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LABORATORY CALIBRATION OF COMPOUND SHARP-CRESTED AND CRUMP WEIRS

Report to the
WATER RESEARCH COMMISSION
by
SIGMA BETA CONSULTING ENGINEERS

WRC Report No 442/1/95

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List of symbols

A = flow cross section normal to flow direction

A_p = effective cross-sectional area of weir pool

b = bottom width of flow section

B = top width of flow section

C = Chézy coefficient

C_c = contraction coefficient

C_D = discharge coefficient

d = particle diameter

E = specific energy

F = Froude number

g = gravitational acceleration

G = length downstream sector of Parshall flume

h = head

h_c = critical depth

h_e = effective overflow depth

h_f = head loss

H = total energy head

h_{max} = design head

h_a = head at measuring point upstream of weir

h_b = head at measuring point downstream of weir

k = constant

l = characteristic length scale

L = length dimension

L_1 = low notch length

L_2 = higher notch length

m = side slope
p = pressure
P = pool depth
q = discharge per unit width
Q = discharge
R = eddy radius
R_e = Reynolds number
R_e* = shear Reynolds number
s = energy slope
T = step height
u = exponent
v = flow velocity
V = average flow velocity
V_{max} = maximum flow velocity
$V*$ = shear velocity
x = distance in horizontal direction
y = distance in vertical direction
z = height of bed level above datum

α = velocity (energy) coefficient
β = velocity (momentum) coefficient
γ = ratio maximum: minimum discharge
K = von Kármán coefficient
$\varnothing$ = angle of weir crest with vertical
τ = shear stress
τ_l = laminar shear stress
τ_t = turbulent shear stress

μ = dynamic viscosity

D = Kinematic viscosity

ρ = fluid density

ρ_s = sediment density

E = apparent density

DEFINITIONS AND ACRONYMS USED IN THIS REPORT

Compound weir	A weir in which the crest level is varied in steps across a river section (see Figure 2.4).
Crump weir:	A weir with a triangular section with slopes of 1:2 and 1:5 on the upstream and downstream sides of the crest respectively (see Figure 2.3).
Design overflow height (h_{max}):	Height of water upstream of weir relative to the crest of the low section of the weir for the maximum design discharge over the weir. (see Figure 2.3)
Dividing walls:	Walls that are used to separate discharges over adjacent crests of a compound weir.
Effective overflow depth (h_e):	The average value of the water level above the average crest height of a compound weir (see Figure (i).
Effective pool depth (P_e):	The average value of the water level above the average crest height of a compound weir
Energy head (H):	The sum of the potential and kinetic energy heads relative to the crest of the weir (see Figure (i) This is normally determined at a fixed distance upstream of the weir.
Low and high crests:	In model tests, compound weirs with only two crest heights were tested. These are referred to as the low crest and high crest (weirs) respectively.
Overflow depth (h):	The difference in level between the crest of the weir and the water level measured at a given distance upstream of the weir.
Pool:	The pool formed upstream of a weir due to the damming effect of the weir.
Pool depth (P):	The depth of the pool below the low crest of the weir (see Figure 1.1).
Sharp-crested weir:	A more robust South African version of a thin plate weir to make it suitable for use in rivers (see Figure 2.2).
Step height (T):	The difference in level between the low and the high crest of the weir (see Figure (i).
Thin plate weir:	A vertical barrier with a thin crest used for flow measurement (see Figure 2.1).

ACRONYMS

BSI	British Standards Institute
DWAF	Department of Water Affairs and Forestry
ISO	International Standards Organization
US	University of Stellenbosch
WRC	Water Research Commission

DEFINITION OF PARAMETERS

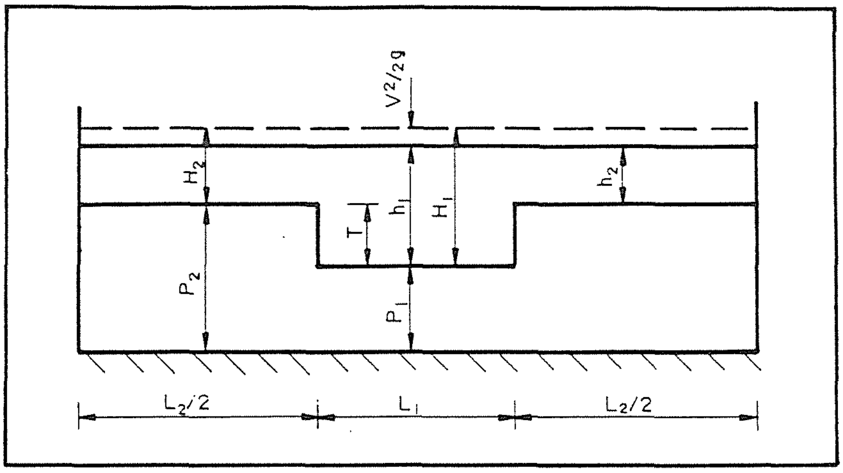

Figure (i) Model configuration

L_1 = Length of low crest

L_2 = Length of high crest

P_1 = Pool depth below crest of low crest

P_2 = Pool depth below crest of high crest

h_1 = Measured water level relative to low crest

H_1 = Energy head relative to low crest

h_2 = Measured water level relative to high crest

H_2 = Energy head relative to high crest

T = Difference in height between the high and low crest relatively

$$P_e = \frac{P_1 \times L_1 + P_2 \times L_2}{(L_1 + L_2)} \qquad \text{for } h > T$$

$$= \frac{P_1 \times L_1 + (P_1 + h_1)L_2}{L_1 + L_2} \qquad \text{for } h < T$$

$$H_e = \frac{H_1 \times L_1 + H_2 \times L_2}{(L_1 + L_2)}$$

$$= H_1 \qquad \text{for } h < T$$

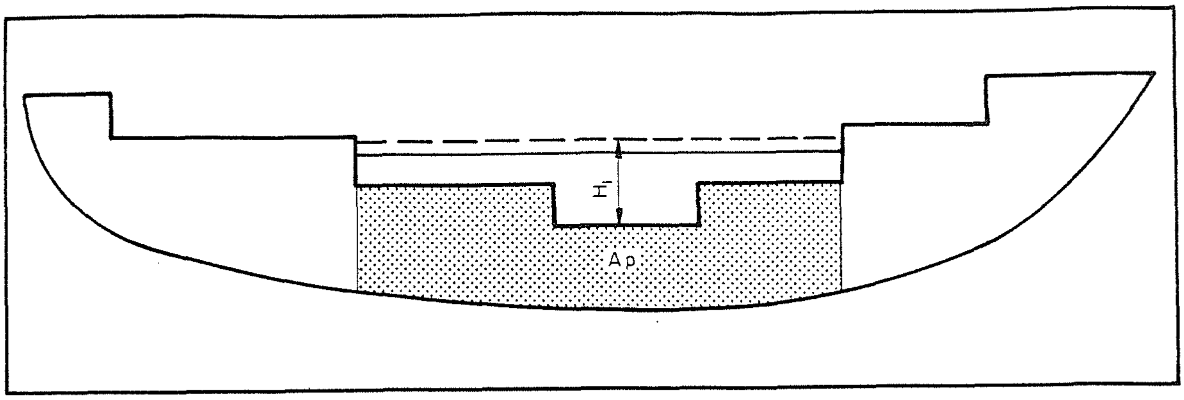

Figure (ii) Prototype configuration

To determine H_e and P_e only the sections of the weir that are overtopped are used

$$\left.\begin{aligned} P_e &= \frac{A_p}{(L_1+L_2)} \\[2ex] H_e &= \frac{H_1\times L_1+H_2\times L_2}{(L_1+L_2)}\end{aligned}\right]\quad \text{when two crest levels are overtopped}$$

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As project leader I wish to thank the following persons and organizations for their contributions to the project and to the two reports which have been produced.

(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 Director of the *WRC* for his able leadership on the project.

(ii) The *Department of Water Affairs & 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.

Mr *Pieter Wessels* has played an invaluable role in the project not only as the main link between ourselves and the Department, but also as tenacious advocate of precision.

(iii) My colleague, Dr *Jan Rossouw*, played the key role in the tests which were performed on Crump and Sharp-crested weirs as well as being the main author of one of the reports.

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

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Mr GR Basson
Mr S van Biljon
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Mr JJ van Heerden
Prof TW von Backström
Mr FP Marais

A. ROOSEBOOM, PROJECT LEADER

ABSTRACT

This report covers the first of the two main parts of investigations which have been completed for the Water Research Commission by *Sigma Beta*. The main purpose of the investigations was to:

> "Develop improved flow gauging structures for Southern African rivers"

under the sub-headings:

(i) Upgrading of existing gauging stations through re-calibration and standardization.

(ii) Development of an ideal new gauging structure which would require minimum maintenance and still provide acceptable results in sediment-laden rivers.

Compound sharp-crested and Crump weirs, where the crest height of the weir is varied in a number steps across the river section, are commonly used for flow gauging in South African rivers. British standards require that dividing walls should be used with compound weirs in order to separate the flows over the different crest sections of the weir. Where dividing walls are not used, the standards require that these weirs should be calibrated in situ or in models.

Approximately 90 percent of the river flow gauging structures in South Africa consist of sharp-crested and Crump weirs without dividing walls. The calibration of these types of structures, in terms of the British standards is necessary in order to ensure internationally acceptable accuracies.

This report follows on extensive series of calibration tests that were performed on compound sharp crested and Crump weirs. These tests were performed in the hydraulics laboratories of the Civil Engineering Department of the University of Stellenbosch. Earlier results from tests on compound Crump weirs at the hydraulics laboratory of the Department of Water Affairs and Forestry in Pretoria are also included in this report. The main purpose of these tests was to determine the magnitude of errors that are introduced through the South African practice of using compound weirs without dividing walls for flow measurement. The effect of a number of parameters including pool depth, overflow height, step heights between adjacent weir crests, relative lengths of adjacent crests, etc. on the accuracy of the measurement was determined. In order to determine the worth of dividing walls, most of the tests were performed both with and without these walls. The results of these tests were used to develop discharge formulae and techniques in order to improve the accuracy with which the discharge can be determined from past and future water stage records. Recommendations are also included on sound practice for flow gauging with compound sharp-crested and Crump weirs.

The results of the study prove conclusively that accurate flow measurements are possible with sharp-crested and Crump weirs without dividing walls. The standard method of analysis used to date leads to the slight overestimation of discharge values when the flow depths above adjacent weirs differ by more than 50 per cent. This overestimation varies from an average of 7 percent when the flow over

the higher crest commences and reduces to zero when the flow depth above the higher crest becomes more than 50 percent of the depth above the low crest. This overestimation can easily be corrected by adjusting the discharge coefficient for the weir. Adjustments whereby the discharge coefficient is expressed as a function of the ratio of the effective head and effective pool depth behind the weir, prove to give very satisfactory results. Not only did this lead to accuracies of approximately 4 percent at the 95% confidence level, but the corrections also proved to be insensitive to shallow and irregular pool conditions.

Tests with dividing walls indicated under-estimation of the flow rate under certain circumstances if the head is calculated from water levels recorded upstream of the low crest of the weir. This under-estimation results from the assumption of constant energy levels upstream of different crests. The under-estimation can be as high as 15 to 20% in cases of a high step height in combination with a shallow pool whilst the overflow depths over adjacent weirs differ by more than 50 percent. This under-estimation can be reduced to less than 10 percent if the step height to pool depth ratio is kept below 0,5.

The results of the study have led to the recommendation that sharp-crested and Crump weirs without dividing walls can be used for flow gauging in rivers. Traditional discharge coefficients can be adapted to improve the accuracy of discharge calculations for this type of weir. Where dividing walls are not used, the step heights should be limited to ensure that the ratio of step height to pool depth does not exceed 0,5. In cases of very wide rivers with non ideal pool conditions dividing walls should be used and water levels should be recorded upstream of a number of the crests unless specific calibration tests are undertaken. This is especially true for the more important gauging stations where a high degree of accuracy is required.

It may be concluded that the one main objective of the study, viz. to

> "Upgrade the calibration of existing gauging stations in order to provide reliable measurements"

has been achieved.

The results of the investigations related to the other main objective, viz, to:

> "Develop an improved gauging structure for overcoming sedimentation problems"

are included in a separate report, WRC Report No. 442/2/94.

LABORATORY CALIBRATION OF COMPOUND SHARP-CRESTED AND CRUMP WEIRS

1. INTRODUCTION

This report deals with the results of comprehensive tests and investigations into the accuracy of compound sharp-crested and Crump measuring weirs under typical South African conditions.

These tests and investigations formed part of extensive investigations into calibration uncertainties and maintenance problems which have been encountered in South Africa. This report may be read in conjunction with WRC Report No 442/2/94. "River discharge measurement in South Africa rivers: The development of improved measuring techniques".

Sharp crested and Crump weirs are the two types of structures that are most frequently used for flow gauging in South African rivers. Over the years many of these weirs were constructed. To improve the sensitivity during low flows and to increase the range of flow conditions that can be gauged by these structures, compound weirs are mostly used. In the compound weir the level of the crests of the weir is varied in a number of steps across the river cross-section. The low flows then pass only over the lowest section of the weir and as the flow increases flow occurs progressively over more of the crests. This ensures that as in the case of V-notch weirs, the flow can be measured relatively accurately over a wide range of flow discharges without causing an excessive increase in the water level in the river upstream of the weir during high flows.

The basic theory and calibration coefficients for both types of weirs are well established for the case when only a single crest level is used. These relationships are also applicable for compound weirs provided that dividing walls are constructed which separate the flows over the different crests of a weir. If water levels are recorded in between the dividing walls upstream of each crest, the flow over each crest can be calculated using the standard calibration relationship for a single weir.

