.95
32	0.2764	31.05	31.00	31.10	31.25	31.10	31.20	31.80	31.80	31.80	31.80	31.80
33	0.3030	32.05	31.95	32.05	32.10	31.85	32.20	32.90	32.95	32.90	32.90	32.90
34	0.3247	32.70	32.60	32.70	32.90	32.60	32.90	33.60	33.60	33.60	33.60	33.60
35	0.3488	33.50	33.50	33.50	33.70	33.30	33.70	34.45	34.45	34.45	34.40	34.40
36	0.3751	34.20	34.30	34.35	34.65	34.10	34.65	35.30	35.40	35.35	35.25	35.25
37	0.3977	35.05	35.00	35.05	35.30	34.80	35.30	36.10	36.10	36.10	36.05	36.05

CALIBRATION OF FLUME AND COMPOUND WEIR SETUP
Results of model tests

Model 11, Setup 1: Lay-out 3R with sharp-crested weir

	Q (m^3/s)	2.1	2.2	2.3	2.11	2.22	2.33	4	5	6	7	8
1	0.0059	3.50	3.50	3.50	3.55	3.55	3.55	3.85	3.85	3.85	3.90	3.95
1.1	0.0076	4.45	4.50	4.45	4.50	4.55	4.55	4.95	4.95	4.95	5.00	5.05
2	0.0107	5.30	5.30	5.25	5.25	5.40	5.30	5.90	5.90	5.85	5.95	6.05
2.1	0.0126	5.90	5.95	5.85	5.90	5.95	5.90	6.65	6.65	6.65	6.70	6.75
3	0.0147	6.35	6.50	6.35	6.40	6.50	6.40	7.25	7.25	7.25	7.35	7.35
3.1	0.0176	6.95	7.10	6.95	7.05	7.15	7.05	8.00	8.00	8.00	8.10	8.10
4	0.0200	7.55	7.55	7.55	7.50	7.80	7.55	8.60	8.65	8.60	8.70	8.70
5	0.0270	8.85	9.05	8.80	8.90	9.05	8.85	10.45	10.45	10.45	10.55	10.55
6	0.0302	9.10	9.40	9.05	9.10	9.30	9.05	10.80	10.80	10.80	10.90	10.95
7	0.0358	10.40	10.60	10.40	10.60	10.60	10.55	11.65	11.70	11.65	11.80	11.80
7.1	0.0403	10.90	11.10	10.90	11.10	11.05	11.05	12.00	12.00	12.00	12.10	12.15
8	0.0455	11.70	11.75	11.70	11.70	11.65	11.70	12.50	12.50	12.50	12.65	12.65
9	0.0000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	0.0502	12.40	12.30	12.40	12.35	12.25	12.30	12.95	12.95	12.95	13.10	13.10
11	0.0555	12.90	12.80	12.85	12.80	12.75	12.75	13.40	13.40	13.35	13.50	13.50
11.1	0.0606	13.30	13.20	13.25	13.25	13.20	13.25	13.75	13.75	13.70	13.85	13.90
12	0.0648	13.65	13.60	13.65	13.70	13.55	13.65	14.10	14.10	14.05	14.20	14.25
13	0.0698	14.10	14.05	14.05	14.15	14.00	14.15	14.50	14.50	14.50	14.60	14.60
14	0.0750	14.40	14.35	14.40	14.50	14.30	14.45	14.80	14.80	14.75	14.90	14.90
14.1	0.0794	14.75	14.70	14.70	14.85	14.75	14.80	15.10	15.10	15.10	15.20	15.20
15	0.0859	15.10	15.10	15.10	15.25	15.05	15.25	15.50	15.50	15.50	15.70	15.65
16	0.0904	15.45	15.45	15.45	15.65	15.40	15.60	15.85	15.85	15.85	15.90	15.95
17	0.0946	15.70	15.60	15.65	15.80	15.60	15.80	16.05	16.10	16.05	16.10	16.15
18	0.1252	17.30	17.25	17.30	17.50	17.20	17.50	17.70	17.70	17.70	17.75	17.80
19	0.1530	18.50	18.40	18.50	18.75	18.40	18.75	18.95	19.00	18.95	19.00	19.00
20	0.1757	19.40	19.35	19.40	19.70	19.35	19.70	19.90	19.90	19.85	19.90	19.95
21	0.2028	20.40	20.35	20.40	20.70	20.30	20.75	20.90	20.90	20.90	20.90	20.95
22	0.2754	23.00	22.90	23.00	23.55	22.95	23.50	23.65	23.70	23.65	23.60	23.65
23	0.3000	23.90	23.80	23.90	24.45	23.80	24.50	24.60	24.60	24.60	24.50	24.55
24	0.2296	21.55	21.45	21.55	21.95	21.40	21.95	22.10	22.10	22.10	22.00	22.10
25	0.3259	24.70	24.60	24.70	25.25	24.60	25.30	25.45	25.45	25.45	25.35	25.30
26	0.3778	26.25	26.20	26.15	26.95	26.15	26.95	27.10	27.10	27.05	26.95	26.85
27	0.4025	27.00	26.90	26.95	27.65	27.00	27.80	27.90	27.90	27.85	27.70	27.60
28	0.4288	27.70	27.60	27.65	28.35	27.60	28.45	28.60	28.60	28.60	28.35	28.30
29	0.4522	28.30	28.20	28.15	29.10	28.20	29.05	29.30	29.30	29.35	29.05	29.00
30	0.2510	22.25	22.10	22.30	22.75	22.15	22.75	22.95	22.95	22.90	22.80	23.00
31	0.3550	25.65	25.55	25.60	26.20	25.45	26.25	26.40	26.40	26.45	26.25	26.25

APPENDIX

9.2

ANALYSIS OF CALIBRATION TESTS
(FINALLY RECOMMENDED STRUCTURES)

CALIBRATION OF FLUME AND COMPOUND WEIR SETUP

Analysis of test results

Model 9, Setup 1: Lay-out 2R with sharp-crested weir

b =	0.264	m
d =	0.132	m
b_2 =	0.528	m
L =	1.34	m
b_f =	2	m
p =	0.025	m

	y_c (m)	A_c (m²)	B_c (m)	Q_{Tflume} (m³/s)	E_{sc} (m) = E_{s2} (m)		y_2 (m)	Q_{Bflume} (m³/s)	C_{d2}
1	0.059	0.019	0.382	0.013	0.0839	0.0839	0.0795	0.0123	0.92
2	0.076	0.026	0.417	0.020	0.1076	0.1076	0.1005	0.0198	0.97
3	0.037	0.011	0.338	0.006	0.0531	0.0531	0.0508	0.0056	0.93
4	0.050	0.016	0.364	0.010	0.0712	0.0712	0.0678	0.0093	0.92
5	0.061	0.020	0.386	0.014	0.0864	0.0864	0.0818	0.0131	0.93
6	0.068	0.023	0.400	0.017	0.0961	0.0961	0.0905	0.0159	0.95
7	0.079	0.027	0.422	0.022	0.1113	0.1113	0.1038	0.0211	0.98
8	0.086	0.030	0.437	0.025	0.1209	0.1209	0.1120	0.0247	0.99

	y_c (m)	A_c (m²)	B_c (m)	Q_{Tflume} (m³/s)	E_{sc} (m) = E_{s1} (m)		y_1 (m)	Q_{Bflume} (m³/s)	H	P	Q_{weir} (m³/s)	Q_{Tot} (m³/s)	C_{dt}
9	0.105	0.039	0.474	0.035	0.1457	0.1457	0.1452	0.0305	0.0137	0.1570	0.0040	0.0344	0.88
10	0.109	0.041	0.482	0.037	0.1513	0.1513	0.1507	0.0322	0.0193	0.1570	0.0067	0.0389	0.87
11	0.113	0.042	0.489	0.039	0.1559	0.1559	0.1552	0.0337	0.0239	0.1570	0.0092	0.0429	0.86
12	0.117	0.044	0.498	0.042	0.1615	0.1615	0.1607	0.0355	0.0295	0.1570	0.0127	0.0481	0.85
13	0.119	0.045	0.501	0.043	0.1638	0.1638	0.1628	0.0369	0.0318	0.1570	0.0141	0.0511	0.86
14	0.148	0.063	0.660	0.061	0.1961	0.1961	0.1938	0.0524	0.0641	0.1570	0.0408	0.0932	0.86
15	0.129	0.051	0.523	0.050	0.1781	0.1781	0.1767	0.0435	0.0461	0.1570	0.0248	0.0683	0.87
16	0.122	0.047	0.508	0.045	0.1686	0.1686	0.1675	0.0398	0.0366	0.1570	0.0175	0.0573	0.88
17	0.141	0.058	0.660	0.054	0.1856	0.1856	0.1838	0.0473	0.0536	0.1570	0.0311	0.0784	0.87
18	0.145	0.061	0.660	0.057	0.1904	0.1904	0.1883	0.0501	0.0584	0.1570	0.0354	0.0855	0.87
19	0.170	0.077	0.660	0.083	0.2285	0.2285	0.2237	0.0781	0.0965	0.1570	0.0757	0.1538	0.94
20	0.185	0.087	0.660	0.100	0.2514	0.2514	0.2443	0.0963	0.1194	0.1570	0.1046	0.2009	0.97
21	0.201	0.097	0.660	0.117	0.2744	0.2744	0.2648	0.1142	0.1424	0.1570	0.1368	0.2510	0.97
22	0.214	0.106	0.660	0.133	0.2940	0.2940	0.2817	0.1348	0.1620	0.1570	0.1665	0.3013	1.01
23	0.228	0.115	0.660	0.151	0.3150	0.3150	0.3002	0.1505	0.1830	0.1570	0.2008	0.3513	1.00
24	0.238	0.122	0.660	0.165	0.3311	0.3311	0.3137	0.1676	0.1991	0.1570	0.2284	0.3961	1.01
25	0.251	0.131	0.660	0.182	0.3495	0.3495	0.3288	0.1890	0.2175	0.1570	0.2617	0.4507	1.04
26	0.258	0.136	0.660	0.193	0.3611	0.3611	0.3388	0.1975	0.2291	0.1570	0.2835	0.4810	1.03
27	0.121	0.046	0.506	0.044	0.1667	0.1667	0.1657	0.0382	0.0347	0.1570	0.0161	0.0544	0.87
28	0.140	0.057	0.660	0.053	0.1829	0.1829	0.1813	0.0447	0.0509	0.1570	0.0288	0.0735	0.85
29	0.153	0.066	0.660	0.066	0.2036	0.2036	0.2008	0.0570	0.0716	0.1570	0.0482	0.1052	0.87
30	0.162	0.072	0.660	0.074	0.2163	0.2163	0.2127	0.0656	0.0843	0.1570	0.0617	0.1273	0.88
31	0.170	0.077	0.660	0.083	0.2283	0.2283	0.2237	0.0749	0.0963	0.1570	0.0755	0.1504	0.91
32	0.177	0.082	0.660	0.091	0.2392	0.2392	0.2335	0.0846	0.1072	0.1570	0.0888	0.1735	0.93
33	0.145	0.061	0.660	0.058	0.1909	0.1909	0.1888	0.0494	0.0589	0.1570	0.0358	0.0852	0.86
34	0.147	0.062	0.660	0.060	0.1945	0.1945	0.1923	0.0512	0.0625	0.1570	0.0392	0.0904	0.85
35	0.150	0.064	0.660	0.062	0.1981	0.1981	0.1957	0.0534	0.0661	0.1570	0.0427	0.0961	0.86

CALIBRATION OF FLUME AND COMPOUND WEIR SETUP

Analysis of test results

Model 9, Setup 2: Lay-out 2R with Crump weir

b =	0.264	m
d =	0.132	m
b_2 =	0.528	m
L =	1.34	m
b_1 =	2	m
p =	0.025	m

	y_c (m)	A_c (m^2)	B_c (m)	Q_{Tgeut} (m^3/s)	E_{sc} (m) = E_{s2} (m)		y_2 (m)	Q_{Bgeut} (m^3/s)	C_{d2}
1	0.039	0.012	0.342	0.007	0.0563	0.0563	0.0538	0.0063	0.92
2	0.067	0.022	0.397	0.016	0.0945	0.0945	0.0890	0.0154	0.95
3	0.085	0.030	0.434	0.024	0.1193	0.1194	0.1105	0.0243	1.00

	y_c (m)	A_c (m^2)	B_c (m)	Q_{Tgeut} (m^3/s)	E_{sc} (m) = E_{s3} (m)		y_3 (m)	Q_{Bgeut} (m^3/s)	H	p	Q_{weir} (m^3/s)	Q_{Tot} (m^3/s)	C_{d3}
4	0.118	0.045	0.500	0.042	0.1628	0.1628	0.1618	0.0359	0.0308	0.1570	0.0144	0.0503	0.85
5	0.139	0.057	0.660	0.052	0.1817	0.1817	0.1800	0.0457	0.0497	0.1570	0.0295	0.0753	0.88
6	0.148	0.063	0.660	0.061	0.1960	0.1960	0.1935	0.0529	0.0640	0.1570	0.0431	0.0960	0.87
7	0.169	0.076	0.660	0.081	0.2265	0.2265	0.2218	0.0721	0.0945	0.1570	0.0774	0.1496	0.89
8	0.184	0.087	0.660	0.099	0.2503	0.2503	0.2433	0.0893	0.1183	0.1570	0.1084	0.1977	0.90
9	0.200	0.097	0.660	0.117	0.2741	0.2741	0.2645	0.1083	0.1421	0.1570	0.1427	0.2510	0.92
10	0.215	0.107	0.660	0.135	0.2960	0.2960	0.2838	0.1244	0.1640	0.1570	0.1769	0.3013	0.92
11	0.227	0.115	0.660	0.150	0.3141	0.3141	0.2995	0.1399	0.1821	0.1570	0.2070	0.3469	0.93
12	0.241	0.124	0.660	0.169	0.3351	0.3351	0.3175	0.1586	0.2031	0.1570	0.2439	0.4025	0.94
13	0.253	0.132	0.660	0.185	0.3529	0.3529	0.3323	0.1769	0.2209	0.1570	0.2766	0.4536	0.96
14	0.261	0.137	0.660	0.196	0.3648	0.3648	0.3423	0.1883	0.2328	0.1570	0.2993	0.4877	0.96

CALIBRATION OF FLUME AND COMPOUND WEIR SETUP

Analysis of test results

Model 10, Setup 1: Lay-out 1R with sharp-crested weir

b =	0.174	m
d =	0.174	m
b_2 =	0.348	m
L =	1.52	m
b_5 =	2	m
p =	0.027	m

	y_c (m)	A_c (m²)	B_c (m)	Q_{Tgauge} (m³/s)	E_{sc} (m) = E_{s2} (m)		y_2 (m)	Q_{Bgauge} (m³/s)	C_{d2}
1	0.020	0.004	0.194	0.002	0.0289	0.0289	0.0280	0.0013	0.86
2	0.033	0.006	0.207	0.003	0.0475	0.0475	0.0458	0.0030	0.88
3	0.054	0.011	0.228	0.007	0.0774	0.0774	0.0738	0.0069	0.93
4	0.068	0.014	0.242	0.011	0.0977	0.0977	0.0925	0.0102	0.95
5	0.074	0.016	0.248	0.012	0.1058	0.1058	0.0998	0.0120	0.97
6	0.084	0.018	0.258	0.015	0.1197	0.1197	0.1120	0.0151	1.00
7	0.092	0.020	0.266	0.017	0.1295	0.1295	0.1208	0.0174	1.00
8	0.099	0.022	0.273	0.020	0.1400	0.1400	0.1300	0.0200	1.01
9	0.106	0.024	0.280	0.022	0.1488	0.1488	0.1375	0.0225	1.02
10	0.111	0.025	0.285	0.024	0.1552	0.1552	0.1428	0.0245	1.03
11	0.118	0.027	0.292	0.026	0.1646	0.1646	0.1503	0.0277	1.06

	y_c (m)	A_c (m²)	B_c (m)	Q_{Tgauge} (m³/s)	E_{sc} (m) = E_{s1} (m)		y_1 (m)	Q_{Bgauge} (m³/s)	H	p	Q_{weir} (m³/s)	Q_{Total} (m³/s)	C_{d1}
13	0.139	0.034	0.313	0.035	0.1936	0.1936	0.1932	0.0324	0.0196	0.2010	0.0077	0.0402	0.93
14	0.143	0.035	0.317	0.037	0.1985	0.1985	0.1980	0.0340	0.0245	0.2010	0.0108	0.0448	0.93
15	0.147	0.036	0.321	0.038	0.2038	0.2038	0.2032	0.0357	0.0298	0.2010	0.0145	0.0503	0.93
16	0.150	0.037	0.324	0.040	0.2082	0.2082	0.2075	0.0377	0.0342	0.2010	0.0179	0.0556	0.95
17	0.154	0.039	0.328	0.041	0.2125	0.2125	0.2117	0.0389	0.0385	0.2010	0.0214	0.0603	0.94
18	0.156	0.039	0.330	0.043	0.2161	0.2161	0.2152	0.0406	0.0421	0.2010	0.0244	0.0650	0.95
19	0.159	0.040	0.333	0.044	0.2200	0.2200	0.2190	0.0420	0.0460	0.2010	0.0280	0.0699	0.95
20	0.163	0.042	0.337	0.046	0.2243	0.2243	0.2232	0.0436	0.0503	0.2010	0.0320	0.0757	0.96
21	0.178	0.047	0.480	0.047	0.2278	0.2278	0.2265	0.0442	0.0538	0.2010	0.0353	0.0796	0.95
22	0.181	0.049	0.480	0.049	0.2316	0.2316	0.2302	0.0462	0.0576	0.2010	0.0392	0.0854	0.95
23	0.183	0.050	0.480	0.050	0.2352	0.2352	0.2337	0.0470	0.0612	0.2010	0.0430	0.0899	0.93
24	0.185	0.051	0.480	0.052	0.2383	0.2383	0.2367	0.0484	0.0643	0.2010	0.0463	0.0948	0.93
25	0.188	0.052	0.480	0.054	0.2422	0.2422	0.2403	0.0508	0.0682	0.2010	0.0506	0.1014	0.95
26	0.197	0.056	0.480	0.060	0.2552	0.2552	0.2527	0.0593	0.0812	0.2010	0.0659	0.1252	0.98
27	0.206	0.061	0.480	0.068	0.2693	0.2693	0.2660	0.0648	0.0953	0.2010	0.0839	0.1487	0.96
28	0.214	0.064	0.480	0.074	0.2809	0.2809	0.2767	0.0744	0.1069	0.2010	0.0998	0.1742	1.01
29	0.223	0.069	0.480	0.082	0.2946	0.2946	0.2895	0.0810	0.1206	0.2010	0.1200	0.2009	0.99
30	0.230	0.072	0.480	0.088	0.3056	0.3056	0.2995	0.0883	0.1316	0.2010	0.1368	0.2251	1.00
31	0.237	0.076	0.480	0.094	0.3161	0.3161	0.3092	0.0946	0.1421	0.2010	0.1539	0.2484	1.00
32	0.244	0.079	0.480	0.100	0.3262	0.3262	0.3180	0.1057	0.1522	0.2010	0.1707	0.2764	1.05
33	0.252	0.083	0.480	0.108	0.3384	0.3384	0.3292	0.1110	0.1644	0.2010	0.1920	0.3030	1.03
34	0.257	0.085	0.480	0.113	0.3462	0.3462	0.3360	0.1187	0.1722	0.2010	0.2060	0.3247	1.05
35	0.264	0.088	0.480	0.119	0.3557	0.3557	0.3445	0.1251	0.1817	0.2010	0.2237	0.3488	1.05
36	0.270	0.092	0.480	0.125	0.3659	0.3659	0.3535	0.1320	0.1919	0.2010	0.2430	0.3751	1.05
37	0.276	0.094	0.480	0.131	0.3744	0.3744	0.3610	0.1380	0.2004	0.2010	0.2597	0.3977	1.05