For economical and practical reasons, dividing walls are often omitted in the construction of compound weirs in South African rivers and streams. One of the main practical reasons given for omitting the dividing walls is that floating debris such as branches and trees often become entangled by these walls, adversely affecting the calibration of the structures.

In addition to omitting the dividing walls, it is also becoming common practice in South Africa to record upstream water levels only in the vicinity of the crest with the lowest level. This practice is followed regardless of whether dividing walls are used or not.

These practices of omitting dividing walls and of recording water levels only upstream of the crest with the lowest level, have led to doubts being expressed about the accuracy with which flow can be measured by means of these structures. A need was identified to test these structures in order to determine the accuracy that can be achieved using the standard calibration formulae. If the accuracy was found to be unacceptable, means were to be sought to adjust the calibration formulae in order to improve the accuracy of flow measurement.

This report describes the calibration tests that were performed and summarizes the results of these tests. The tests were executed in the hydraulics laboratories of the University of Stellenbosch. Results from earlier tests, conducted in the hydraulic laboratories of the Department of Water Affairs and Forestry (DWAF) in Pretoria, are also included in the analysis. Only tests where flow took place over more than one crest are considered in this report. Non-modular flow, i.e. when the water level downstream of the weir has an influence on the water level upstream of the weir, is also not considered here. The main purpose of this investigation was therefore to calibrate compound weirs under modular flow conditions with flows occurring over more than one crest, using only a single water level recording, for cases with and without dividing walls.

These calibration tests were done as part of a larger project sponsored by the Water Research Commission (WRC) in which one main aim was to develop a new flow gauging structure. In the report dealing with the new structure, more extensive background information is given on flow gauging in general whereas in this report background information is confined to sharp-crested and Crump weirs.

A brief description of sharp-crested and Crump weirs as applied in South African rivers and streams is provided. The basic theory used in relating the water level upstream of the weir to the discharge is described. Results of previous research and calibration tests on these types of structures are summarized. This background is then used to define the aims and objectives of the present series of calibration tests. The test facilities and testing techniques are described next and finally the results are presented and conclusions are drawn.

2. SHARP-CRESTED AND CRUMP WEIRS AS APPLIED IN FLOW GAUGING ON SOUTH AFRICAN RIVERS

2.1 GENERAL

Sharp-crested weirs have been used for flow gauging in South Africa since approximately the turn of this century. One of the first of these structures was built in the Pienaars River during 1904 and is still in operation today. Nearly 65 percent of all the flow gauging stations that are presently in operation in South African rivers are sharp-crested weirs.

The first Crump weir was constructed in South Africa in 1976. This type of structure became very popular because of its ease of construction, robustness, insensitivity to minor damage of its crest and a constant discharge coefficient in the modular flow range. At present nearly 25 percent of all flow gauging structures in South African rivers are Crump weirs.

Sharp-crested and Crump weirs therefore totally dominate the river flow gauging scene in South Africa and this amplifies the need for proper calibration of these structures.

In this chapter examples will be given of the application of these two weir types in South Africa. Problems experienced with these structures will be described including the problems experienced in applying existing calibration formulae to compound weirs with and without dividing walls. This information will then be used to define the need for as well as the aims and objectives of the present calibration studies.

2.2 SHARP-CRESTED WEIRS

The classical thin-plate weir has a crest profile consisting of a narrow horizontal top surface at right angles to the upstream face of a steel plate and a chamfer of not less than 45° at the downstream edge, as shown in Figure 2.1. These thin-plate weirs have found widespread application in flow gauging in laboratories and canals. Extensive calibration tests have been performed on this type of structure under a wide variety of flow conditions.

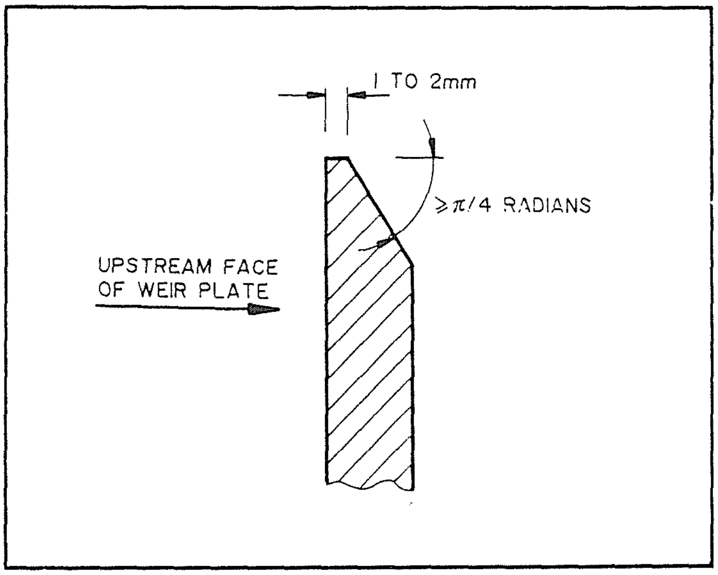


Figure 2.1: Thin Plate Weir

Thin plate weirs are rather fragile and are easily damaged by for instance debris in typical rivers. The shape of the thin plate weir was altered in South Africa to form a sharp crested weir as shown in Figure 2.2. The angle iron forming the crest is much more robust than the classical thin plate weir plate and is more suitable for use in rivers. Virtually all the sharp-crested weirs in South African rivers were built as shown in Figure 2.2. The calibration formula for the thin-plate weir was adapted to allow for the use of the angle iron crest (Kriel, 1963).

The greatest limitation of the sharp-crested weir is the effect on measured water levels as a result of down-stream submergence.

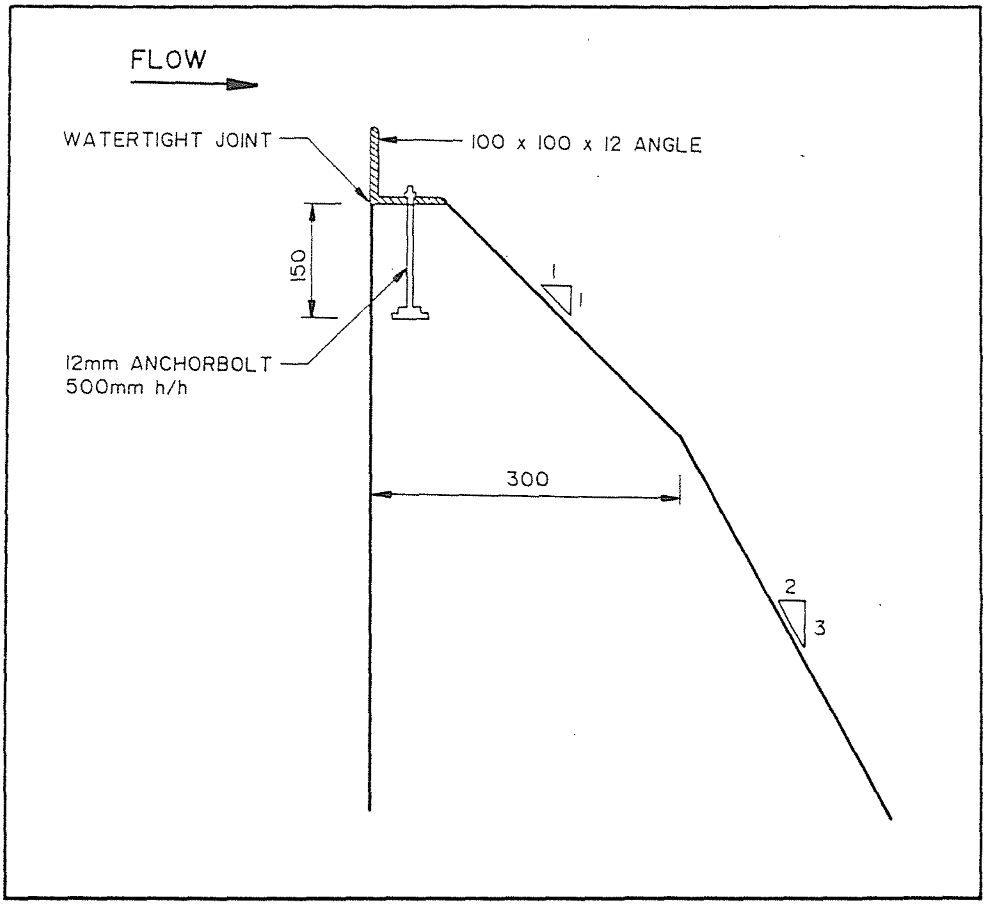


Figure 2.2: Sharp Crested Weir

2.3 CRUMP WEIRS

The Crump weir is, at present, the most popular type of triangular weir worldwide. E.S. Crump published a paper during 1952 in England in which he described a new type of triangular profile weir with upstream and downstream slopes of 1:2 and 1:5 respectively, see Figure 2.3.

During 1976 the first Crump weir was constructed in South Africa. There are two types of Crump weirs that are generally used for flow measurement in natural rivers, namely the horizontal Crump weir and the V-Crump weir. The side slopes of the V-Crump are presently standardized at 1 vertical to 10 horizontal. (Figure 2.4 contains photographs of horizontal and V-Crump weirs).

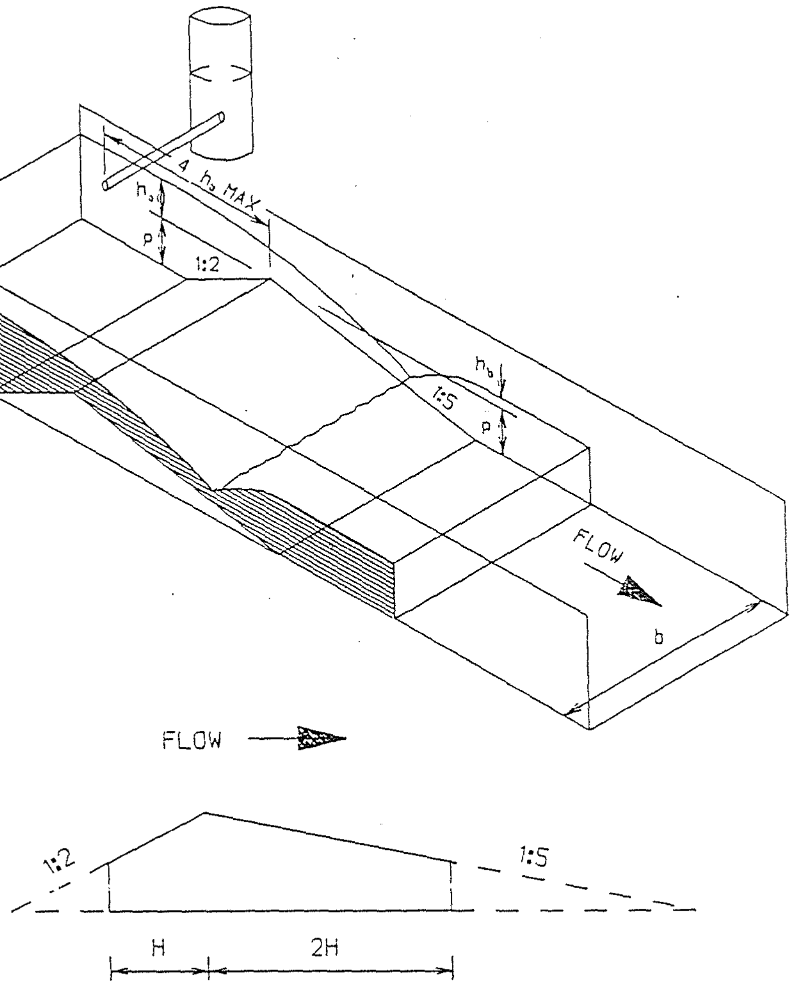
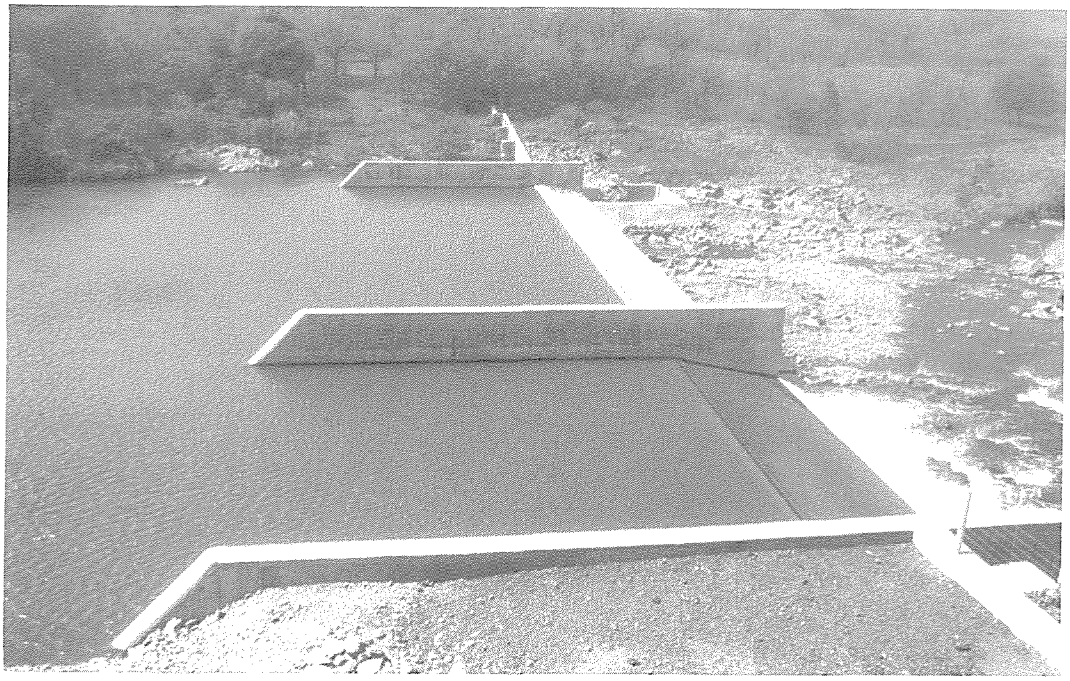


Figure 2.3: Crump Weir

2.4 WATER LEVEL RECORDING

Continuous records of stage are normally obtained in South Africa by means of mechanical types of recorder with recording graph paper wrapped around a drum. The drum is driven by a clock mechanism which rotates the drum at either one revolution per week or one revolution per month. A float with a counterweight system follows the rise and fall of the water level in the river within a stilling well and a pen records this movement on the rotating graph paper. This paper is changed either weekly or monthly, depending on the speed of the clock.