CALIBRATION OF FLUME AND COMPOUND WEIR SETUP

Analysis of test results

Model 11, Setup 1: Lay-out 3R with sharp-crested weir

b = 0.412 m
d = 0.103 m
b_2 = 0.721 m
L = 1.147 m
b_5 = 2 m
p = 0.025 m

	y_c (m)	A_c (m²)	B_c (m)	Q_{Tflume} (m³/s)	E_{sc} (m) = E_{s1} (m)		y_2 (m)	Q_{Bflume} (m³/s)	C_{d2}
1	0.026	0.012	0.490	0.006	0.0382	0.0382	0.0355	0.0059	1.02
1.1	0.033	0.015	0.511	0.008	0.0480	0.0480	0.0453	0.0076	0.00
2	0.039	0.019	0.530	0.011	0.0568	0.0568	0.0528	0.0107	0.99
2.1	0.044	0.021	0.544	0.013	0.0635	0.0635	0.0590	0.0126	0.97
3	0.048	0.023	0.557	0.015	0.0692	0.0692	0.0640	0.0147	0.98
3.1	0.054	0.026	0.573	0.018	0.0766	0.0766	0.0705	0.0176	0.99
4	0.058	0.029	0.585	0.020	0.0822	0.0822	0.0753	0.0200	1.00

	y_c (m)	A_c (m²)	B_c (m)	Q_{Tflume} (m³/s)	E_{sc} (m) = E_{s1} (m)		y_1 (m)	Q_{Bflume} (m³/s)	H	p	Q_{weir} (m³/s)	Q_{Tot} (m³/s)	C_{d3}
5	0.074	0.039	0.635	0.030	0.1051	0.1051	0.1046	0.0268	0.0021	0.1280	0.0002	0.0270	0.89
6	0.077	0.041	0.643	0.032	0.1087	0.1087	0.1080	0.0293	0.0057	0.1280	0.0009	0.0302	0.92
7.1	0.086	0.047	0.671	0.039	0.1210	0.1210	0.1200	0.0351	0.0180	0.1280	0.0051	0.0403	0.91
8	0.090	0.049	0.682	0.041	0.1262	0.1262	0.1250	0.0379	0.0232	0.1280	0.0075	0.0455	0.91
10	0.094	0.052	0.693	0.044	0.1308	0.1308	0.1295	0.0403	0.0278	0.1280	0.0099	0.0502	0.91
11	0.097	0.054	0.703	0.047	0.1354	0.1354	0.1338	0.0431	0.0324	0.1280	0.0125	0.0555	0.92
11.1	0.100	0.056	0.711	0.049	0.1391	0.1391	0.1373	0.0459	0.0361	0.1280	0.0147	0.0606	0.93
12	0.107	0.062	0.853	0.052	0.1428	0.1428	0.1408	0.0478	0.0398	0.1280	0.0170	0.0648	0.92
13	0.110	0.064	0.853	0.055	0.1471	0.1471	0.1450	0.0499	0.0441	0.1280	0.0199	0.0698	0.91
14	0.112	0.066	0.853	0.057	0.1502	0.1502	0.1478	0.0529	0.0472	0.1280	0.0220	0.0750	0.93
14.1	0.114	0.068	0.853	0.060	0.1536	0.1536	0.1510	0.0550	0.0506	0.1280	0.0244	0.0794	0.92
15	0.117	0.070	0.853	0.063	0.1579	0.1579	0.1550	0.0583	0.0549	0.1280	0.0277	0.0859	0.93
16	0.119	0.072	0.853	0.066	0.1616	0.1616	0.1585	0.0599	0.0586	0.1280	0.0305	0.0904	0.91
17	0.121	0.074	0.853	0.068	0.1640	0.1640	0.1607	0.0622	0.0610	0.1280	0.0324	0.0946	0.92
18	0.133	0.084	0.853	0.082	0.1819	0.1819	0.1770	0.0773	0.0789	0.1280	0.0479	0.1252	0.94
19	0.142	0.092	0.853	0.094	0.1961	0.1961	0.1897	0.0914	0.0931	0.1280	0.0616	0.1530	0.97
20	0.149	0.098	0.853	0.104	0.2067	0.2067	0.1988	0.1031	0.1037	0.1280	0.0725	0.1757	0.99
21	0.157	0.105	0.853	0.115	0.2186	0.2186	0.2090	0.1172	0.1156	0.1280	0.0856	0.2028	1.02
22	0.179	0.123	0.853	0.146	0.2508	0.2508	0.2367	0.1508	0.1478	0.1280	0.1247	0.2754	1.03
23	0.186	0.129	0.853	0.157	0.2616	0.2616	0.2460	0.1611	0.1586	0.1280	0.1389	0.3000	1.02
24	0.166	0.112	0.853	0.127	0.2312	0.2312	0.2200	0.1293	0.1282	0.1280	0.1003	0.2296	1.02
25	0.193	0.135	0.853	0.168	0.2718	0.2718	0.2545	0.1730	0.1688	0.1280	0.1529	0.3259	1.03
26	0.206	0.146	0.853	0.189	0.2916	0.2916	0.2708	0.1965	0.1886	0.1280	0.1813	0.3778	1.04
27	0.212	0.152	0.853	0.200	0.3012	0.3012	0.2788	0.2068	0.1982	0.1280	0.1957	0.4025	1.03
28	0.218	0.157	0.853	0.210	0.3102	0.3102	0.2860	0.2192	0.2072	0.1280	0.2096	0.4288	1.04
29	0.224	0.162	0.853	0.220	0.3189	0.3189	0.2932	0.2288	0.2159	0.1280	0.2234	0.4522	1.04
30	0.173	0.118	0.853	0.137	0.2417	0.2417	0.2293	0.1378	0.1387	0.1280	0.1132	0.2510	1.01
31	0.200	0.141	0.853	0.180	0.2834	0.2834	0.2642	0.1857	0.1804	0.1280	0.1693	0.3550	1.03

APPENDIX

10.1

SUBMERGENCE TEST RESULTS ON FLUME (FINALLY RECOMMENDED STRUCTURES)

EFFECT OF SUBMERGENCE ON CALIBRATION OF FLUME
Results of model tests

Model 9, Setup 1: Lay-out 2R with sharp-crested weir

	Q (m^3/s)	2.1	2.2	2.3	2.11	2.22	2.33	4	5	6	7	8	9	10	11
37.1	0.056	20.50	20.50	20.55	20.65	20.65	20.80	20.65	20.65	20.75	20.75	20.80	9.30	9.23	9.15
37.2	0.056	20.90	20.95	20.95	21.15	21.00	21.15	21.00	21.05	21.05	21.10	21.20	12.60	12.75	12.90
37.3	0.056	22.00	21.95	21.95	22.20	22.10	22.20	22.00	22.05	22.10	22.10	22.20	16.85	16.53	16.20
37.4	0.056	23.85	23.85	23.85	23.90	23.95	24.05	23.85	23.85	23.85	23.90	24.00	20.35	19.95	19.55
37.5	0.056	27.50	27.50	27.45	27.55	27.60	27.50	27.40	27.45	27.45	27.50	27.65	25.35	25.10	24.85
38.1	0.010	27.45	27.45	27.45	27.60	27.55	27.60	27.60	27.65	27.65	27.65	27.80	14.05	13.60	13.15
38.2	0.010	28.60	28.55	28.60	28.70	28.65	28.70	28.65	28.65	28.70	28.75	28.90	19.30	18.68	18.05
38.3	0.010	30.35	30.35	30.35	30.45	30.50	30.45	30.40	30.45	30.45	30.55	30.70	23.60	23.28	22.95
38.4	0.010	32.95	32.85	32.95	32.95	32.95	32.95	32.95	32.95	33.00	33.05	33.20	28.05	27.63	27.20
38.5	0.010	36.15	36.15	36.15	36.25	36.25	36.20	36.15	36.20	36.20	36.25	44.35	32.35	32.03	31.70
39.1	0.148	32.55	32.55	32.55	32.70	32.60	32.60	32.75	32.75	32.80	32.85	32.95	14.60	13.98	13.35
39.2	0.148	33.40	33.40	33.40	33.55	33.45	33.50	33.55	33.60	33.60	33.65	33.80	19.60	18.85	18.10
39.3	0.148	34.90	34.95	34.95	35.10	34.95	35.10	35.10	35.10	35.15	35.20	35.30	23.95	23.45	22.95
39.4	0.148	36.05	36.05	36.05	36.15	36.10	36.10	36.10	36.15	36.15	36.25	36.40	26.65	25.88	25.10
40.1	0.021	10.60	10.75	10.60	10.65	10.85	10.60	11.85	11.90	11.90	11.95	12.05	7.25	7.10	6.95
40.2	0.021	10.75	10.95	10.75	10.90	11.10	10.85	12.05	12.05	12.10	12.10	12.25	9.55	9.38	9.20
40.3	0.021	12.10	12.25	12.10	12.20	12.35	12.10	13.05	13.05	13.10	13.20	13.30	11.55	11.40	11.25
40.4	0.021	14.25	14.30	14.30	14.40	14.40	14.40	14.55	14.55	14.55	14.60	14.75	13.35	13.25	13.15
40.5	0.021	16.35	16.35	16.35	16.40	16.45	16.40	16.35	16.40	16.40	16.35	16.50	15.60	15.50	15.40
40.6	0.021	20.25	20.25	20.25	20.30	20.35	20.30	20.25	20.25	20.25	20.30	20.45	19.80	19.70	19.60