(a) Crump Weir *Without Dividing Walls* (C5 H003 Modder Rivier: Sannaspos)



(b) Crump Weir *With Dividing Walls* *(X1H001 Komati River: Hooggenoeg)*

Figure 2.4: Photographs of Crump Weirs (Provided by *P. Wessels*)

The inlet to the stilling well is normally located at a distance of four times the design overflow height upstream of the low crest of the weir.

Figure 2.5 shows an example of a water level recorder.

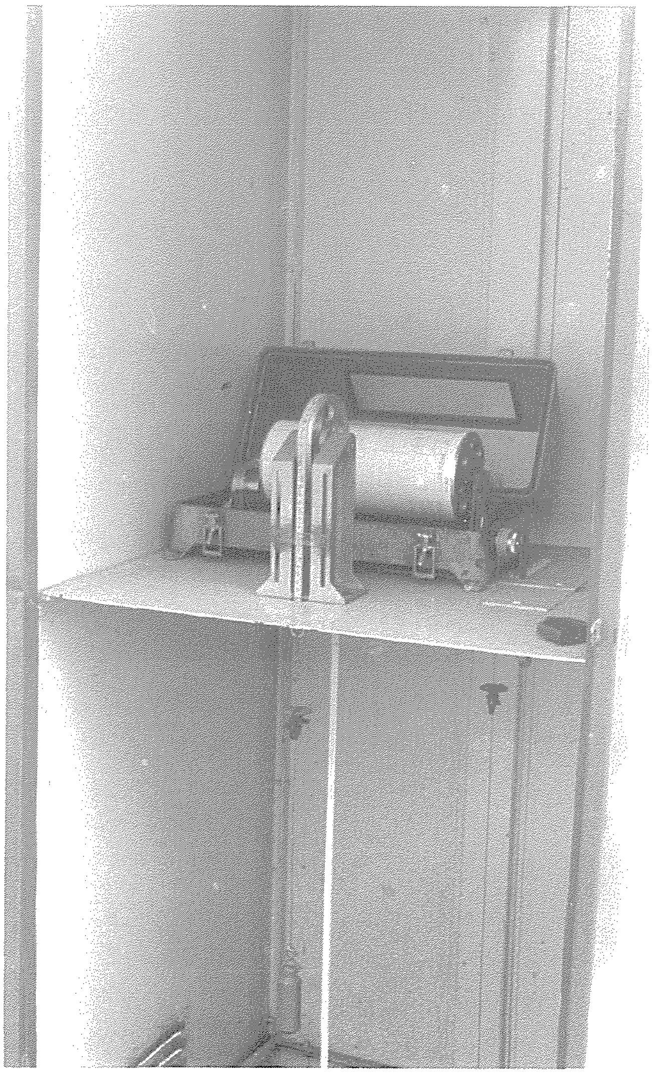


Figure 2.5: Photograph of Water Level Recorder
(*P. Wessels*)

2.5 COMPOUND WEIRS

Because of the large variation in flow rates encountered in virtually all South African rivers and streams, compound weirs are commonly used. More than 95 per cent of all sharp-crested and Crump weirs constructed in South African rivers are compound weirs. The basic idea behind a compound weir is to vary the crest level of the weir in a number of steps across the stream in order to obtain the same effect as with a V-notch weir. The lower flows pass over the lowest crest and as the flow rate increases the next crest height is overtopped. This improves the sensitivity of the structure at low flows and at the same time limits the increase in upstream levels during higher flows. In this way the range of flows that can be measured accurately with the structure is increased.

British standards require that dividing walls should be constructed with compound weirs to separate the water flowing over adjacent crests at different levels (BSI, 1981). By recording water levels upstream of each crest, the discharge over each crest and therefore the total discharge, can be calculated using the standard discharge formulae. If water levels are not recorded upstream of each crest, assumptions about the energy levels upstream of the crests where no water levels are recorded, must be based on the recorded levels.

In South Africa less than 5 percent of all compound weirs constructed to date, have been built with dividing walls. Reasons given for omitting these dividing walls mainly relate to problems with debris being trapped by the walls. There are however differing opinions regarding the relative quantities of debris being trapped by these walls and by the crests of the weirs.

In virtually all the cases where dividing walls have been constructed in South Africa, water levels are only recorded upstream of the lowest crest. Some guidelines about the methods to be used for calculating the discharge in such cases can be found in the British Standard (BSI, 1984). In the absence of generally accepted international standards, the British standards have been taken to reflect internationally acceptable standard.

British standards require that calibration of compound structures without dividing walls should be undertaken in situ or in models and these standards do not cover this type of structure (BSI, 1981). These deviations from international standards constitute the main reasons for the present research programme.

2.6 PROBLEMS EXPERIENCED IN FLOW GAUGING WITH SHARP-CRESTED AND CRUMP WEIRS ON SOUTH AFRICAN RIVERS

As with all overflow types of flow gauging structures, the sharp crested and Crump weirs require relatively smooth and even flow patterns upstream of the weirs. This is achieved where river channels upstream of weirs are straight and roughly rectangular in section. A relatively deep pool upstream of a weir also ensures smooth water surfaces. Accuracy of flow measurement in general increases with an increase in the depth of the pool.

One of the major problems experienced with flow gauging weirs in South Africa is to maintain sufficient pool depths and even flow conditions in upstream pools. Sediment deposits and the growth of reeds and other plants in the pools disturb the flow patterns and can lead to large inaccuracies in flow gauging. A pool that is continuously becoming shallower due to sedimentation also requires frequent surveys to determine the flow cross-section required for the calculation of the approach flow velocity. This velocity is required for the calculation of the energy head relative to the weir crest for use in the discharge formula for the weir. The inability to maintain stable pools upstream of flow gauging weirs in many South African rivers, is most probably the factor that contributes most to the inaccuracies of flow gauging with these structures.

A second problem caused by sedimentation of the pools, is that the inlet pipe of the stilling well used for water level recording, often becomes blocked. Under these circumstances, the recorded water levels are obviously meaningless.

Other problems that influence the accuracy of discharge measurements by weirs are caused by debris such as branches and trees that become trapped by the crests and dividing walls; submergence of weirs caused by high water levels downstream and the accuracy with which the zero levels of water level recorders can be set relative to the crest of the lowest weirs.

Most of the problems mentioned here are addressed more fully in the report dealing with the development of a new flow gauging structure. In the study to calibrate the compound sharp-crested and Crump weirs, relatively ideal approach conditions that fall within the standards set by BSI and ISO were simulated. A number of additional tests have however been conducted where the effect of siltation in the pool was simulated by using very shallow pools with and without channels through the pools. The purpose was to establish the magnitude of errors that can be expected under these circumstances.

3. AIMS AND OBJECTIVES OF THE STUDY

The general practice in South Africa is to construct compound sharp-crested and Crump weirs in rivers and streams without dividing walls. This is contrary to the specification of the British Standards Institution (BSI, 1981) which states that all compound structures should be separated by dividing walls and that where dividing walls are not used, such structures should be calibrated in situ or in models.

Although very many compound structures have been built in South Africa without dividing walls, only a few have been calibrated according to the abovementioned standards mostly through in situ flow measurements by using current meters. Such calibrations could often only be done for a limited range of flow conditions and some doubt also exists about the accuracy of the calibration methods used.

A clear need was therefore identified for more systematic and accurate calibration of compound weirs without dividing walls. This could best be done in hydraulic models where the geometry of the weirs and the pools could be systematically varied and where discharge rates could be accurately measured and adjusted. By testing each weir configuration with and without dividing walls, the relative merits of dividing walls could also be established.

The aim of this study therefore was to determine the magnitude of errors that are made in calculating the discharge for compound weirs with and without dividing walls when using standard discharge formulae for these weirs. The calculation of the discharge would be based on the water level recorded upstream of the low crest as is normal practice in the prototype. The influence of relative overflow lengths, step heights between adjacent crests, pool depths, etc on the accuracy had to be established. In cases where the accuracies were found to be unacceptable, new discharge coefficients had to be established which would ensure that past and future water level records could be translated into discharge records with maximum possible accuracy.

Since the sharp-crested and Crump weirs are most frequently used for flow gauging in South Africa, the tests were limited to these two weir types. Only weirs with horizontal crests were tested.

Because the main aim of the study was to determine the influence of omitting the dividing walls on the accuracy of the flow measurement, idealized rectangular pools that conform to the specifications of the BSI standards were mainly used in the tests. A number of tests where siltation levels in the pools should have led to serious deviations from the accepted standards for the pool, were also conducted to determine the errors that can be made under such circumstances.

4. BASIC THEORY

4.1 INTRODUCTION

The basic principle mostly applied in flow measurement structures with free surface flows, is to create hydraulic controls where by the flow mode changes from subcritical to supercritical. This ensures that a unique relationship exists between the water level upstream of the structure and the rate of discharge over the structure. This principle also applies to flow gauging in the case of sharp-crested and Crump weirs.

The theoretical approach in deriving a discharge formula, however, is different for these two types of weirs. In the case of a sharp-crested weir the theory for a thin-plate weir is used whereas in the case of the Crump weir the derivation is based on the theory for a broad-crested weir. Because of the fact that the derivation of the discharge formulae for these types of weirs gives some insight into the values of the discharge coefficients that can be expected, the classical derivations will be discussed here.

4.2 DERIVATION OF DISCHARGE FORMULAE

4.2.1 SHARP-CRESTED WEIR

The derivation of a discharge formula for the sharp-crested weir as given below is based on the derivation contained in Massey (1989).

Consider a sharp-edged rectangular weir as shown in Figure 4.1. The classical analysis is based on four assumptions:

(i) Upstream of the weir, flow is uniform, i.e flow lines are parallel and velocities are constant; thus the pressure variation is hydrostatic.

(ii) The free water surface remains horizontal up to the weir, and all particles passing over the crest move horizontally.

(iii) Pressure throughout the nappe is atmospheric.

(iv) The effects of viscosity and surface tension are negligible.

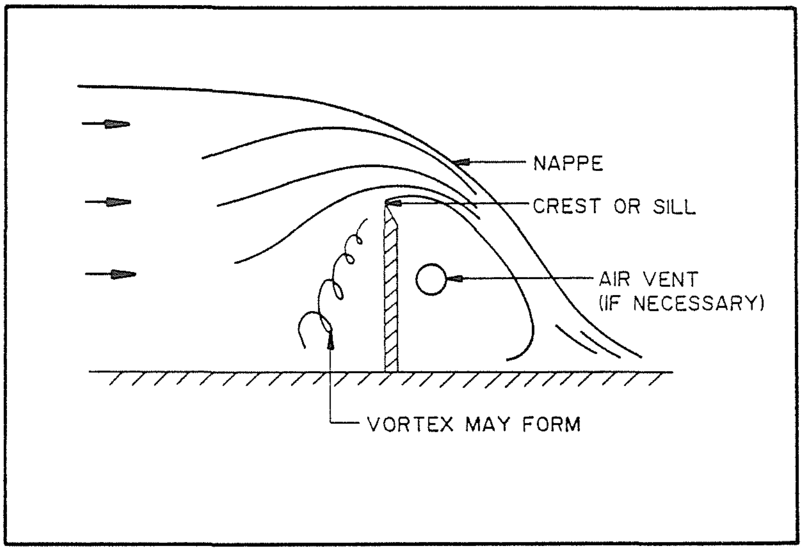


Figure 4.1: Real Flow Pattern Over Sharp-crested Weir

These assumptions lead to the idealized flow pattern shown in Figure 4.2.

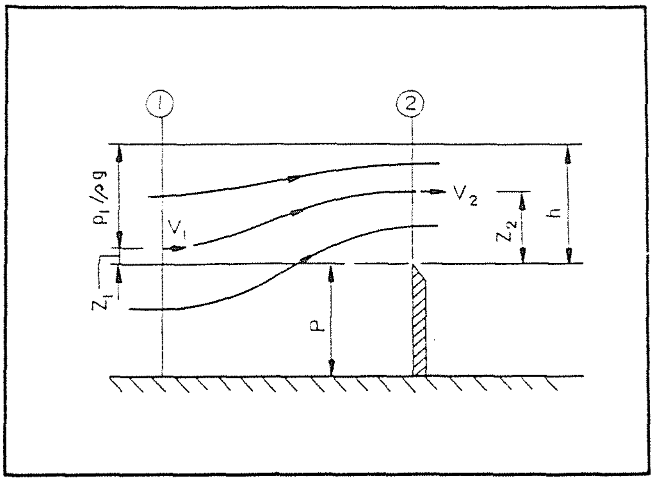


Figure 4.2: Idealized Flow Pattern

Applying *Bernoulli*'s equation along a streamline leads to:

$$\frac{p_1}{\rho g} + Z_1 + \frac{v_1^2}{2g} = 0 + Z_2 + \frac{v_2^2}{2g}$$

since $\frac{p_1}{\rho g} + z_1 = h$ this reduces to

$$h + \frac{v_1^2}{2g} = z_2 + \frac{v_2^2}{2g}$$

or $v_2 = \left[2g\left(h - z_2 + \frac{v_1^2}{2g} \right) \right]^{1/2}$

The theoretical discharge Q_t therefore is

$$\begin{aligned} Q_t &= b\int_0^h v_2 \cdot dz_2 \\ &= \frac{2}{3}\, b\sqrt{2g}\left[\left(h + \frac{v_1^2}{2g} \right)^{3/2} - \left(\frac{v_1^2}{2g} \right)^{3/2} \right] \qquad \text{.......... 4.1} \\ &= \frac{2}{3}\, b\sqrt{2g}\left[H^{3/2} - \left(\frac{v_1^2}{2g} \right)^{3/2} \right] \qquad \text{with } b = \text{flow width} \end{aligned}$$

Of the assumptions made thus far, only assumption (ii) is questionable since it is well known that the water surface will not stay horizontal up to the weir. The other three assumptions are normally not unreasonable provided that

- a proper pool is created upstream of the notch (assumption (i)
- the nappe is properly aerated (assumption (iii))
- and the overflow depth is not too small (assumption (iv))

If a discharge coefficient is introduced to convert the theoretical discharge (Q_t) to a true discharge (Q), equation 4.1 becomes

$$Q=C_D.\frac{2}{3}b\sqrt{2g}\left[H^{3/2}-\left(\frac{v_1^2}{2g}\right)^{3/2}\right] \quad \text{.......} 4.2$$

The discharge coefficient C_D mainly constitutes a contraction coefficient to allow for the idealized assumption of a horizontal water surface up to the weir. This discharge coefficient can therefore be expected to have values similar to a contraction coefficient for a rectangular orifice i.e. in the order of C_D = 0,6. Because the contraction at the bottom of the nappe will also be dependent on the degree to which the flow is contracted from the pool to the weir, a weak dependence can be expected between C_D and h/P.