EFFECT OF SUBMERGENCE ON CALIBRATION OF FLUME

Results of model tests

Model 10, Setup 1: Lay-out 1R with sharp-crested weir

	Q (m^3/s)	2.1	2.2	2.3	2.11	2.22	2.33	4	5	6	7	8	9	10	11
38.11	0.021	9.25	9.10	9.20	13.65	16.00	13.74	15.15	15.15	15.15	10.05	10.05	7.50	7.75	8.10
38.12	0.021	9.25	9.10	9.20	13.70	16.00	13.75	15.25	15.25	15.25	10.05	10.05	9.50	9.85	10.20
38.13	0.021	9.25	9.10	9.20	14.55	16.00	14.60	15.85	15.85	15.85	10.05	10.05	12.90	13.05	13.35
38.14	0.021	9.25	9.10	9.20	16.10	16.00	16.05	17.15	17.15	17.15	10.05	10.05	15.10	15.20	15.35
38.15	0.021	9.25	9.10	9.20	20.95	16.00	19.65	20.30	20.30	20.30	10.05	10.05	18.90	18.90	19.00
38.16	0.021	9.25	9.10	9.20	24.25	16.00	24.20	24.30	24.30	24.30	10.05	10.05	23.25	23.25	23.20
38.17	0.021	9.25	9.10	9.20	30.95	16.00	30.95	31.00	31.00	31.00	10.05	10.05	30.40	30.40	30.40
39.11	0.040	9.25	9.10	9.20	21.45	16.00	21.40	22.30	22.30	22.30	10.05	10.05	6.60	6.95	7.20
39.12	0.040	9.25	9.10	9.20	21.60	16.00	21.55	22.45	22.45	22.45	10.05	10.05	7.85	8.85	9.25
39.13	0.040	9.25	9.10	9.20	22.00	16.00	22.00	22.70	22.70	22.70	10.05	10.05	10.65	11.55	12.35
39.14	0.040	9.25	9.10	9.20	22.90	16.00	22.80	23.30	23.30	23.30	10.05	10.05	14.80	15.40	16.40
39.15	0.040	9.25	9.10	9.20	25.05	16.00	25.10	25.30	25.30	25.30	10.05	10.05	19.60	20.15	20.80
39.16	0.040	9.25	9.10	9.20	29.25	16.00	29.25	29.40	29.40	29.40	10.05	10.05	26.50	26.70	26.90
39.17	0.040	9.25	9.10	9.20	34.80	16.00	34.80	34.90	34.90	34.90	10.05	10.05	33.20	33.25	33.30
40.11	0.060	9.25	9.10	9.20	26.40	16.00	26.40	26.85	26.85	26.85	10.05	10.05	9.30	9.55	10.75
40.12	0.060	9.25	9.10	9.20	26.60	16.00	26.60	27.00	27.00	27.00	10.05	10.05	12.65	12.80	13.45
40.13	0.060	9.25	9.10	9.20	27.15	16.00	27.15	27.55	27.55	27.55	10.05	10.05	17.35	17.70	18.00
40.14	0.060	9.25	9.10	9.20	28.70	16.00	28.70	29.00	29.00	29.00	10.05	10.05	22.05	22.10	22.55
40.15	0.060	9.25	9.10	9.20	31.60	16.00	31.60	31.80	31.80	31.80	10.05	10.05	27.50	27.55	27.60
40.16	0.060	9.25	9.10	9.20	35.80	16.00	35.80	36.00	36.00	36.00	10.05	10.05	32.90	32.95	33.05
41.11	0.080	9.25	9.10	9.20	30.05	16.00	30.00	30.50	30.50	30.50	10.05	10.05	11.10	11.80	12.40
41.12	0.080	9.25	9.10	9.20	30.30	16.00	30.30	30.70	30.70	30.70	10.05	10.05	14.50	15.25	16.00
41.13	0.080	9.25	9.10	9.20	30.85	16.00	30.80	31.25	31.25	31.25	10.05	10.05	18.20	18.65	19.20
41.14	0.080	9.25	9.10	9.20	32.25	16.00	32.25	32.60	32.60	32.60	10.05	10.05	23.20	23.45	23.70
41.15	0.080	9.25	9.10	9.20	34.60	16.00	34.60	34.95	34.95	34.95	10.05	10.05	28.50	28.55	28.60
41.16	0.080	9.25	9.10	9.20	35.85	16.00	35.90	36.15	36.15	36.15	10.05	10.05	30.85	30.85	30.85
42.11	0.097	9.25	9.10	9.20	32.75	16.00	32.80	33.25	33.25	33.25	10.05	10.05	13.70	14.55	15.40
42.12	0.097	9.25	9.10	9.20	33.05	16.00	33.05	33.50	33.50	33.50	10.05	10.05	16.70	17.05	17.35
42.13	0.097	9.25	9.10	9.20	33.65	16.00	33.65	34.10	34.10	34.10	10.05	10.05	20.50	20.75	21.05
42.14	0.097	9.25	9.10	9.20	36.45	16.00	36.45	36.85	36.85	36.85	10.05	10.05	27.80	28.05	28.30

EFFECT OF SUBMERGENCE ON CALIBRATION OF FLUME
Results of model tests

Model 11, Setup 1: Lay-out 3R with sharp-crested weir

	Q (m^3/s)	2.1	2.2	2.3	2.11	2.22	2.33	4	5	6	7	8	9	10	11
32.11	0.0249	8.45	8.60	8.45	8.50	8.65	8.45	9.85	9.85	9.85	9.95	9.95	4.90	5.55	5.20
32.12	0.0249	8.60	8.70	8.50	8.55	8.75	8.55	9.90	9.90	9.90	10.00	10.00	6.50	6.85	6.70
32.13	0.0249	8.90	9.10	8.95	8.95	9.15	8.95	10.20	10.20	10.15	10.25	10.25	8.00	8.20	8.30
32.14	0.0249	9.50	9.60	9.45	9.55	9.70	9.45	10.60	10.60	10.60	10.70	10.70	8.95	8.95	8.95
32.15	0.0249	11.05	11.05	10.95	11.05	11.10	11.00	11.55	11.55	11.55	11.70	11.70	10.10	10.10	10.10
32.16	0.0249	12.60	12.60	12.65	12.60	12.65	12.55	12.80	12.80	12.80	12.90	12.90	11.75	11.75	11.75
32.17	0.0249	14.40	14.40	14.35	14.40	14.40	14.35	14.45	14.45	14.45	14.55	14.55	13.55	13.55	13.55
32.18	0.0249	16.30	16.30	16.35	16.30	16.35	16.25	16.30	16.30	16.30	16.40	16.40	15.65	15.65	15.65
32.19	0.0249	18.70	18.70	18.65	18.75	18.75	18.75	18.75	18.75	18.75	18.85	18.85	18.30	18.30	18.30
33.11	0.0742	18.10	18.05	18.05	18.15	18.05	18.05	18.35	18.35	18.35	18.45	18.50	4.20	6.45	5.30
33.12	0.0742	18.40	18.35	18.35	18.45	18.35	18.45	18.65	18.65	18.65	18.75	18.75	9.10	10.25	9.20
33.13	0.0742	19.50	19.50	19.50	19.60	19.55	19.55	19.70	19.70	19.70	19.80	19.85	14.00	14.35	14.05
33.14	0.0742	21.55	21.55	21.55	21.60	21.55	21.60	21.70	21.70	21.70	21.80	21.80	17.65	18.25	17.85
33.15	0.0742	25.40	25.40	25.40	25.45	25.40	25.40	25.45	25.45	25.45	25.55	25.55	23.10	23.45	23.30
33.16	0.0742	29.60	29.60	29.55	29.60	29.60	29.60	29.60	29.60	29.60	29.70	29.70	28.10	28.30	28.20
33.17	0.0742	32.95	32.95	32.95	33.00	32.95	32.95	33.00	33.00	33.00	33.10	33.10	31.70	32.05	31.90
34.11	0.1242	23.15	23.10	23.15	23.25	22.90	23.30	23.40	23.40	23.40	23.55	23.60	6.40	7.85	7.50
34.12	0.1242	23.70	23.60	23.70	23.85	23.70	23.80	24.00	24.00	24.00	24.10	24.15	10.80	12.35	11.80
34.13	0.1242	25.00	24.90	24.95	25.05	24.95	25.05	25.20	25.20	25.25	25.35	25.35	16.00	17.35	16.40
34.14	0.1242	26.80	26.70	26.75	26.90	26.75	26.85	27.00	26.95	27.00	27.15	27.10	20.35	21.17	20.65
34.15	0.1242	30.00	29.90	29.95	30.10	29.95	30.05	30.10	30.10	30.10	30.20	30.25	25.40	26.30	25.80
34.16	0.1242	34.10	34.05	34.05	34.15	34.10	34.15	34.20	34.20	34.20	34.30	34.35	30.85	31.65	31.30
34.17	0.1242	36.35	36.40	36.35	36.40	36.40	36.40	36.45	36.50	36.45	36.55	36.60	34.15	34.20	34.15

APPENDIX

10.2

ANALYSIS OF SUBMERGENCE TEST RESULTS ON FLUME (FINALLY RECOMMENDED STRUCTURES)

EFFECT OF SUBMERGENCE ON CALIBRATION OF FLUME

Analysis of test results

Model 9, Setup 1: Lay-out 2R with sharp-crested weir

	Ho	hv	t	t/hv	ho/hv
37.1	0.206	0.207	0.092	0.445	0.992
37.2	0.206	0.212	0.128	0.603	0.972
37.3	0.206	0.222	0.165	0.744	0.926
37.4	0.206	0.240	0.200	0.832	0.857
37.5	0.206	0.275	0.251	0.912	0.747
38.1	0.272	0.276	0.136	0.493	0.984
38.2	0.272	0.287	0.187	0.651	0.946
38.3	0.272	0.305	0.233	0.764	0.892
38.4	0.272	0.330	0.276	0.838	0.824
38.5	0.272	0.362	0.320	0.884	0.749
39.1	0.325	0.327	0.140	0.428	0.994
39.2	0.325	0.335	0.189	0.562	0.968
39.3	0.325	0.351	0.235	0.668	0.925
39.4	0.325	0.361	0.259	0.716	0.898
40.1	0.105	0.106	0.071	0.668	0.984
40.2	0.105	0.109	0.094	0.862	0.961
40.3	0.105	0.122	0.114	0.938	0.860
40.4	0.105	0.144	0.133	0.920	0.726
40.5	0.105	0.164	0.155	0.945	0.637
41.5	0.105	0.203	0.197	0.973	0.516

EFFECT OF SUBMERGENCE ON CALIBRATION OF FLUME

Analysis of test results

Model 10, Setup 1: Lay-out 1R with sharp-crested weir

	Ho	hv	t	t/hv	ho/hv
38.11	0.135	0.137	0.078	0.568	0.982
38.12	0.135	0.137	0.099	0.718	0.980
38.13	0.135	0.146	0.131	0.899	0.923
38.14	0.135	0.161	0.152	0.947	0.837
38.15	0.135	0.203	0.189	0.933	0.663
38.16	0.135	0.242	0.232	0.959	0.555
38.17	0.135	0.310	0.304	0.982	0.435
39.11	0.214	0.214	0.069	0.323	0.996
39.12	0.214	0.216	0.087	0.401	0.990
39.13	0.214	0.220	0.115	0.523	0.970
39.14	0.214	0.229	0.155	0.680	0.934
39.15	0.214	0.251	0.202	0.805	0.851
39.16	0.214	0.293	0.267	0.913	0.730
39.17	0.214	0.348	0.333	0.955	0.614
40.11	0.262	0.264	0.099	0.374	0.993
40.12	0.262	0.266	0.130	0.487	0.986
40.13	0.262	0.272	0.177	0.651	0.966
40.14	0.262	0.287	0.222	0.775	0.914
40.15	0.262	0.316	0.276	0.872	0.830
40.16	0.262	0.358	0.330	0.921	0.733
41.11	0.298	0.300	0.118	0.392	0.993
41.12	0.298	0.303	0.153	0.503	0.984
41.13	0.298	0.308	0.187	0.606	0.968
41.14	0.298	0.323	0.235	0.727	0.925
41.15	0.298	0.346	0.286	0.825	0.862
41.16	0.298	0.359	0.309	0.860	0.831
42.11	0.325	0.328	0.146	0.444	0.990
42.12	0.325	0.331	0.170	0.515	0.982
42.13	0.325	0.337	0.208	0.617	0.964
42.14	0.325	0.365	0.281	0.770	0.890