Since the upstream velocity v_1 depends on the discharge Q, the calculations of Q for a known value of h can only be performed by trial and error if equation 4.2 is used. This equation is therefore frequently adapted and simplified to produce equation 4.3 below by neglecting the $v_1^2/2g$ term i.e.

$$Q = C_D\frac{2}{3}\,b\sqrt{2g}\,h^{3/2} \quad \text{.......} 4.3$$

In this equation it is obvious that C_D will also become a function of $v_1^2/2g$, and that the value of C_D will vary when $v_1^2/2g$, is not negligible compared to *h*.

Another simplification that is often made to equation 4.2 is to drop only the last $\left(v_1^2/2g\right)^{3/2}$ term, which leads to equation 4.4 i.e.

$$Q = C_D\,.\frac{2}{3}b\sqrt{2g}\,H^{3/2} \quad \text{.......} 4.4$$

This form of the equation has found wide acceptance because it expresses the discharge as a function of the energy head rather than the water level. It also is similar in form to the equations used for broad crested weirs - See section 4.2.2. Equation 4.4 will therefore be used in this study.

4.2.2 CRUMP WEIR

The theoretical derivation of a discharge formula for a Crump weir is based on the theory for a broad-crested weir. The assumptions that are normally made are

i. Upstream of the weir, flow is uniform, velocities are constant and flow lines are parallel, thus the pressure variation is hydrostatic.

ii. The crest of the weir is horizontal and sufficiently wide to ensure that flow lines over the crest are parallel, again signifying hydrostatic pressure variation.

iii. Downstream of the weir the water level is sufficiently low to ensure that critical conditions occur at the control section i.e. that submergence does not occur.

iv. The effects of viscosity and surface tension can be neglected.

v. Energy losses are negligible between the upstream section and the control section on the weir.

The derivation then proceeds as follows:

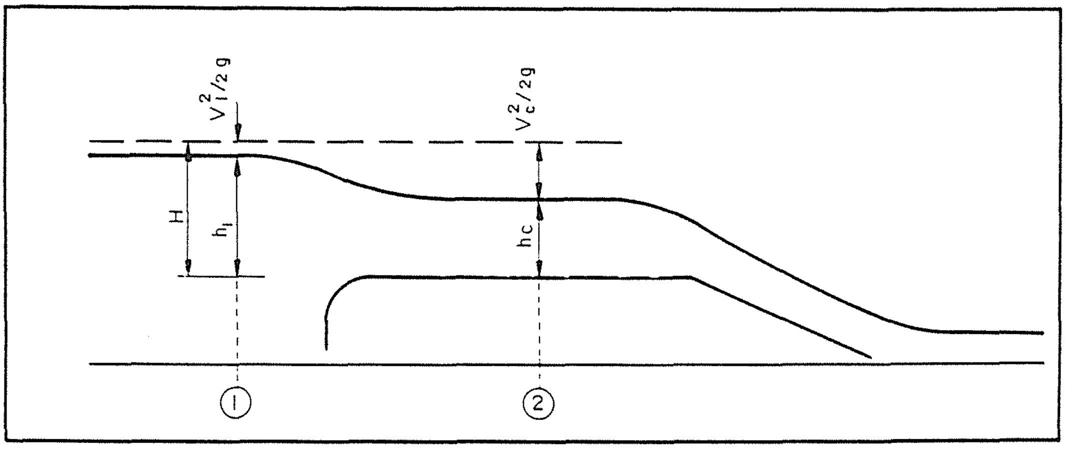


Figure 4.3: Flow Over a Broad-crested Weir

Applying the *Bernoulli* equation between sections 1 and 2

$$h_c+\frac{v_c^2}{2g}=h+\frac{v_1^2}{2g}=H$$

For a rectangular channel

$$h_c=\sqrt[3]{\frac{Q^2}{b^2.g}}$$

and $\frac{Q}{b}=v_c h_c$

and $\frac{v_c^2}{2g}=\frac{hc}{2}$

$$\therefore \frac{3}{2}h_c=H$$

$$\frac{3}{2}\sqrt[3]{\frac{Q^2}{b^2.g}}=H$$

$$\therefore Q=\frac{2}{3}b\sqrt{\frac{2}{3}g}\,H^{3/2} \qquad \text{.......4.5}$$

None of the assumptions made in the derivation is unrealistic provided that the crest of the weir is sufficiently wide and that modular flow condition occur. The discharge coefficient in the case of a broad-crested weir therefore mainly has to compensate for a small energy loss between section 1 and 2 i.e.

$$Q=C_D\frac{2}{3}\,b\sqrt{\frac{2}{3}g}\,H^{3/2} \qquad \text{.......4.6}$$

For the broad crested weir C_D values are therefore normally close to unity with C_D = 0,98 being a typical value. The C_D value is also independent of h and P values since contraction does not play a role here as it does with the thin-plate weir.

When the broad crested weir formula (equation 4.6) is applied to the Crump weir, the assumption of horizontal and parallel flow over the weir crest becomes invalid. Flow lines over the control section are now convex and the pressures at this point are therefore lower than hydrostatic - See Figure 4.4.

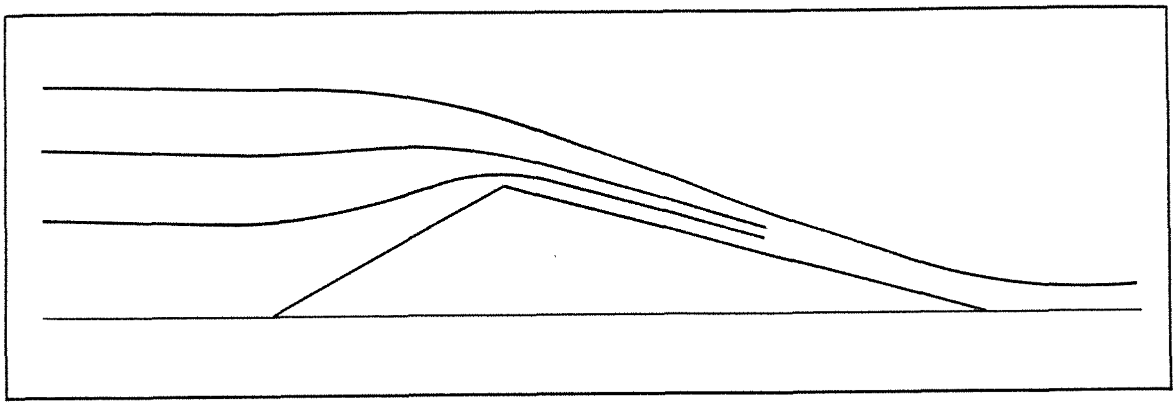


Figure 4.4: Flowlines at Crest of Crump Weir

This deviation from assumption (ii) has the effect of increasing the discharge coefficient to values higher than that for a classical broad-crested weir. This leads to C_D values larger than unity. As is the case with the broad-crested weir, the discharge coefficient remains constant in equation 4.6 for a wide range of overflow depths (h) and pool depths (P).

5. INTERNATIONAL STANDARDS FOR SHARP-CRESTED AND CRUMP WEIRS

5.1 GENERAL

Extensive research and calibration tests have already been undertaken on both thin-plate and Crump weirs. Summaries of most of this work can be found in *Delft Hydraulics Laboratory* (1976) and *Ackers and White* (1978). *The British Standards Institution* and the *International Standards Organisation* have drawn up standards for flow measurements with Crump and thin-plate weirs (BSI, 1984 and ISO, 1980). A document has also been published which gives guidance on the installation and use of compound structures for flow measurements (BSI, 1981).

The summaries that are given here are based on information contained in BSI (1981) and BSI (1984).

5.2 STANDARDS COMMON TO BOTH WEIR TYPES

The following requirements are common to both the thin-plate and Crump weirs.

(i) The approach channel upstream of the weir should be straight and allow for the flow to be uniform and steady.

(ii) The head should be measured at a point 4 to 5 times the maximum design head upstream of the weir crest for the thin plate weir. For the Crump weir this measurement should take place at a distance of 2 times the design head upstream of the crest. In South Africa the general practice is to measure the head at a distance of 4 times the design head upstream of the weir for both types of weir.

(iii) The zero of the head measuring device should be accurately set at the level of the weir crest.

5.3 THIN PLATE WEIRS

In the *British Standards Institution* document (BSI, 1984) the following discharge formulas are given for the basic weir form

(i) Kindsvater Carter formula

(ii) SIA formula

(iii) Rehbock formula

(iv) IMFT formula

(v) HRS formula

The uncertainties at the 95% confidence level which are attributable to the coefficient of discharge in the different formulae will, according to this standard, not be greater than 1,5% for values of h/P less than 1,0, not greater than 2% for values of h/P between 1,0 and 1,5 and not greater than 3% for values of h/P between 1,5 and 2,5. These accuracies are applicable only if additional restrictions on the values of h, b, p, h/P and (B - b)/2 given in the document are also satisfied.

Because of the similarity in discharge values obtained by the various formulae, it was decided to use only one of these formulae in this study. The preferred formula is the IMFT formula, which is the only formula that is written directly in terms of the energy head H, rather than the overflow depth h. The inclusion of the $v^2/2g$ term in this way leads to a formula with a discharge coefficient which does not vary greatly since it conforms more closely to the theory (see section 4.2.1).

The IMFT formula for a full width weir reads:

$$Q = C_D.\frac{2}{3}\sqrt{2g}\, bH^{3/2} \quad \text{.......} \quad 5.1$$

with $C_D = 0{,}627 + 0{,}018\ \dfrac{H}{P}$

Limitations on the applicability of this formula are:

i. $h/P < 2.5$
ii. $h > 0{,}03$ m
iii. $b > 0{,}20$ m
iv. $P > 0{,}10$ m

As can be seen the form of the equation corresponds to that of Equation 4.4, derived in section 4.2.1. Within the limitations indicated above the C_D value varies between 0,627 for $H/P = 0$ and 0,682 for $H/P = 2{,}5$.

5.4 CRUMP WEIRS

Only one discharge formula is given for the Crump weir in BSI (1984). The formula reads:

$$Q = \frac{2}{3}\sqrt{\frac{2}{3}g}\, C_D \,.\, b \,.\, H^{3/2} \quad \text{.......} \quad 5.2$$

with $C_D = 1{,}163\left(1 - \frac{0{,}0003}{h}\right)^{3/2}$

Limitations on the applicability of this formula are:

i. $h > 0{,}06$ m for a fine concrete crest
ii. $P > 0{,}06$ m
iii. $b > 0{,}30$ m
iv. $H/P < 3{,}5$
v. $b/h > 2{,}0$

The form of the formula corresponds exactly with the formula for a broad-crested weir, as derived in section 4.2.2 (see equation 4.6). Within the given limitations the C_D value can vary from 1,154 for h equal to 0,06 m to 1,163 for large values of h. This is a variation of less than 1% over the full range of h values and for practical purposes the value of C_D can be taken as constant at 1,163.

The reason for a C_D value of more than unity lies in the convex flow lines over the crest, while parallel horizontal flow lines were assumed in the derivation, as has been explained in section 4.2.2.

5.5 COMPOUND WEIRS

A *British Standards Institution* publication (BSI (1981)) deals specifically with compound structures. This document specifies that:

(i) The individual sections of the compound weir shall be separated by dividing walls such that each section can be treated as a simple weir, thus minimizing three-dimensional flow conditions.

(ii) Compound flow measuring structures without dividing walls need in situ or model calibration and are not covered by the standard.

(iii) The dividing walls, which separate individual sections of the compound structure, shall be at least 0,3 m thick to avoid sharp curvatures at their upstream noses (cutwaters) which may be semi-circular or semi-elliptical.

(iv) To minimize cross flows at the cutwaters of the dividing walls and subsequent flow separation, the difference in levels between adjacent weir crests shall not be more than 0,5 m.

(v) The upstream head shall be measured at any one of the individual sections of the compound structure. It is usually not economic to measure water levels upstream of each individual section and hence it is necessary to assume that the total head level is constant over the full width of the compound weir. The total head is calculated at the individual section where the water level is being recorded.