EFFECT OF SUBMERGENCE ON CALIBRATION OF FLUME

Analysis of test results

Model 11, Setup 1: Lay-out 3R with sharp-crested weir

	Ho	hv	t	t/hv	ho/hv
32.11	0.084	0.085	0.052	0.616	0.994
32.12	0.084	0.086	0.067	0.782	0.985
32.13	0.084	0.090	0.082	0.912	0.941
32.14	0.084	0.095	0.090	0.942	0.887
32.15	0.084	0.110	0.101	0.916	0.764
32.16	0.084	0.126	0.118	0.934	0.670
32.17	0.084	0.144	0.136	0.943	0.586
32.18	0.084	0.163	0.157	0.962	0.518
32.19	0.084	0.188	0.183	0.976	0.449
33.11	0.181	0.181	0.053	0.294	0.997
33.12	0.181	0.185	0.095	0.516	0.978
33.13	0.181	0.196	0.141	0.722	0.922
33.14	0.181	0.216	0.179	0.829	0.836
33.15	0.181	0.254	0.233	0.916	0.710
33.16	0.161	0.296	0.282	0.953	0.610
33.17	0.181	0.330	0.319	0.967	0.547
34.11	0.232	0.233	0.073	0.311	0.998
34.12	0.232	0.238	0.117	0.489	0.975
34.13	0.232	0.251	0.166	0.662	0.927
34.14	0.232	0.269	0.207	0.771	0.864
34.15	0.232	0.301	0.258	0.859	0.772
34.16	0.232	0.342	0.313	0.916	0.680
34.17	0.232	0.364	0.342	0.939	0.638

APPENDIX

10.3

SUBMERGENCE TEST RESULTS ON FLUME & SHARP-CREST WEIR (FINALLY RECOMMENDED STRUCTURES)

EFFECT OF SUBMERGENCE ON CALIBRATION OF FLUME AND COMPOUND WEIR SETUP
Results of model tests

Model 9, Setup 1: Lay-out 2R with sharp-crested weir

	Q (m^3/s)	2.1	2.2	2.3	2.11	2.22	2.33	4	5	6	7	8	9	10	11
19.1	0.151	22.15	22.15	22.20	22.30	22.00	22.30	22.45	22.50	22.50	22.45	22.60	14.45	14.50	14.35
19.2	0.151	22.55	22.60	22.55	22.70	22.40	22.70	22.85	22.90	22.90	22.85	23.00	16.90	16.85	16.95
19.3	0.151	23.95	23.95	23.95	24.00	23.75	24.00	24.15	24.15	24.20	24.15	24.30	20.75	20.65	20.70
19.4	0.151	25.75	25.75	25.75	25.80	25.75	25.75	25.90	25.90	25.95	25.90	26.05	23.95	23.95	23.85
21.1	0.247	26.40	26.35	26.40	26.80	26.45	26.85	26.85	26.85	26.85	26.65	26.85	18.15	17.70	17.50
21.2	0.247	27.70	27.70	27.70	28.00	27.90	28.10	28.05	28.05	28.10	28.00	28.00	23.00	21.90	21.70
21.3	0.247	29.35	29.35	29.40	29.60	29.45	29.65	29.55	29.60	29.70	29.90	29.80	26.45	25.85	25.45
23.1	0.350	29.80	29.80	29.80	30.30	29.80	30.30	30.35	30.35	30.40	30.30	30.45	19.55	19.75	18.85
23.2	0.350	31.90	31.90	31.90	32.40	31.95	32.45	32.40	32.40	32.45	32.40	32.45	27.20	26.45	26.50
23.3	0.350	34.85	34.85	34.85	35.15	34.85	35.20	35.15	35.15	35.20	35.15	35.30	32.35	31.50	32.15
25.1	0.451	32.70	32.60	32.70	33.30	32.55	33.35	33.35	33.40	33.45	33.25	33.40	21.00	20.80	22.70
25.2	0.451	34.15	34.15	34.15	34.65	34.15	34.70	34.75	34.75	34.85	34.75	34.80	27.55	26.75	28.65
25.3	0.451	35.75	35.75	35.80	36.25	35.75	36.20	36.25	36.30	36.30	36.20	36.35	30.75	30.25	31.10

EFFECT OF SUBMERGENCE ON CALIBRATION OF FLUME AND COMPOUND WEIR SETUP

Results of model tests

Model 10, Setup 1: Lay-out 1R with sharp-crested weir

	Q (m^3/s)	2.1	2.2	2.3	2.11	2.22	2.33	4	5	6	7	8	9	10	11
4.11	0.010	9.25	9.10	9.20	9.35	9.20	9.30	10.05	10.05	10.05	10.05	10.05	5.05	6.70	5.95
4.12	0.010	9.40	9.25	9.40	9.50	9.35	9.40	10.15	10.15	10.15	10.15	10.15	6.75	7.25	7.50
4.13	0.010	10.20	10.20	10.30	10.35	10.25	10.30	10.90	10.95	10.95	10.90	10.90	8.70	9.25	9.50
4.14	0.010	11.70	11.95	12.00	12.05	12.00	12.05	12.55	12.55	12.55	12.60	12.55	10.95	11.45	11.60
4.15	0.010	14.20	14.20	14.20	14.20	14.20	14.20	14.55	14.60	14.55	14.60	14.55	13.40	13.90	14.05
4.16	0.010	17.30	17.30	17.35	17.30	17.35	17.30	17.60	17.60	17.60	17.65	17.60	17.15	17.20	17.25
6.11	0.015	11.30	11.15	11.30	11.40	11.15	11.35	12.45	12.50	12.45	12.45	12.45	5.70	5.95	6.40
6.12	0.015	11.50	11.30	11.50	11.55	11.30	11.50	12.55	12.55	12.55	12.55	12.55	7.70	7.95	8.20
6.13	0.015	11.85	11.75	11.85	11.85	11.70	11.85	12.90	12.90	12.90	12.85	12.85	9.85	10.10	10.35
6.14	0.015	12.65	12.70	12.70	12.75	12.60	12.70	13.65	13.65	13.65	13.65	13.65	11.35	11.60	11.85
6.15	0.015	14.30	14.30	14.30	14.45	14.30	14.40	15.15	15.15	15.15	15.15	15.15	13.50	13.75	14.00
6.16	0.015	16.80	16.80	16.75	16.80	16.80	16.80	17.40	17.40	17.40	17.35	17.35	16.15	16.40	16.65
8.11	0.020	13.10	13.10	12.90	13.10	12.80	13.00	14.55	14.60	14.55	14.55	14.55	4.20	4.45	4.70
8.12	0.020	13.10	13.10	13.00	13.15	12.90	13.10	14.65	14.65	14.65	14.65	14.65	6.00	6.25	6.50
8.13	0.020	13.10	13.10	13.10	13.20	13.00	13.20	14.70	14.75	14.70	14.70	14.70	7.60	7.85	8.10
8.14	0.020	13.50	13.45	13.40	13.60	13.35	13.50	14.95	15.00	14.95	14.95	14.95	9.60	9.85	10.10
8.15	0.020	14.40	14.40	14.30	14.50	14.30	14.45	15.75	15.75	15.75	15.75	15.75	12.75	13.00	13.25
8.16	0.020	16.60	16.60	16.60	16.50	16.55	16.60	17.70	17.70	17.70	17.70	17.70	15.60	15.85	16.10
13.11	0.040	17.65	17.45	17.60	17.85	17.75	17.85	19.35	19.40	19.35	19.40	19.35	8.45	9.25	10.20
13.12	0.040	17.80	17.80	17.80	18.05	18.00	18.05	19.45	19.50	19.45	19.45	19.45	11.30	12.00	12.70
13.13	0.040	18.75	18.50	18.60	18.70	18.60	18.65	19.65	19.70	19.70	19.75	19.70	14.90	15.35	15.60
13.14	0.040	20.45	20.50	20.45	20.45	20.40	20.40	20.80	20.80	20.80	20.80	20.80	18.60	19.15	19.20
13.15	0.040	23.10	23.10	23.10	23.10	23.05	23.10	23.20	23.20	23.20	23.20	23.15	22.25	22.45	22.40
13.16	0.040	27.00	27.00	27.00	27.05	27.00	27.00	27.05	27.05	27.05	27.05	27.00	26.30	26.75	26.80
17.11	0.060	19.95	20.35	19.90	20.25	20.25	20.20	21.20	21.25	21.20	21.25	21.25	11.20	12.00	12.20
17.12	0.060	20.60	20.60	20.50	20.45	20.45	20.40	21.30	21.35	21.35	21.35	21.35	14.45	15.10	15.20
17.13	0.060	21.25	21.25	21.20	21.20	21.15	21.15	21.75	21.80	21.75	21.75	21.75	17.90	18.40	18.60
17.14	0.060	23.10	23.10	23.10	23.15	23.05	23.05	23.30	23.30	23.30	23.30	23.30	21.15	21.55	21.70
17.15	0.060	26.10	26.10	26.10	26.10	26.10	26.10	26.25	26.25	26.25	26.25	26.25	25.10	25.50	25.90
17.16	0.060	29.20	29.20	29.20	29.20	29.20	29.20	29.25	29.30	29.25	29.25	29.25	28.55	28.85	29.00
21.11	0.080	22.05	22.05	22.05	21.95	21.95	22.00	22.70	22.70	22.70	22.70	22.70	11.05	11.70	11.85
21.12	0.080	22.10	22.10	22.10	22.15	22.05	22.10	22.75	22.75	22.75	22.75	22.75	14.20	14.90	15.00
21.13	0.080	22.65	22.65	22.65	22.70	22.55	22.65	23.10	23.15	24.10	23.15	23.15	18.00	18.70	18.80
21.14	0.080	24.65	24.65	24.65	24.70	24.65	24.70	24.90	24.90	24.90	24.90	24.85	22.15	22.85	22.75
21.15	0.080	28.15	28.15	28.15	28.20	28.15	28.15	28.25	28.30	28.25	28.25	28.25	26.90	27.45	27.35
21.16	0.080	33.30	33.30	33.30	33.30	33.25	33.30	33.30	33.35	33.30	33.35	33.30	32.65	32.95	32.95
25.11	0.101	23.55	23.55	23.55	23.60	23.50	23.55	24.10	24.15	24.10	24.15	24.15	12.60	13.40	13.15
25.12	0.101	23.60	23.60	23.60	23.65	23.55	23.60	24.15	24.15	24.15	24.15	24.15	15.20	16.10	16.25
25.13	0.101	24.15	24.15	24.20	24.25	24.10	24.20	24.60	24.65	24.60	24.60	24.60	19.10	19.70	19.65
25.14	0.101	26.10	26.10	26.10	26.15	26.05	26.10	26.35	26.35	26.35	26.35	26.35	23.10	23.95	23.85
25.15	0.101	29.45	29.45	29.45	29.50	29.45	29.50	29.60	29.65	29.60	29.65	29.60	28.50	28.60	28.80
25.16	0.101	34.50	34.50	34.55	34.55	34.50	34.50	34.60	34.60	34.55	34.55	34.55	33.75	34.10	34.10
27.11	0.149	25.40	25.90	26.00	26.05	25.90	26.05	26.60	26.65	26.60	26.70	26.70	16.20	16.35	16.50
27.12	0.149	26.30	26.30	26.30	26.40	26.25	26.40	26.85	26.90	26.85	26.80	26.80	19.20	19.45	19.10
27.13	0.149	27.25	27.25	27.30	27.35	27.20	27.35	27.61	27.75	27.70	27.70	27.70	23.30	22.85	22.40
27.14	0.149	29.60	29.60	29.60	29.65	29.60	29.65	29.95	29.95	29.95	29.95	29.95	27.80	27.45	27.10
27.15	0.149	33.15	33.10	33.10	33.20	33.10	33.20	33.30	33.35	33.30	33.30	33.30	32.35	32.10	31.85
27.16	0.149	36.55	36.55	36.55	36.55	36.60	36.60	36.60	36.70	36.70	36.70	36.70	35.85	35.70	35.60
29.11	0.201	28.40	28.30	28.40	28.50	28.20	28.50	29.00	29.05	29.00	29.00	29.00	17.50	18.00	18.70
29.12	0.201	28.70	28.60	28.70	28.80	28.55	28.80	29.30	29.30	29.30	29.25	29.25	20.75	21.00	20.95
29.13	0.201	29.80	29.75	29.80	29.90	29.70	29.95	30.35	30.35	30.35	30.30	30.30	25.05	24.70	24.40
29.14	0.201	31.70	31.70	31.70	31.85	31.70	31.90	32.15	32.20	32.15	32.15	32.15	29.45	28.90	28.35
29.15	0.201	36.80	36.80	36.80	36.90	36.80	36.90	37.05	37.10	37.05	37.00	37.00	35.80	35.65	35.50
31.11	0.248	30.25	30.20	30.35	30.45	30.20	30.50	31.05	31.05	31.00	31.05	31.05	20.25	21.20	20.55
31.12	0.248	30.80	30.75	30.85	31.00	30.70	31.00	31.50	31.50	31.50	31.50	31.50	23.20	23.80	23.25
31.13	0.248	31.90	31.90	31.90	32.10	31.90	32.05	32.60	32.60	32.60	32.55	32.55	27.50	26.75	26.95
31.14	0.248	33.60	33.55	33.60	33.75	33.55	33.75	34.10	34.15	34.10	34.10	34.10	30.20	29.95	29.70
31.15	0.240	36.60	36.60	36.60	36.70	36.60	36.70	36.95	36.95	36.95	36.90	36.90	34.50	34.50	34.50
33.11	0.303	32.15	32.05	32.15	32.30	31.85	32.35	33.00	33.00	33.00	32.95	32.95	18.65	19.85	18.90
33.12	0.303	32.40	32.30	32.40	32.60	31.90	32.60	33.20	33.20	33.20	33.20	33.20	22.70	23.20	22.40
33.13	0.303	33.25	33.20	33.25	33.50	32.20	33.45	34.10	34.15	34.10	34.00	34.00	25.90	26.85	26.40
33.14	0.303	34.95	34.90	34.95	35.05	34.90	35.00	35.65	35.65	35.65	35.60	35.60	28.85	29.70	29.65
33.15	0.303	36.60	36.60	36.65	36.75	36.60	36.70	37.10	37.10	37.10	37.10	37.10	32.70	32.85	32.60