6. BASIC APPROACH FOLLOWED IN LABORATORY CALIBRATION OF COMPOUND SHARP-CRESTED AND CRUMP WEIRS

The normal procedures for calibrating a weir structure in the laboratory have been as follows:

i. Derive a theoretical relationship between the discharge and the energy-head as was done in Section 4.2 i.e.

For the Sharp-crested weir:

$$Q=C_D.\frac{2}{3}\sqrt{2g}\,bH^{3/2}$$

and for the Crump weir:

$$Q = C_D \cdot \frac{2}{3}\sqrt{\frac{2}{3}g}\, b H^{3/2}$$

ii. Construct a model of the weir in such a way that the flow rate Q and the overflow depth (h) can be accurately measured. The flow rate must obviously be measured by other means than by the structure that is being calibrated.

iii. With the flow rate Q and the flow depth h known, it is possible to calculate the velocity of approach $v = Q/A$ where A is the flow area in the pool upstream of the weir. With v known the energy head $H = h + v^2/2g$ can be calculated.

iv. The discharge coefficient C_D for the weir can now be calculated for each combination of Q and h from the equations given above.

For simple weirs, where all the water flows over a single crest and the flow can be considered to be two-dimensional, sufficient tests have been conducted to fully describe the calibration of these weirs.

For sharp-crested weirs the discharge coefficient C_D in equation 4.4 above was found to be

$$C_D = 0{,}627 + 0{,}018\frac{H}{P} \qquad \text{(IMFT formula)}$$

For the Crump weir C_D in equation 4.6 was found to be constant i.e. $C_D = 1{,}163$ for $h > 0{,}1$ m.

In the case of the thin plate weir C_D was found to be weakly dependent on only two parameters, H and P, whereas in the case of the Crump weir C_D did not depend on any pool or overflow-depth parameters.

When compound weirs are considered, the discharge coefficient can be expected to be influenced by more parameters. Since flow is no longer two-dimensional, especially in the case without dividing walls, some of the assumptions made in deriving the discharge formulas such as equations 4.4 and 4.6, are violated. The errors introduced through violation of the assumptions can be expected to increase as the degree to which these assumptions are being violated, is increased. Parameters which can be expected to have the biggest influence on the accuracy of the standard equations are those which will cause the largest degree of cross flow. These are; the difference in crest levels between adjacent weirs, the relative depth of overtopping over adjacent weirs, the relative crest lengths of adjacent weirs and the relative velocities in the pool upstream of the weir. Most of these parameters are not independent and the difference in adjacent crest levels for instance will influence most of the other parameters listed above.

Because of the large number of parameters that are expected to influence the accuracy of the discharge formulae, systematic model tests in which these parameters were varied to cover the conditions that can be expected to occur in the prototype, were performed. The parameters that required investigation included discharge (Q), pool depth (P), relative crest lengths (L_1/L_2) and the difference in elevation between adjacent crests, T. To be able to establish the influence of omitting the dividing walls, the approach was to test each model set-up with and without dividing walls.

Rather than standard calibration tests, the approach was also firstly to determine the errors that are made in calculating the discharge if the standard formulae and techniques generally applied in South Africa, are used. The discharge was calculated from the water level recorded at the standard distance 4 H_{max} upstream of the low crest. Where the errors made by the standard method of discharge calculations are found to be substantial, new discharge coefficients will be defined in terms of the parameters that have been found to influence these discharge coefficients.

Since the main aim of the study was to calibrate compound weirs, all tests were done with flow occurring over two different crest levels. Tests were done with and without dividing walls, using only one position of water level recording. All tests were done under modular flow conditions i.e. care was taken to ensure that the water level downstream of the weir had no influence on the upstream water level. The approach channel was rectangular in most of the tests. Testing was concentrated in the ranges where, for the two types of weirs, flow conditions were within the limits specified in the ISO and BSI standards. Some tests were also conducted where the specifications especially with respect to pool configuration and pool depth were violated in order to determine the influence of these violations on the calculated discharge and discharge coefficients.

7. MODEL FACILITIES, LAY-OUT AND TECHNIQUES

7.1 GENERAL

Tests which have been executed as part of the WRC project were all performed in the hydraulics laboratory of the Department of Civil Engineering at the University of Stellenbosch. Earlier tests on compound Crump structures, were done at the hydraulics laboratories of the Department of Water Affairs and Forestry in Pretoria. The tests and facilities at both these institutions will be described here.

7.2 TESTS PERFORMED IN THE DEPARTMENT OF WATER AFFAIRS AND FORESTRY LABORATORIES

This model was constructed at the hydraulics laboratory of the Department of Water Affairs and Forestry in Pretoria-West. A schematic lay-out of the model is shown in Figure 7.1.

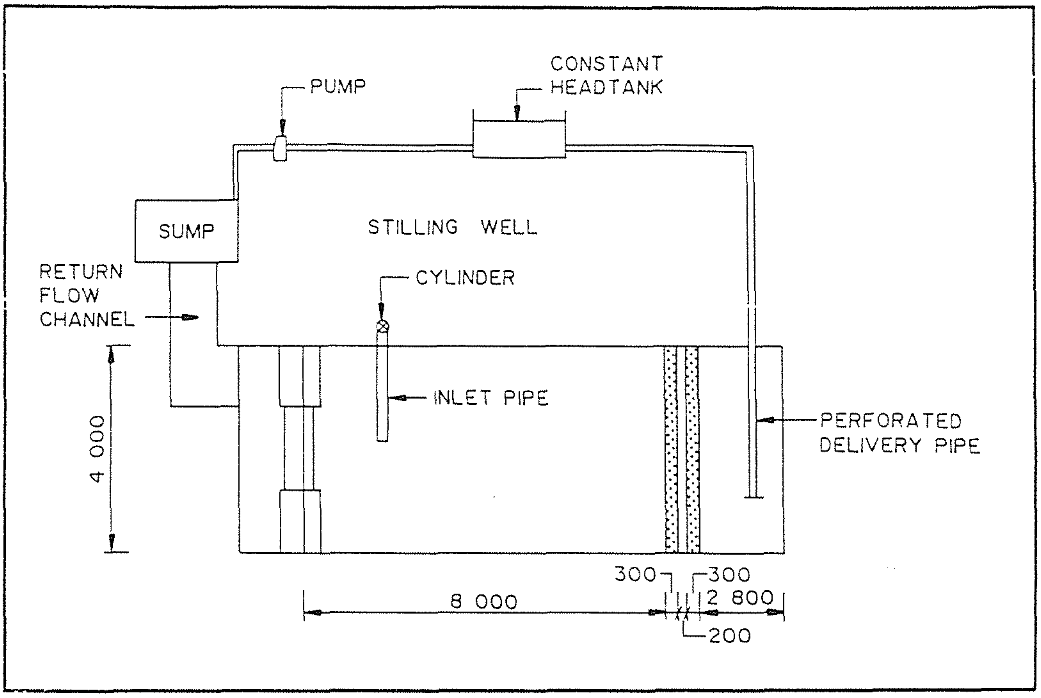


Figure 7.1: Schematic Lay-out of DWAF-model

Water was supplied to the model from a constant head tank via a 300 mm pipeline. The flow rate supplied to the model was recorded by an electromagnetic flow meter in the supply pipe. The water was discharged into the constant head tank using a diffuser and a grid system to ensure uniform flow with a minimum of surface disturbance in the approach channel to the model weir. The approach channel which also formed the pool upstream of the weir was approximately 4m wide and 8m long.

For each weir set-up the water level was recorded at distances of 0, 2 H_{max}, 4 H_{max} and 6 H_{max} upstream of the low notch. The water level was recorded using a pipe connected to a stilling well situated outside the flow channel. A weak soap solution was used in the well to eliminate surface tension effects.

Dividing walls were made out of 10mm perspex sheets. In the tests without dividing walls the dividing walls were fixed to the side of the flow channel in order to ensure that the nett overflow length of the weir remained constant.

The models of the Crump weirs were constructed out of smooth mortar. The pool upstream of the weir was kept rectangular in all the tests and the bottom of the pool was also finished with smooth mortar.

The maximum discharge that could be obtained in the model was 177 *l*/s. Regular checks on the calibration of the electromagnetic flow meters were done by volumetric methods.

7.3 TESTS PERFORMED IN THE UNIVERSITY OF STELLENBOSCH LABORATORIES

A schematic layout of the test facility in the hydraulics laboratory of the University of Stellenbosch is included in Figure 7.2. Water supply to this model was from two constant head tanks at heights of 5m and 12,5m above the model floor. Two 300 mm diameter pipes connected the constant head tanks to the model. The flow rate in the supply pipes was measured by means of 213 mm diameter orifice plate gauges connected to either water or mercury manometers. The discharge was controlled by means of a valve in each of the supply pipes. A maximum flow rate of more than 400l/s could be achieved by using two supply pipelines in parallel.

Water was supplied to the model, again using a grid system to ensure uniform flow and a lattice network floating on the water surface to dampen any surface disturbances in the approach channel to the weir. The approach channel in which the weir was installed was 2,96 m wide and 9 m long up to the crest of the weir.

The thin-plate weir model was constructed out of 7 mm thick PVC sheeting, mounted on a metal frame in order to be able to adjust the relative heights of the two crest levels of the compound weir. The Crump weir was constructed out of smooth concrete.

Where dividing walls were used, 10mm thick PVC sheeting, mounted on a metal frame, was used for this purpose for both the tests on the thin plate and Crump weirs. These dividing walls were 2,1m long.

The return flow rate from the model was measured in the return flow channel of 1 m width by means of a thin-plate weir of 800 mm width and a pool depth of 0,500 m. The purpose of the measurement of the return flow was to have an independent check on the flows measured by means of the orifice plates in the supply pipes.

Water levels were recorded at distances of 0, 2 H_{max}, 4 H_{max} and 6 H_{max} upstream of both the low and the high crest of the weir. Only two crest levels were used in each test i.e. a low crest and a high crest. Water levels were recorded with a needle gauge mounted on a beam. To relate the recorded levels to the crest of the low weir, needle gauge readings were also taken on fixed reference plates mounted at each recording position. These reference plates were carefully levelled and their heights relative to the crest of the low weir were determined by using a dumpy level.