EFFECT OF SUBMERGENCE ON CALIBRATION OF FLUME AND COMPOUND WEIR SETUP
Results of model tests

Model 11, Setup 1: Lay-out 3R with sharp-crested weir

	Q (m^3/s)	2.1	2.2	2.3	2.11	2.22	2.33	4	5	6	7	8	9	10	11
2.11	0.107	5.35	5.35	5.30	5.30	5.40	5.35	5.95	5.95	5.90	5.95	5.95	3.80	4.00	4.30
2.12	0.107	5.50	5.55	5.45	5.45	5.60	5.45	6.10	6.10	6.10	6.20	6.20	4.95	4.60	4.85
2.13	0.107	6.00	6.05	6.00	6.05	6.10	6.10	6.50	6.50	6.50	6.60	6.60	5.70	5.55	5.65
2.14	0.107	6.65	6.70	6.65	6.60	6.75	6.65	7.05	7.05	7.05	7.20	7.20	6.55	6.35	6.45
2.15	0.107	7.30	7.35	7.30	7.25	7.40	7.30	7.65	7.65	7.65	7.75	7.75	7.55	7.50	7.20
4.11	0.020	7.60	7.65	7.60	7.55	7.70	7.65	8.70	8.70	8.65	8.80	8.80	4.65	4.55	4.55
4.12	0.020	7.70	7.75	7.65	7.65	7.75	7.70	8.75	8.75	8.75	8.90	8.95	6.05	6.15	5.95
4.13	0.020	7.95	8.10	7.90	7.95	8.15	8.00	9.00	9.00	9.00	9.10	9.10	7.30	7.45	7.20
4.14	0.020	8.80	8.95	8.75	8.75	9.00	8.85	9.65	9.65	9.65	9.75	9.80	8.55	8.65	8.40
4.15	0.020	9.85	9.95	9.80	9.75	10.00	9.85	10.50	10.55	10.50	10.60	10.60	9.75	9.85	9.60
6.11	0.030	9.15	9.50	9.10	9.25	9.50	9.20	10.85	10.85	10.85	10.95	10.95	5.20	5.60	5.50
6.12	0.030	9.20	9.55	9.15	9.25	9.60	9.15	10.90	10.90	10.90	10.95	10.95	6.50	6.95	6.90
6.13	0.030	9.45	9.80	9.40	9.45	9.85	9.50	11.00	11.00	11.00	11.10	11.10	8.00	8.35	8.15
6.14	0.030	11.00	11.05	10.95	11.00	11.10	11.05	11.55	11.60	11.55	11.70	11.70	9.95	10.05	10.05
6.15	0.030	12.05	12.05	12.05	12.05	12.10	11.75	12.30	12.30	12.25	12.40	12.40	11.40	11.40	11.40
6.16	0.030	14.00	14.00	14.00	14.05	14.05	14.05	14.05	14.05	14.05	14.15	14.15	13.55	13.65	13.65
10.11	0.050	12.45	12.35	12.45	12.40	12.35	12.35	13.00	13.00	13.00	13.10	13.10	5.65	5.90	5.75
10.12	0.050	12.50	12.45	12.50	12.50	12.45	12.40	13.00	13.05	13.00	13.15	13.15	7.95	8.25	8.05
10.13	0.050	13.05	13.00	13.05	13.00	13.05	12.95	13.35	13.40	13.35	13.50	13.50	10.55	10.75	10.65
10.14	0.050	14.45	14.45	14.40	14.50	14.45	14.45	14.60	14.60	14.60	14.70	14.70	13.00	13.30	13.30
10.15	0.050	16.70	16.70	16.65	16.75	16.70	16.75	16.75	16.80	16.75	16.80	16.85	16.15	16.15	16.20
13.11	0.698	14.15	14.10	14.15	14.25	14.10	14.20	14.55	14.55	14.55	14.60	14.65	7.65	7.55	7.55
13.12	0.698	14.35	14.30	14.35	14.45	14.30	14.40	14.65	14.70	14.65	14.75	14.80	10.15	10.40	10.20
13.13	0.698	15.00	14.95	14.95	15.10	14.95	15.05	15.20	15.25	15.20	15.30	15.35	12.20	12.55	12.50
13.14	0.698	16.25	16.20	16.25	16.30	16.25	16.30	16.40	16.40	16.40	16.45	16.55	14.70	14.85	14.80
13.15	0.698	18.10	18.10	18.10	18.15	18.10	18.15	18.20	18.20	18.20	18.25	18.30	17.30	17.50	17.55
13.16	0.698	20.20	20.20	20.15	20.30	20.30	20.30	20.25	20.30	20.25	20.30	20.30	19.75	19.85	19.90
16.11	0.090	15.55	15.55	15.55	15.70	15.50	15.70	15.90	15.90	15.90	15.95	16.00	9.40	9.95	9.85
16.12	0.090	16.00	16.00	15.95	16.15	16.00	16.15	16.30	16.35	16.30	16.40	16.40	12.15	12.40	12.35
16.13	0.090	16.80	16.75	16.75	16.85	16.75	16.90	17.00	17.05	17.05	17.10	17.10	14.15	14.50	14.40
16.14	0.090	18.40	18.35	18.35	18.45	18.35	18.45	18.55	18.60	18.55	18.60	18.60	16.90	17.20	17.20
16.15	0.090	20.35	20.30	20.30	20.40	20.35	20.40	20.45	20.45	20.45	20.50	20.50	19.45	19.70	19.70
16.16	0.090	21.85	21.80	21.75	21.85	21.80	21.85	21.90	21.90	21.90	21.95	21.95	21.40	21.40	21.40
19.11	0.153	18.60	18.55	18.60	18.85	18.60	18.85	19.05	19.05	19.05	19.10	19.10	11.00	11.55	11.40
19.12	0.153	18.95	18.85	18.95	19.20	18.90	19.20	19.35	19.35	19.35	19.35	19.45	13.10	13.70	13.50
19.13	0.153	19.35	19.30	19.35	19.60	19.35	19.60	19.75	19.80	19.75	19.80	19.80	15.40	15.75	15.55
19.14	0.153	20.30	20.25	20.30	20.50	20.30	20.55	20.70	20.70	20.65	20.70	20.70	17.70	17.70	17.70
19.15	0.153	22.10	22.05	22.05	22.25	22.10	22.25	22.30	22.35	22.30	22.35	22.35	20.60	20.60	20.60
19.16	0.153	24.55	24.50	24.50	24.60	24.55	24.65	24.70	24.70	24.70	24.75	24.65	23.85	23.85	23.85
29.11	0.452	28.50	28.55	28.35	29.25	28.40	29.25	29.40	29.40	29.40	29.20	29.10	16.35	18.40	16.40
29.12	0.452	28.25	29.00	28.95	29.85	28.95	29.80	30.00	30.05	30.00	29.80	29.70	20.10	21.35	20.70
29.13	0.452	30.15	30.00	30.00	30.60	29.95	30.75	30.85	30.90	30.90	30.70	30.70	24.25	24.85	24.40
29.14	0.452	32.10	32.05	32.05	32.65	32.00	32.70	32.85	32.80	32.75	32.60	32.60	26.95	28.80	27.95
29.15	0.452	34.10	34.10	33.95	34.50	33.95	34.55	34.70	34.70	34.70	34.50	34.55	30.60	31.90	31.10
29.16	0.452	36.45	36.40	36.35	36.75	36.35	36.85	36.80	36.80	36.80	36.75	36.80	34.50	34.85	34.25
30.11	0.251	22.45	22.35	22.45	22.90	22.40	22.90	23.05	23.10	23.05	23.05	23.00	13.80	14.25	14.00
30.12	0.251	23.05	22.95	23.00	23.45	22.95	23.45	23.55	23.60	23.55	23.55	23.50	17.10	17.55	17.05
30.13	0.251	24.40	24.35	24.40	24.75	24.40	24.75	24.85	24.90	24.85	24.85	24.85	19.90	21.15	20.65
30.14	0.251	26.50	26.45	26.45	26.80	26.50	26.80	26.80	26.85	26.85	26.85	26.80	23.65	24.60	24.40
30.15	0.251	29.45	29.40	29.40	29.65	29.45	29.75	29.70	29.70	29.65	29.75	29.70	28.00	28.60	28.20
30.16	0.251	32.95	32.90	32.90	33.05	32.95	33.05	33.10	33.15	33.10	33.20	33.20	32.10	32.55	32.40
31.11	0.355	25.95	25.80	25.80	26.45	25.75	26.50	26.50	26.65	26.65	26.60	26.50	15.10	17.25	16.40
31.12	0.355	26.55	26.40	26.50	27.00	26.35	27.10	27.20	27.25	27.25	27.20	27.10	19.45	20.20	19.70
31.13	0.355	27.70	27.50	27.55	28.15	27.55	28.20	28.35	28.40	28.35	28.25	28.25	21.85	23.55	22.80
31.14	0.355	29.70	29.60	29.65	30.05	29.55	30.15	30.20	30.25	30.15	30.20	30.10	25.70	26.95	26.35
31.15	0.355	31.70	31.60	31.75	32.05	31.65	32.05	32.15	32.15	32.15	32.10	32.00	29.70	29.75	29.80
31.16	0.355	34.40	34.40	34.35	34.65	34.35	34.70	34.70	34.70	34.70	34.70	34.60	32.70	33.30	32.90
31.17	0.355	37.05	37.00	36.95	37.10	36.95	37.15	37.20	37.20	37.20	37.20	37.20	36.10	36.15	36.20