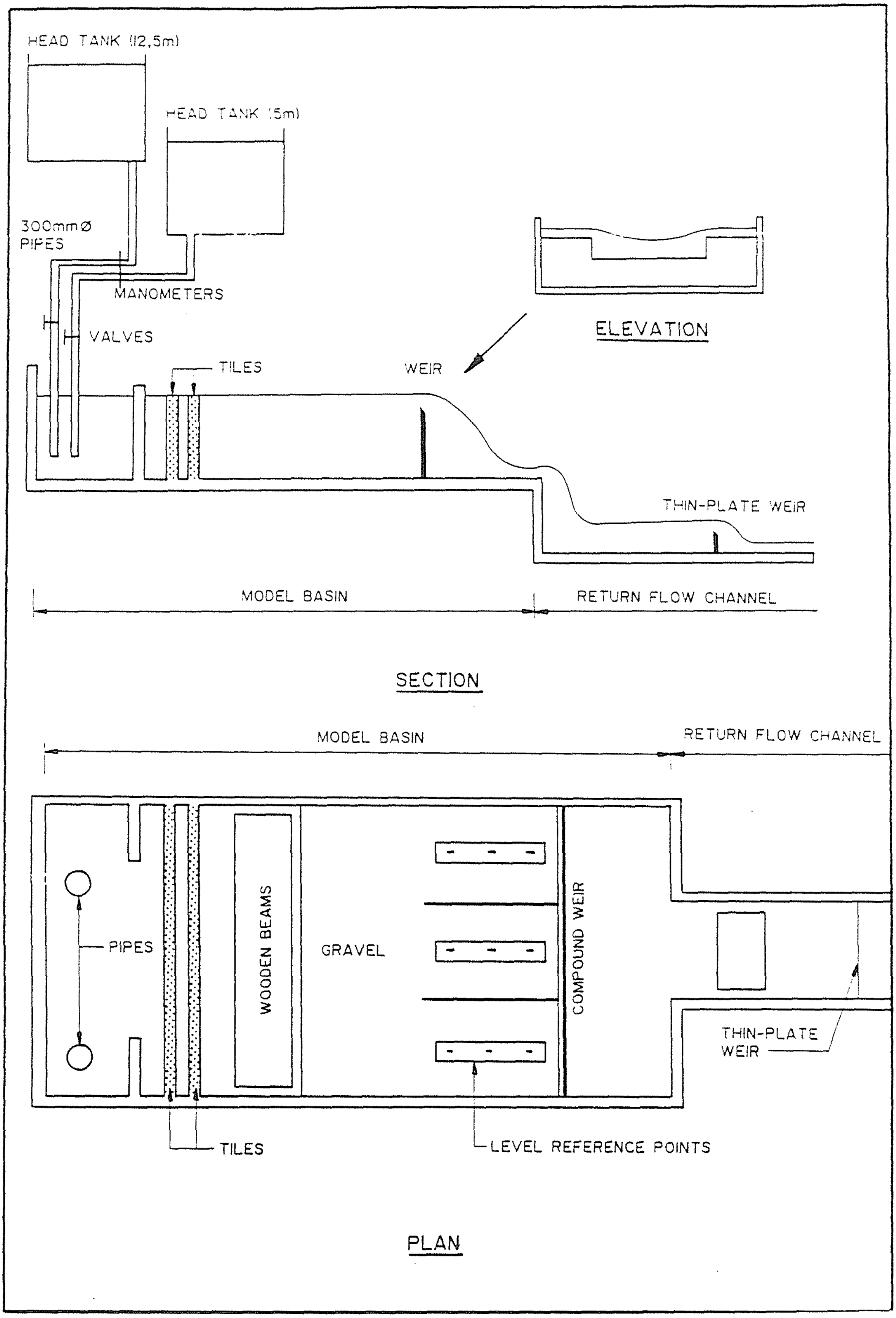


Figure 7.2: Schematic Lay-out of Stellenbosch-model

A photograph showing the general model set-up are shown in Figure 7.3

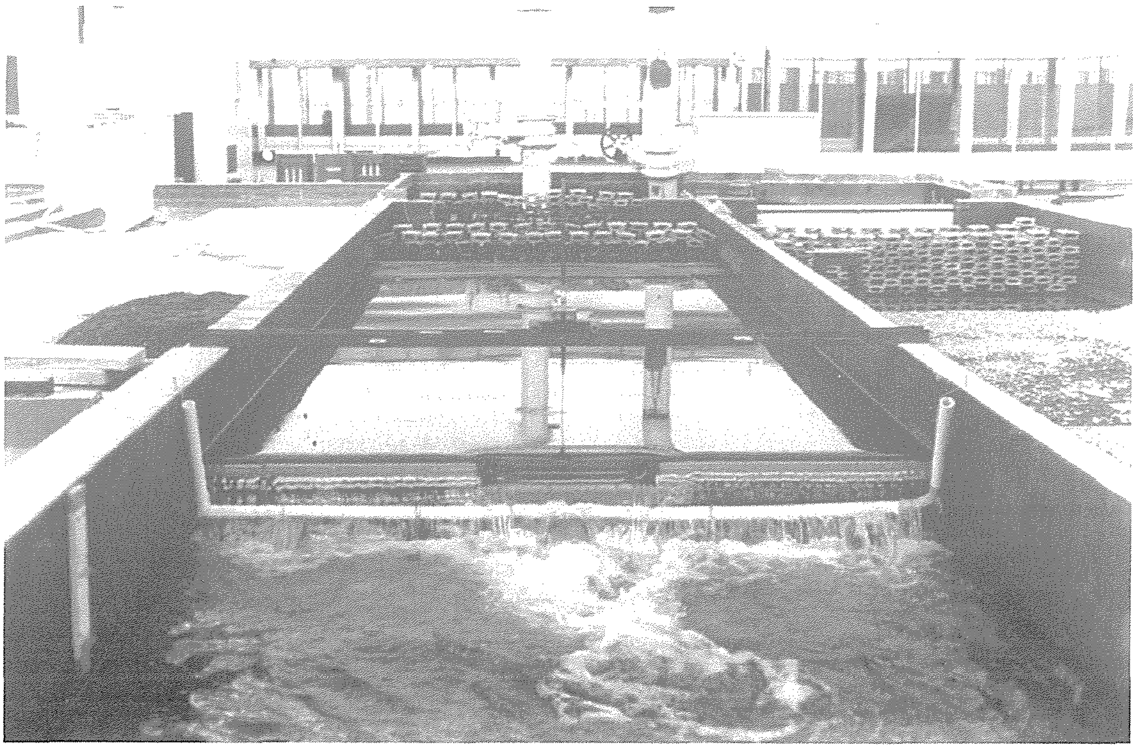


Figure 7.3: Photograph of Stellenbosch-model

8. TEST PROGRAMME

8.1 DEFINITION OF PARAMETERS

A schematic sketch of the weir configuration as tested in the model is shown in Figure 8.1.

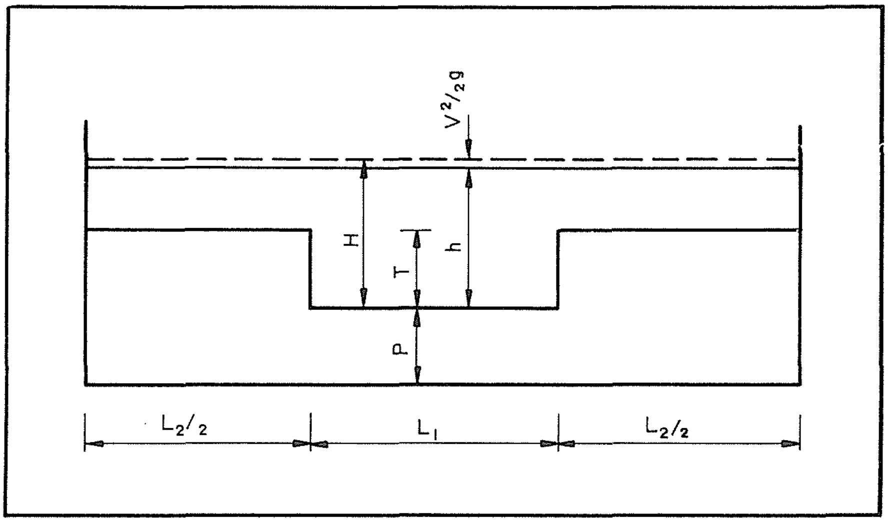


Figure 8.1: Definition Sketch

The parameters as defined for this study are as follows:

P = Pool depth below crest of low notch.
T = Difference in height between two crests of the compound weir.
L_1 = Length of low crest.
L_2 = Length of high crest.
h = Measured water level relative to low crest.
H = Energy head relative to low crest.

In all the tests only two crest levels were used i.e. a low crest and a high crest.

In all but the last test series the pool was rectangular in shape.

8.2 TESTS ON THIN-PLATE WEIRS

8.2.1 FIRST SERIES OF TESTS WITH AND WITHOUT DIVIDING WALLS

The purpose of the first series of tests on compound thin-plate weirs was to determine the size of the errors that are made if the standard analysis techniques, as applied in the prototype, are used. In these tests a rectangular approach channel was used throughout. Approximate values of parameters used in these tests are summarized below.

Parameter	Values used (m)
L_1	1,18 0,74 0,50
L_2	1,75 2,19 2,43
P	0,05 0,10 0,20 0,3
T	0,05 0,10 0,20

Table 8.1: Approximate Values of Parameters Used in First Series of Tests on Thin-Plate Weirs

Discharges of approximately 50, 100, 200, 300 and 400 *l*/s were used in these tests.

Not all combinations of the above parameters were tested. The range of dimensionless parameters that were tested is listed in Table 8.2 below.

Parameter	$\frac{L_2}{L_1}$	$\frac{H_1}{P}$	$\frac{T}{P}$
Minimum	1,5	0,25	0,25
Maximum	5	3,6*	2

Table 8.2: Range of Dimensionless Parameters Tested in First Series of Tests

* This value falls outside the application limit of the IMFT equation of $H_1/p < 2,5$

All the tests in this series were done with and without dividing walls.

8.2.2 SECOND SERIES OF TESTS WITHOUT DIVIDING WALLS

Towards the end of the test programme, a series of tests were conducted in which the main purpose was to determine the effect of siltation in the pool on the accuracy of the measurements. Channels were formed within the pools as shown in Figure 8.2 below. The pool depth P was also reduced in steps up to a minimum depth of zero which would represent a pool with silt deposits up to the level of the low crest of the weir.

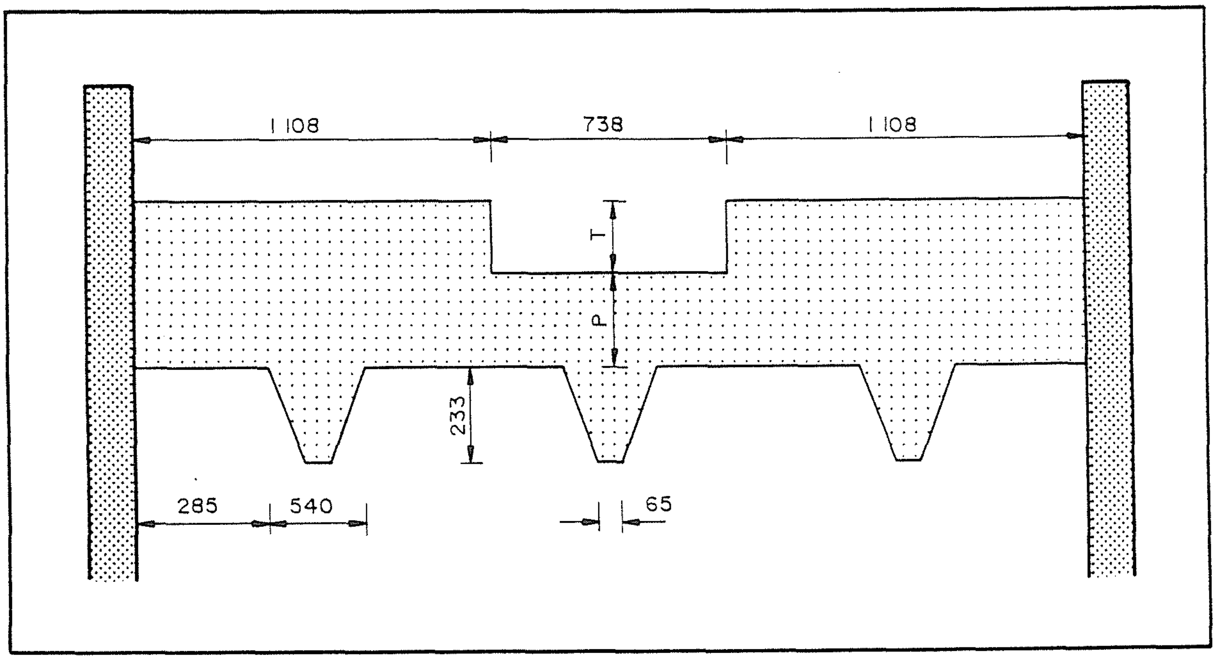


Figure 8.2: Channel Configuration of 2nd Series to Tests

The channels formed in the pool were all trapezium shaped with depths of 233 mm, top widths of 540 mm and bottom widths of 65 mm. Tests were conducted where all three channels were used simultaneously (denoted by LMR), or only one channel in the centre (denoted by M) or an off-center channel (denoted by L). Pool depths of 0, 16 and 85 mm were used in these tests. In all these tests the step height T was approximately 104 mm and values of L_1 and L_2 were 738 mm and 2 216 mm respectively. Discharges of 50, 100, 200, 300 and 400 l/s were used in these tests. This information is summarized in Table 8.3 below.

Channel configuration	P (mm)	T (mm)	L_1 (mm)	L_2 (mm)	Q *l*/s
LMR, M, L and no channel	0, 16, 85	104	730	2 216	50 to 400

Table 8.3:Parameters Used in 2nd Series of Tests on Thin Plate Weirs Without Dividing Walls

All these tests were performed only on thin-plate weirs and no dividing walls were used in these tests.

8.3 TESTS ON CRUMP WEIRS

8.3.1 TESTS PERFORMED IN THE DEPARTMENT OF WATER AFFAIRS AND FORESTRY (DWAF) LABORATORIES IN PRETORIA

The following parameters were selected in the tests that were performed in the hydraulics laboratories of the Department of Water Affairs and Forestry in Pretoria.

Parameter	**Range tested**
L_1 (mm)	672 to 1597
L_2 (mm)	3332 to 2416
P (mm)	93 to 269
T (mm)	71 to 97
Q (*l*/s)	20 to 177

Table 8.4: Range of Values Used in DWAF Tests on Crump Weirs

The range of the parameters expressed in terms of dimensionless parameters L_2/L_1, H_1/P and T/P is listed in Table 8.5 below.

Parameter	$\frac{L_2}{L_1}$	$\frac{H_1}{P}$	$\frac{T}{P}$
Minimum	1,5	0,13	0,37
Maximum	5,0	1,7	0,95

Table 8.5: Range of Dimensionless Parameters Used in DWAF Tests on Weirs

8.3.2 TESTS PERFORMED IN THE UNIVERSITY OF STELLENBOSCH LABORATORIES

The purpose of the tests on the Crump weir at Stellenbosch was mainly to extend the range of weir configurations and flow conditions that were previously tested in the DWAF laboratories. This was achieved by means of the greater maximum discharge that was available in the Stellenbosch laboratory (400 *l*/s in Stellenbosch compared to 177 *l*/s in Pretoria) and by using a narrower flow channel (3 m in Stellenbosch compared to 4 m in Pretoria). The number of tests which were performed on these Crump Weirs in Stellenbosch (i.e. 28) was significantly less than the number of tests on the thin plate weirs (i.e. 68). The reason for this was that a large number of test results were already available from the tests on the Crump Weir in Pretoria. The Stellenbosch tests on the Crump were therefore seen mainly as an extension of the tests in Pretoria.

Approximate values of the parameters selected used in the Stellenbosch tests on the Crump weir are summarised in Table 8.6 below.

Parameter	**Values used (mm)**		
L_1	479	735	1 197
L_2	2 498	2 242	1 780
P	98	171	-
T	107	-	-

Table 8.6: Values of Parameters Used in Stellenbosch Tests on the Crump Weir

The range of dimensionless parameters used in the Stellenbosch tests is shown in Table 8.7 below.

Parameter	$\frac{L_2}{L_1}$	$\frac{H_1}{P}$	$\frac{T}{P}$
Minimum	1,5	0,5	0,6
Maximum	5,2	1,5	1,2

Table 8.7: Range of Dimensionless Parameters Used in Stellenbosch Tests on the Crum Weir

All the tests on the Crump weir at Stellenbosch were performed with and without dividing walls.

9. OBSERVATIONS

9.1 GENERAL

The data recorded during all the tests are summarized in tabular form in Appendix A. The data will also be available from CCWR in order to enable interested researchers to perform further or alternative analyses with the data.

9.2 TESTS ON THIN-PLATE WEIRS PERFORMED IN STELLENBOSCH

9.2.1 FIRST SERIES OF TESTS

The observations during the first series of tests on thin plate weirs as described in Section 8.2.1, are given in Appendix A Tables A1 and A2. Table A1 contains the tests with dividing walls and Table A2 without dividing walls.