APPENDIX

10.4

ANALYSIS OF SUBMERGENCE TEST RESULTS ON FLUME & SHARP-CREST WEIR (FINALLY RECOMMENDED STRUCTURES)

EFFECT OF SUBMERGENCE ON CALIBRATION OF FLUME AND COMPOUND WEIR SETUP
Analysis of test results

Model 9, Setup 1: Lay-out 2R with sharp-crested weir

	Ho	hv	t	t/hv	ho/hv
19.1	0.2215	0.2230	0.1443	0.6472	0.9933
19.2	0.2215	0.2270	0.1690	0.7445	0.9758
19.3	0.2215	0.2400	0.2070	0.8625	0.9229
19.4	0.2215	0.2578	0.2392	0.9279	0.8594
21.1	0.2640	0.2683	0.1778	0.6629	0.9842
21.2	0.2640	0.2805	0.2220	0.7914	0.9412
21.3	0.2640	0.2963	0.2592	0.8748	0.8911
23.1	0.2988	0.3030	0.1938	0.6397	0.9860
23.2	0.2988	0.3243	0.2672	0.8240	0.9214
23.3	0.2988	0.3518	0.3200	0.9097	0.8493
25.1	0.3285	0.3333	0.2150	0.6452	0.9857
25.2	0.3285	0.3468	0.2765	0.7974	0.9474
25.3	0.3285	0.3623	0.3070	0.8475	0.9068

EFFECT OF SUBMERGENCE ON CALIBRATION OF FLUME AND COMPOUND WEIR SETUP

Analysis of test results

Model 10, Setup 1: Lay-out 1R with sharp-crested weir

	Ho	hv	t	t/hv	ho/hv
4.11	0.0925	0.0933	0.0590	0.6327	0.9920
4.12	0.0925	0.0945	0.0717	0.7584	0.9788
4.13	0.0925	0.1033	0.0915	0.8862	0.8959
4.14	0.0925	0.1205	0.1133	0.9405	0.7676
4.15	0.0925	0.1420	0.1378	0.9707	0.6514
4.16	0.0925	0.1730	0.1720	0.9942	0.5347
6.11	0.1120	0.1138	0.0602	0.5289	0.9846
6.12	0.1120	0.1153	0.0795	0.6898	0.9718
6.13	0.1120	0.1185	0.1010	0.8523	0.9451
6.14	0.1120	0.1273	0.1160	0.9116	0.8802
6.15	0.1120	0.1443	0.1375	0.9532	0.7764
6.16	0.1120	0.1680	0.1640	0.9762	0.6667
8.11	0.1300	0.1305	0.0445	0.3410	0.9962
8.12	0.1300	0.1313	0.0625	0.4762	0.9905
8.13	0.1300	0.1320	0.0785	0.5947	0.9848
8.14	0.1300	0.1355	0.0985	0.7269	0.9594
8.15	0.1300	0.1448	0.1300	0.8981	0.8981
8.16	0.1300	0.1655	0.1585	0.9577	0.7855
13.11	0.1765	0.1785	0.0930	0.5210	0.9888
13.12	0.1765	0.1805	0.1200	0.6648	0.9778
13.13	0.1765	0.1868	0.1528	0.8184	0.9451
13.14	0.1765	0.2043	0.1898	0.9294	0.8641
13.15	0.1765	0.2310	0.2237	0.9683	0.7641
13.16	0.1765	0.2703	0.2662	0.9849	0.6531
17.11	0.2003	0.2023	0.1180	0.5834	0.9901
17.12	0.2003	0.2043	0.1492	0.7303	0.9804
17.13	0.2003	0.2118	0.1830	0.8642	0.9457
17.14	0.2003	0.2310	0.2147	0.9293	0.8669
17.15	0.2003	0.2610	0.2550	0.9770	0.7672
17.16	0.2003	0.2920	0.2880	0.9863	0.6858
21.11	0.2190	0.2198	0.1153	0.5248	0.9966
21.12	0.2190	0.2213	0.1470	0.6644	0.9898
21.13	0.2190	0.2268	0.1850	0.8159	0.9658
21.14	0.2190	0.2470	0.2258	0.9143	0.8866
21.15	0.2190	0.2818	0.2723	0.9666	0.7773
21.16	0.2190	0.3330	0.3285	0.9865	0.6577
25.11	0.2345	0.2358	0.1305	0.5536	0.9947
25.12	0.2345	0.2363	0.1585	0.6709	0.9926
25.13	0.2345	0.2423	0.1948	0.8043	0.9680
25.14	0.2345	0.2613	0.2363	0.9046	0.8976
25.15	0.2345	0.2950	0.2863	0.9706	0.7949
25.16	0.2345	0.3453	0.3398	0.9843	0.6792
27.11	0.2605	0.2605	0.1635	0.6276	1.0000
27.12	0.2605	0.2640	0.1925	0.7292	0.9867
27.13	0.2605	0.2735	0.2285	0.8355	0.9525
27.14	0.2605	0.2965	0.2745	0.9258	0.8786
27.15	0.2605	0.3320	0.3210	0.9669	0.7846
27.16	0.2605	0.3658	0.3572	0.9765	0.7122
29.11	0.2838	0.2850	0.1807	0.6339	0.9956
29.12	0.2838	0.2880	0.2090	0.7257	0.9852
29.13	0.2838	0.2993	0.2472	0.8260	0.9482
29.14	0.2838	0.3188	0.2890	0.9067	0.8902
29.15	0.2838	0.3690	0.3565	0.9661	0.7690
31.11	0.3030	0.3048	0.2067	0.6782	0.9943
31.12	0.3030	0.3100	0.2342	0.7554	0.9774
31.13	0.3030	0.3208	0.2707	0.8439	0.944/
31.14	0.3030	0.3375	0.2995	0.8874	0.8978
31.15	0.3030	0.3670	0.3450	0.9401	0.8256
33.11	0.3215	0.3233	0.1913	0.5919	0.9946
33.12	0.3215	0.3260	0.2277	0.6984	0.9862
33.13	0.3215	0.3348	0.2638	0.7882	0.9604
33.14	0.3215	0.3503	0.2940	0.8394	0.9179
33.15	0.3215	0.3673	0.3272	0.8909	0.8754