Test numbers S01 to S66 were allocated to this test series. For each test two discharges are listed i.e. the discharge as measured with the manometer in the supply pipe and the discharge as measured with the thin-plate weir in the return channel. All water levels are given relative to the crest of the low weir. Water levels at distances of 0, H_{max}, 2 H_{max}, 4 H_{max} and 6 H_{max} upstream of both the low and high weir crests are listed. For tests S01 to S18 water levels were recorded upstream of both high crests, (i.e. left and right in Tables A1 and A2) but due to the symmetry of the weir lay-out, water levels upstream of the right hand high crest were omitted after test S18.

9.2.2 SECOND SERIES OF TESTS

The observations during the second series of tests on the thin-plate weir, where the effect of siltation in the pool was investigated, are given in Table A3. All these tests were performed without dividing walls. The channels in the pool as shown in Figure 8.2, are indicated as L, M and R in Table A3 with LMR indicating that all three channels were used. Where no channel was formed in the pool this is indicated by "no" in the "channel configuration" column.

In all these tests water levels were only recorded at a distance of 4 H_{max} upstream of the low (middle) and high (left and right) crests.

9.3 TESTS ON THE CRUMP WEIR

9.3.1 TESTS IN PRETORIA

The observations of all the DWAF tests on Crump weirs with and without dividing walls are given in Table A4 and A5 respectively. The discharges listed are the discharges that were measured with the electromagnetic flow meter in the supply pipeline. All water levels were measured relative to the low crest, as before. Water levels were recorded upstream of the low crest only.

9.3.2 TESTS IN STELLENBOSCH

The observations from the tests on the Crump weir with and without dividing walls at Stellenbosch are given in Appendix Tables A6 and A7 respectively. The format of these tables is identical to that of Table A1 described in paragraph 9.2.1 above.

10. GENERAL APPROACH IN THE ANALYSIS OF THE DATA

10.1 GENERAL

The approach that will be followed in the analysis of the data will firstly be to analyze the data for the case where the best accuracy can be expected. This will be where dividing walls are used and the water levels are recorded upstream of each crest. In this way each crest is treated as an individual weir and standard discharge formulae and discharge coefficients should apply. This analysis should provide a good indication of the accuracy of discharge measurement that can be obtained in the model under ideal flow conditions.

The second step in the analysis will be to determine the decrease in accuracy that can be expected with the dividing walls, if only one water level is recorded i.e. upstream of the low crest. This is the method that is specified in the BSI standards. The influence of the assumption of a constant head across the weir on the accuracy, can be determined in this way.

The next step in the analysis will be to quantify the errors that can be expected if the dividing walls are omitted and the water level is only recorded upstream of the low crest. Since this approach is used in most of the prototype gauging weirs in South Africa, efforts will be made to find analysis techniques which will minimize the error in calculating discharge for this case.

The analysis for both the thin-plate weir and the Crump weir will be presented together for the cases described above since the effect on the results of dividing walls and positions of level recording are expected to be similar for both structures.

In the analysis of the data as described above, only the data where there are no serious deviations from the limits of applicability of the formulae as described in paragraphs 5.3 and 5.4, will be used. Improvements to the formulae, discharge coefficients and assumptions to improve the accuracy of flow measurements with compound structures will be based on these tests.

In the final analysis the effect of non-ideal pool conditions, as tested in the second series of tests on the thin-plate weir, will be investigated. This analysis should indicate how sedimentation in the pool, leading to very shallow pools and pools defined with flow channels within the pool, will affect the accuracy of flow measurement.

In all analyses the water level recorded at 4 H_{max} upstream of the low weir will be used in calculations since this is the standard position used for water level recording in South Africa. The water levels recorded at other positions are listed in the observations and are occasionally used to explain certain phenomena that were observed during the tests.

10.2 CALCULATION OF THE DISCHARGE Q FROM THE RECORDED WATER LEVEL h

The procedure which is used to calculate the discharge from the recorded water level h is an iterative process which proceeds as follows:

(i) The energy head (H) in the first iteration is assumed to be equal to the recorded water level height (h). A first estimate of the discharge over the low weir is thus obtained from the formula

$$\left.\begin{aligned} Q &= C_D \frac{2}{3} \cdot \sqrt{2g}\, L\, H^{3/2} \\ \text{with } C_D &= 0{,}627 + 0{,}018 \frac{H}{P} \end{aligned}\right]$$

For the thin-plate weir

or from

$$\left.\begin{aligned} Q &= C_D \cdot \frac{2}{3} \sqrt{\frac{2}{3} g}\, L\, H^{3/2} \\ \text{with } C_D &= 1{,}167 \left(1 - \frac{0{,}0003}{h}\right)^{3/2} \end{aligned}\right]$$

For the Crump weir

(ii) The approach velocity (v) is estimated from

$$\mathrm{v} = \frac{Q}{A} = \frac{Q}{L(h+P)}$$

(iii) The energy head H is now calculated as

$$H = h + \frac{\mathrm{v}^2}{2g}$$

(iv) The value of H from (iii) above is substituted in the equations of (i) above and a new estimate of Q is obtained.

(v) Steps (ii), (iii) and (iv) and (i) are now repeated until Q remains constant.

(vi) This process is repeated for flow over the high weir. By adding these two discharges the total discharge Q_W is obtained.

The procedure described above is simple if dividing walls are used and water levels upstream of both crests are recorded. In cases where dividing walls are omitted and/or water levels are only recorded at one position, further assumptions need to be made. These will be described in the appropriate sections where these analyses are performed.

10.3 CALCULATION OF THE ERROR IN DISCHARGE MEASUREMENT

To be able to calculate the accuracy with which the compound weir can measure the flow if the above procedure is used, the difference between this discharge and the discharge measured in the supply pipe to the model is calculated. Expressed as a percentage the error is therefore

$$\text{Error} = \left(\frac{Q_w - Q_m}{Q_m}\right) \times 100\%$$

where Q_W is the discharge based on the water level recorder and Q_m the discharge measured in the supply pipeline.

It is assumed in the calculation that Q_m is absolutely correct. This is obviously not the case but it is estimated that errors in Q_m have been less than 2%.

11. ANALYSIS OF TESTS WITH DIVIDING WALLS

11.1 WATER LEVELS RECORDED UPSTREAM OF BOTH CRESTS

The procedure used for calculating the discharge from the water levels upstream of both the low and the high weirs, is exactly as described in section 10.2. Examples of such calculations for test S01 on a thin-plate weir and test C3 on the Crump are given in Appendix B1 and B2 respectively. An extract containing the results of these calculations is printed in Appendix C1 and C2 for the thin-plate and Crump weir respectively.

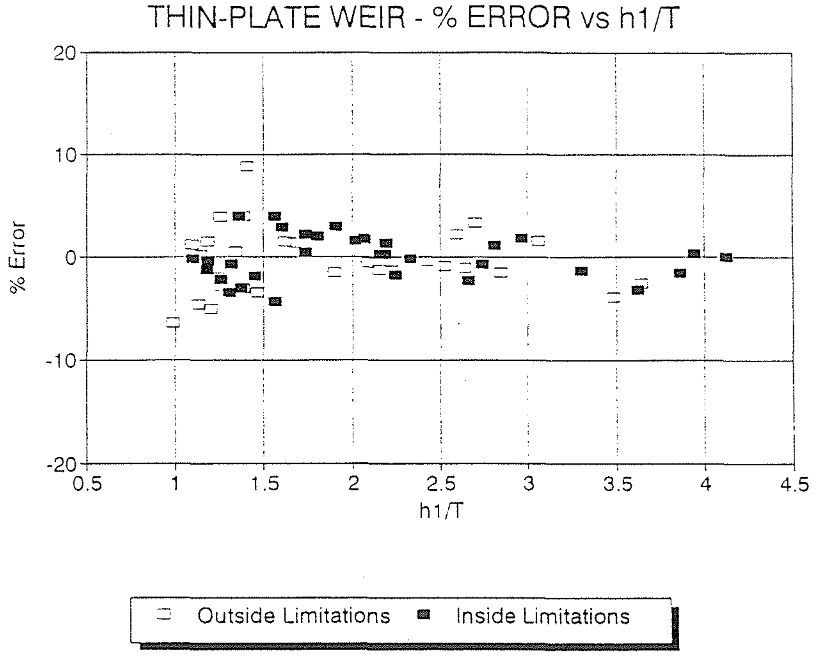
This analysis could only be performed on the tests executed in the Stellenbosch laboratory since water levels upstream of the high crests were not recorded during the Pretoria tests.

The percentage error as a function of h/T is plotted for both the thin plate and Crump weir in Figure 11.1. The parameter h/T is used because it gives an indication of the relative degree of overtopping over the two crests. Flow over the high crest commences when h/T exceeds a value of unity. The average error and standard deviation of the error for each type of structure is also summarized in Table 11.1 below. Assuming the error to be normally distributed, the 95% confidence bands of the error are also indicated in these tables.

Structure	Number of tests	Average error	Standard deviation	95% Confidence bands
Thin-plate	60	-0,3	2,5	-5,5 to +4,8
Crump	28	+0,3	1,4	-2,6 to +3,1

Table 11.1: Average, Standard Deviation and 95% Confidence Band of Percentage Error - Dividing Walls with Water Level Recording Upstream of Each Crest

As can be seen from Figure 11.1 and Table 11.1, relatively accurate estimates of the discharge can be obtained using this method of measurement and analysis. The average errors are negligible for both structures showing that there is no general tendency to over- or underestimate the flow. The confidence bands indicate that in 95 per cent of the cases the accuracy of the discharge estimate will be within 5 per cent for the thin-plate weir and 3 per cent for the Crump weir. These good results do not only indicate that the discharge formulae being used are appropriate, but also show that the model set-up, test techniques and calculation procedures used are acceptable if a 5 per cent error at the 95% confidence level is satisfactory.



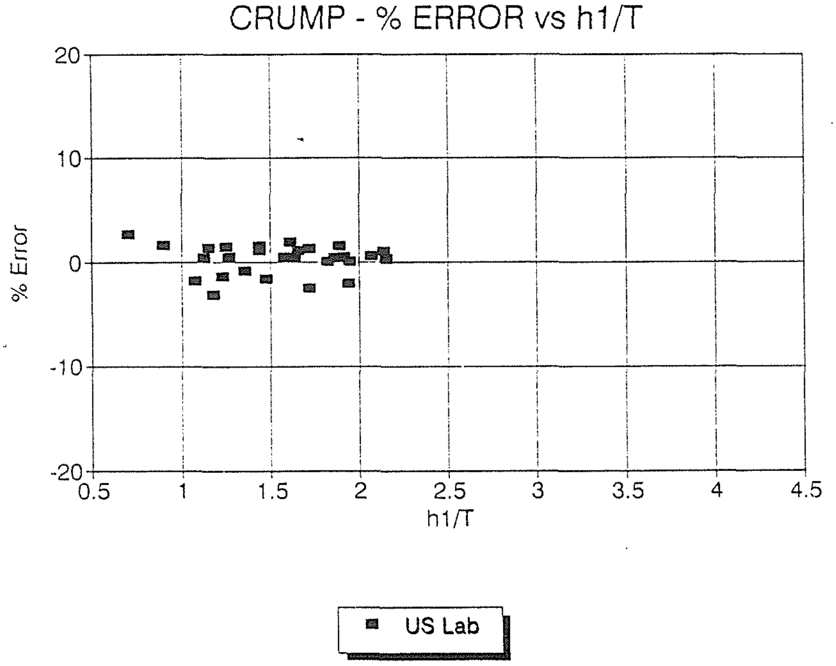


Figure 11.1: **Percentage Error vs h/T for Thin Plate and Crump Weir with Dividing Walls and Water Level Recording Upstream of Both Crests**

11.2 WATER LEVEL RECORDING UPSTREAM OF LOW CREST ONLY

In South Africa the general practice is to record water levels upstream of the low crest only. With dividing walls it is then possible to calculate the energy level and the discharge for the low weir using the iterative process described in paragraph 10.2. To calculate the discharge over the high weir, the assumption is made that the energy level calculated upstream of the low crest is also applicable to the high crest. This assumption is also advocated by the *British Standards Institute* (BSI (1981).

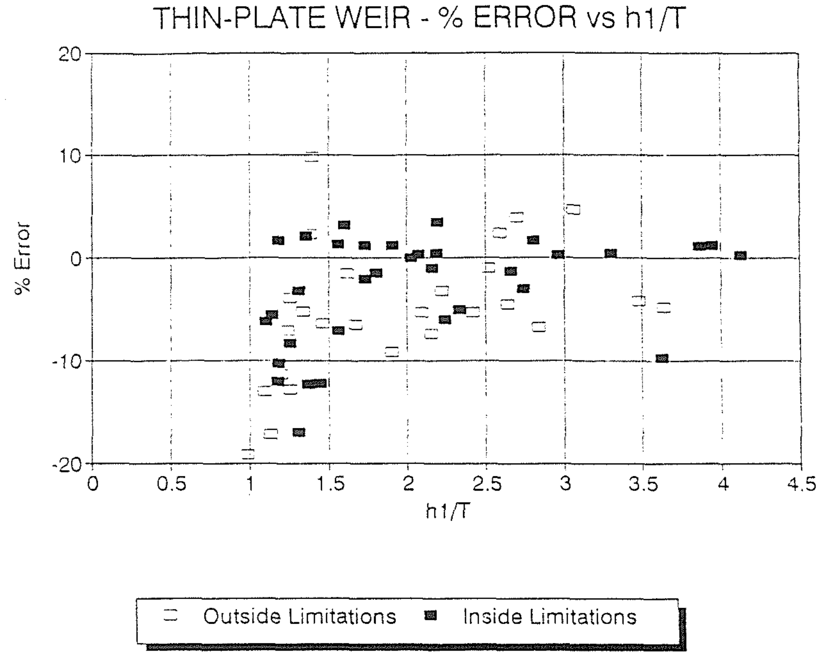
To determine what errors are introduced if this procedure is used, the identical data analyzed in Section 11.1, were re-analyzed. In this re-analysis the water level upstream of the high crest was ignored and the assumption of equal energy levels upstream of both weirs was made. Tests on the Crump weir in the DWAF laboratories could be added to the data used in paragraph 11.1.