EFFECT OF SUBMERGENCE ON CALIBRATION OF FLUME AND COMPOUND WEIR SETUP

Analysis of test results

Model 11, Setup 1: Lay-out 3R with sharp-crested weir

	Ho	hv	t	t/hv	ho/hv
2.11	0.0528	0.0533	0.0403	0.7574	0.9906
2.12	0.0528	0.0545	0.0480	0.8807	0.9679
2.13	0.0528	0.0608	0.0563	0.9273	0.8683
2.14	0.0528	0.0663	0.0645	0.9736	0.7962
2.15	0.0528	0.0728	0.0742	1.0195	0.7251
4.11	0.0753	0.0760	0.0458	0.6031	0.9901
4.12	0.0753	0.0768	0.0605	0.7883	0.9805
4.13	0.0753	0.0798	0.0732	0.9175	0.9436
4.14	0.0753	0.0880	0.0853	0.9697	0.8551
4.15	0.0753	0.0980	0.0973	0.9932	0.7679
6.11	0.0908	0.0923	0.0543	0.5890	0.9837
6.12	0.0908	0.0920	0.0678	0.7373	0.9864
6.13	0.0908	0.0948	0.0817	0.8619	0.9578
6.14	0.0908	0.1103	0.1002	0.9085	0.8231
6.15	0.0908	0.1190	0.1140	0.9580	0.7626
6.16	0.0908	0.1405	0.1362	0.9692	0.6459
10.11	0.1233	0.1238	0.0577	0.4660	0.9960
10.12	0.1233	0.1245	0.0808	0.6493	0.9900
10.13	0.1233	0.1298	0.1065	0.8208	0.9499
10.14	0.1233	0.1448	0.1320	0.9119	0.8515
10.15	0.1233	0.1675	0.1617	0.9652	0.7358
13.11	0.1415	0.1423	0.0758	0.5331	0.9947
13.12	0.1415	0.1443	0.1025	0.7106	0.9809
13.13	0.1415	0.1508	0.1242	0.8237	0.9386
13.14	0.1415	0.1630	0.1478	0.9070	0.8681
13.15	0.1415	0.1815	0.1745	0.9614	0.7796
13.16	0.1415	0.2030	0.1983	0.9770	0.6970
16.11	0.1563	0.1570	0.0973	0.6200	0.9952
16.12	0.1563	0.1615	0.1230	0.7616	0.9675
16.13	0.1563	0.1688	0.1435	0.8504	0.9259
16.14	0.1563	0.1845	0.1710	0.9268	0.8469
16.15	0.1563	0.2040	0.1962	0.9616	0.7659
16.16	0.1563	0.2185	0.2140	0.9794	0.7151
19.11	0.1875	0.1885	0.1132	0.6004	0.9947
19.12	0.1875	0.1920	0.1343	0.6997	0.9766
19.13	0.1875	0.1960	0.1557	0.7942	0.9566
19.14	0.1875	0.2053	0.1770	0.8624	0.9135
19.15	0.1875	0.2225	0.2060	0.9258	0.8427
19.16	0.1875	0.2463	0.2385	0.9685	0.7614
29.11	0.2908	0.2925	0.1705	0.5829	0.9940
29.12	0.2908	0.2983	0.2072	0.6946	0.9749
29.13	0.2908	0.3068	0.2450	0.7987	0.9478
29.14	0.2908	0.3268	0.2790	0.8539	0.8898
29.15	0.2908	0.3453	0.3120	0.9037	0.8421
29.16	0.2908	0.3680	0.3457	0.9393	0.7901
30.11	0.2275	0.2290	0.1402	0.6121	0.9934
30.12	0.2275	0.2345	0.1723	0.7349	0.9701
30.13	0.2275	0.2475	0.2057	0.8310	0.9192
30.14	0.2275	0.2680	0.2422	0.9036	0.8489
30.15	0.2275	0.2970	0.2827	0.9517	0.7660
30.16	0.2275	0.3305	0.3235	0.9788	0.6884
31.11	0.2623	0.2648	0.1658	0.6264	0.9906
31.12	0.2623	0.2705	0.1978	0.7314	0.9695
31.13	0.2623	0.2818	0.2273	0.8069	0.9308
31.14	0.2623	0.3010	0.2633	0.8749	0.8713
31.15	0.2623	0.3205	0.2975	0.9282	0.8183
31.16	0.2623	0.3468	0.3297	0.9507	0.7563
31.17	0.2623	0.3713	0.3615	0.9737	0.7064

APPENDIX

10.5

SUBMERGENCE TEST RESULTS ON FLUME & CRUMP WEIR (FINALLY RECOMMENDED STRUCTURES)

EFFECT OF SUBMERGENCE ON CALIBRATION OF FLUME AND COMPOUND WEIR SETUP

Results of model tests

Model 9, Setup 2: Lay-out 2R with Crump weir

	Q (m^3/s)	2.1	2.2	2.3	2.11	2.22	2.33	4	5	6	7	8	9	10	11
4.11	0.050	14.20	14.65	14.20	15.00	14.95	15.05	16.25	16.25	16.25	16.20	16.20	8.80	8.85	8.85
4.12	0.050	14.30	14.95	14.30	15.10	15.10	15.20	16.30	16.30	16.30	16.25	16.20	10.85	10.90	11.05
4.13	0.050	14.65	15.15	14.65	15.35	15.30	15.40	16.50	16.50	16.40	16.35	16.30	12.95	12.95	13.10
4.14	0.050	15.85	15.85	15.85	16.05	16.10	16.15	16.80	16.80	16.80	16.70	16.70	15.15	15.15	15.15
4.15	0.050	17.20	17.25	17.30	17.30	17.30	17.35	17.70	17.75	17.75	17.50	17.40	17.00	17.00	17.00
4.16	0.050	18.75	18.60	18.75	18.90	18.85	18.90	19.05	19.05	19.06	19.00	19.00	18.65	18.65	18.65
7.11	0.150	20.65	20.65	20.65	21.15	20.60	21.20	22.25	22.25	22.25	21.70	21.75	14.90	15.20	15.00
7.12	0.150	20.75	20.75	20.75	21.25	20.70	21.25	22.25	22.25	22.25	21.75	20.80	16.65	16.85	16.75
7.13	0.150	20.85	20.85	20.85	21.35	20.85	21.35	22.35	22.35	22.35	21.80	21.90	18.85	19.20	18.95
7.14	0.150	21.55	21.55	21.55	21.95	21.55	22.00	22.75	22.80	22.80	22.20	22.25	20.95	21.05	20.85
7.15	0.150	22.70	22.65	22.70	23.05	22.75	23.15	23.60	23.60	23.60	23.05	23.10	22.95	22.95	22.95
7.16	0.150	24.40	24.35	24.40	24.65	24.45	24.70	25.05	25.05	25.00	24.60	24.65	24.55	24.55	24.55
9.11	0.251	24.60	24.55	24.60	25.25	24.40	25.35	26.45	26.50	26.45	25.60	25.65	19.80	20.30	20.00
9.12	0.251	24.70	24.65	24.70	25.35	24.55	25.40	26.55	26.55	26.55	25.70	25.70	22.00	22.50	22.20
9.13	0.251	25.15	25.15	25.15	25.90	25.15	25.85	26.90	26.90	26.90	26.15	26.20	24.85	24.95	24.85
9.14	0.251	26.40	26.40	26.40	27.05	26.45	27.05	28.90	28.90	28.90	26.95	27.00	26.95	27.10	26.95
9.15	0.251	28.45	28.45	28.45	29.00	28.55	29.00	29.55	29.55	29.55	28.95	28.85	28.85	28.85	28.85
11.11	0.347	27.65	27.60	27.65	28.45	27.35	28.55	29.95	29.95	29.95	28.75	28.80	21.75	22.40	21.80
11.12	0.347	27.75	27.70	27.75	28.50	27.45	28.70	30.05	30.05	30.05	28.80	28.80	23.95	24.55	24.30
11.13	0.347	28.00	28.00	28.00	28.90	27.85	28.95	30.25	30.30	30.25	29.00	29.00	26.80	27.25	26.90
11.14	0.347	29.20	29.20	29.20	29.85	29.00	29.90	31.10	31.10	31.10	29.90	29.95	29.60	29.75	29.50
11.15	0.347	31.35	31.35	31.35	31.65	31.25	31.90	32.75	32.75	32.75	31.75	31.70	32.05	31.95	31.85
11.16	0.347	33.05	33.05	33.05	33.55	32.95	33.70	34.25	34.30	34.25	33.40	33.35	33.85	33.75	33.85
13.11	0.454	30.95	30.90	30.90	31.60	30.50	32.00	33.45	33.50	33.45	32.00	32.15	27.75	27.95	28.25
13.12	0.454	31.50	31.40	31.45	32.40	31.15	32.45	33.80	33.80	33.80	32.35	31.45	30.65	30.85	30.95
13.13	0.454	33.45	33.45	33.45	34.25	33.35	34.30	35.35	35.35	35.35	33.90	34.05	34.55	34.55	34.55
13.14	0.454	35.20	35.20	35.20	35.90	35.15	35.95	36.90	36.95	36.90	35.70	35.75	36.45	36.75	37.30

APPENDIX

10.6

ANALYSIS OF SUBMERGENCE TEST RESULTS ON FLUME & CRUMP WEIR (FINALLY RECOMMENDED STRUCTURES)

EFFECT OF SUBMERGENCE ON CALIBRATION OF FLUME AND COMPOUND WEIR SETUP

Analysis of test results

Model 9, Setup 2: Lay-out 2R with Crump weir

	Ho	hv	t	t/hv	ho/hv
4.11	0.1495	0.1503	0.0883	0.5879	0.9950
4.12	0.1495	0.1515	0.1093	0.7217	0.9868
4.13	0.1495	0.1538	0.1300	0.8455	0.9724
4.14	0.1495	0.1610	0.1515	0.9410	0.9286
4.15	0.1495	0.1733	0.1700	0.9812	0.8629
4.16	0.1495	0.1890	0.1865	0.9868	0.7910
7.11	0.2115	0.2118	0.1503	0.7100	0.9988
7.12	0.2115	0.2125	0.1675	0.7882	0.9953
7.13	0.2115	0.2135	0.1900	0.8899	0.9906
7.14	0.2115	0.2198	0.2095	0.9534	0.9625
7.15	0.2115	0.2310	0.2295	0.9935	0.9156
7.16	0.2115	0.2468	0.2455	0.9949	0.8571
9.11	0.2523	0.2530	0.2003	0.7918	0.9970
9.12	0.2523	0.2538	0.2223	0.8762	0.9941
9.13	0.2523	0.2588	0.2488	0.9617	0.9749
9.14	0.2523	0.2705	0.2700	0.9982	0.9325
9.15	0.2523	0.2900	0.2885	0.9948	0.8698
11.11	0.2843	0.2850	0.2198	0.7713	0.9974
11.12	0.2843	0.2860	0.2427	0.8485	0.9939
11.13	0.2843	0.2893	0.2698	0.9329	0.9827
11.14	0.2843	0.2988	0.2962	0.9914	0.9515
11.15	0.2843	0.3188	0.3195	1.0024	0.8918
11.16	0.2843	0.3363	0.3382	1.0057	0.8454
13.11	0.3155	0.3190	0.2798	0.8772	0.9890
13.12	0.3155	0.3243	0.3082	0.9504	0.9730
13.13	0.3155	0.3428	0.3455	1.0080	0.9205
13.14	0.3155	0.3593	0.3683	1.0253	0.8782