Sample calculations for test S01 on the thin-plate weir and test C3 on the Crump, are given in Appendices B3 and B4 respectively. The results of the calculation are also summarized in appended tables C3 and C4 for the thin-plate and Crump weirs respectively.

The results are summarized in Figure 11.2 where the percentage error is again shown as a function of h/T. This figure shows that there is a general tendency for the discharge values to be under-estimated. This tendency is most pronounced during the early stages of overtopping of the high crest i.e. when h/T values fall in the range 1,0 to 1,5. Under-estimates of as high as 19% and 16% were registered for the thin-plate and Crump weirs respectively in this h/T range. Once overtopping of the high crest increases to a level where h/T exceeds 1,5, the tendency for under-estimation of the flow decreases and under-estimates of more than 8% rarely occur for both types of weir.

The tendency for under-estimating the flow is clearly introduced by the assumption of equal energy levels at the low and high crests. Under certain conditions, the energy head above the high crest is considerably more than the energy head above the low crest. This is especially true for high values of T and small values of P with h/T values in the range between 1,0 and 1,5 (see Figure 11.3). Under these conditions strong tendencies for cross flow and flow separation at the cutwaters of the dividing walls develop as can be seen in Figure 11.4.

Efforts to isolate the points where large under-estimations occur and to apply a correction factor which is a function of h/T, T/P and other parameters were not successful. Theoretical analyses to determine the head losses between the high and low crest recording positions were also not satisfactory. It is therefore advisable to try and avoid these underestimations by ensuring that the step height T is not too high (not more than 500 mm as recommended by BSI) and that the pool P is not too shallow. For T = 300 mm and P > 600 mm (i.e. T/P < 0,5) differences in energy height for the two crests were less that 4 percent in all but one of the tests (see Figure 11.3).



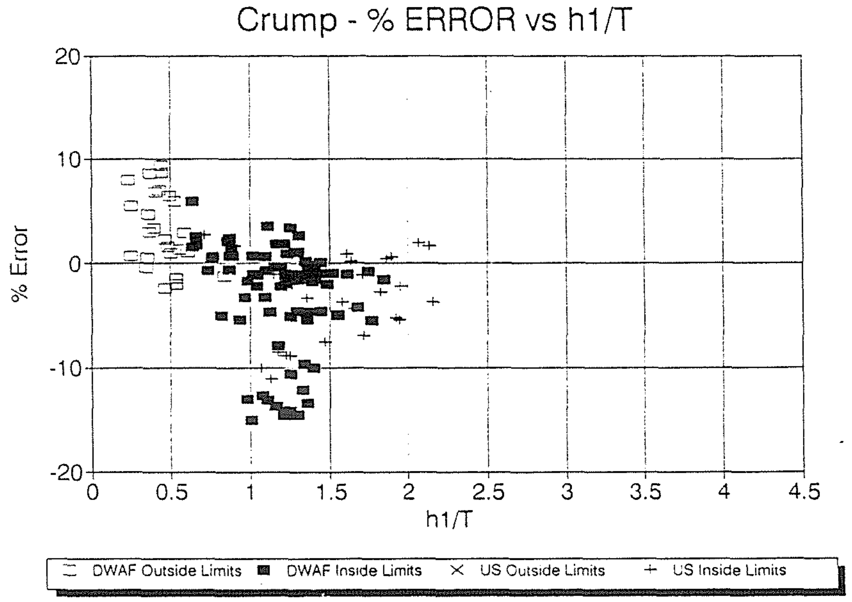


Figure 11.2: **Percentage Error vs h/T for Thin-Plate and Crump Weirs with Dividing Walls - Based on h Upstream of Low Crest**

In a number of tests on the Crump weir in the DWAF laboratories, flow conditions were such that flow only occurred over the low weir (i.e. h/T < 1.0 in Figure 11.1). Under these circumstances there is a tendency for the flow rate to be over-estimated, especially for small h/T values. Due to the limited amount of data in this flow range, no attempt will be made to determine correction factors.

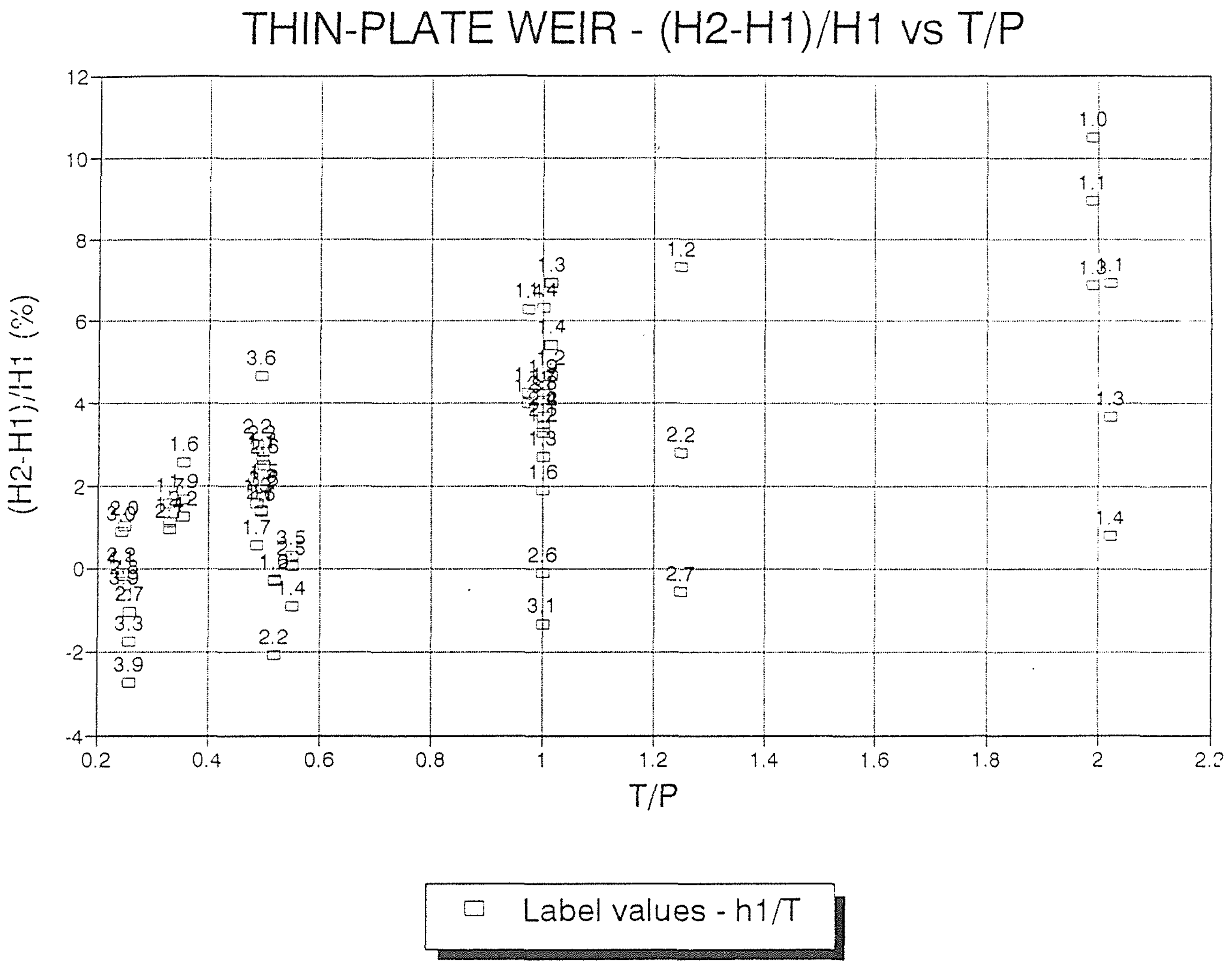


Figure 11.3: **Head Loss Between High and Low Crest as a Function of T/P and h/T**

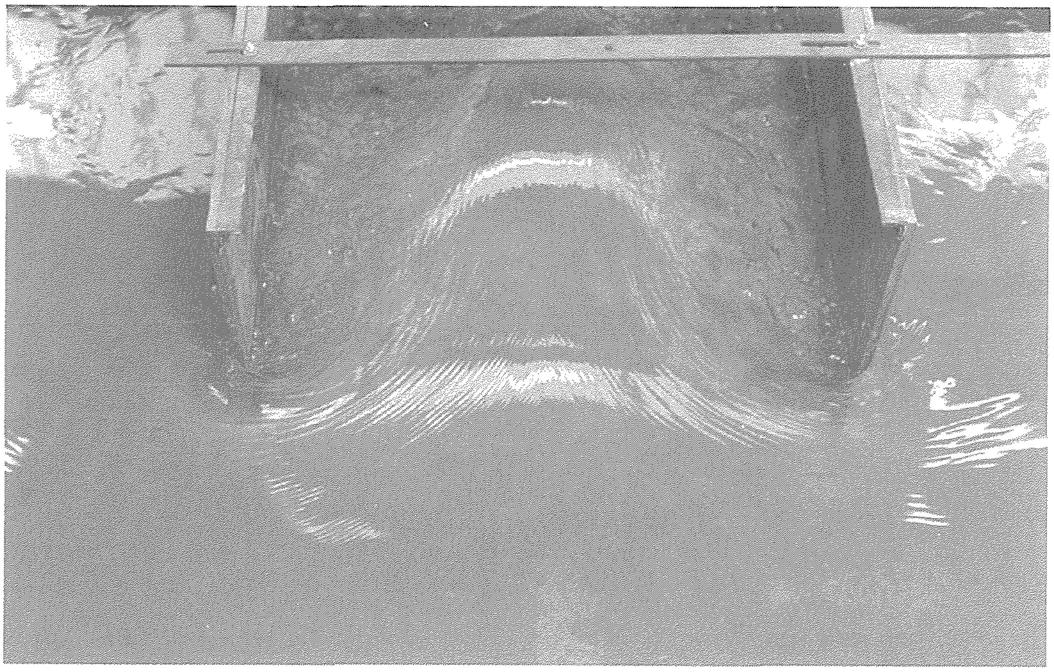


Figure 11.4: Photograph of Cross Flow at Cutwaters of Dividing Walls

12. ANALYSIS OF TESTS WITHOUT DIVIDING WALLS

12.1 GENERAL

The most commonly used method of flow gauging in South African rivers is to use compound sharp-crested and Crump weirs without dividing walls and to record the water level upstream of the low crest only. This method is in contrast with international standards which strongly recommend the use of dividing walls. It was therefore considered important to determine the magnitude of the errors introduced by the South African practice. Means also had to be sought to reduce these errors by for instance redefining the discharge coefficients for these weirs as a function of the weir and pool configuration and as well as the flow conditions.

12.2 ERRORS INTRODUCED WHEN USING STANDARD ANALYSIS PROCEDURES

The South African standard method for calculating discharge for compound sharp-crested and Crump weirs based on the water level upstream of the low crest has been as follows:

(i) Obtain a first estimate of the discharge over each crest by substituting h for H in equations 5.1 and 5.2 i.e. for the thin-plate weir:

$$Q = C_D \cdot \frac{2}{3} \sqrt{2g}\ L\ H^{3/2}$$

$$\text{with } C_D = 0{,}627 + 0{,}018\ \frac{H}{P}$$

and for Crump weir

$$\mathrm{Q} = \mathrm{C_D} \cdot \frac{2}{3}\sqrt{\frac{2}{3} g}\ L\,H^{3/2}$$

$$\text{with } \mathrm{C_D} = 1{,}163\left(1 - \frac{0{,}0003}{h}\right)^{3/2}$$

Since two crests are involved the appropriate values for h, H, P, L and C_D must be calculated for each crest individually.

(ii) Calculate the average approach velocity v as

$$\mathrm{v} = \frac{\mathrm{Q_{total}}}{\mathrm{A_{total}}}$$

$$\text{where } \mathrm{A_{total}} = (L_1 + L_2) \times (P + h)$$

$$\text{and} \qquad \mathrm{Q_{total}} \equiv Q_w$$

(Where the approach velocity differs significantly across a river, allowance needs to be made in accordance with international standards).

(iii) Calculate $H = h + \frac{\mathrm{v}^2}{2g}$

(iv) Substitute the appropriate H-values in the formulae for Q and obtain a new estimate for $\mathrm{Q_{Total}}$.

(v) Repeat steps (ii) to (iv) until Q remains constant.

(vi) Calculate the % error as

$$\text{Error} = \frac{Q_w - Q_m}{Q_m} \times 100\%$$

An example of such a calculation for test S01 and test C3 is given in Appendixces B5 and B6 for the thin plate and Crump weirs respectively.

This procedure was followed in order to calculate the errors for all the first series of tests on the thin-plate weirs at Stellenbosch and all the tests (Stellenbosch plus DWAF) on the Crump weir. The results are shown in Appended tables C5 and C6 and are summarized in Figure 12.1.

As can be seen from Figure 12.1, there is a tendency with both the weir forms to overestimate the discharge for h/T in the range 1 to 2. The overestimation varies from an average around 7 per cent at h/T of 1 to zero at h/T equal or larger than 2. This overestimation of the discharge when there is a large difference in the overflow heights between the low and the high crest, is undoubtedly caused by flow diversion towards the low crest. As the flow over the high crest increases this diversion is reduced and effectively disappears at h/T > 2 when the overflow depth over the high crest exceeds 50% of the overflow depth over the low crest.

In general, this result is very encouraging. It indicates that errors larger than 10 percent are rarely made (only 3 out of 120 tests) when compound weirs are used without dividing walls even if standard analysis techniques are used. The results are better than the results for compound weirs with dividing walls if water levels are only recorded at one point, upstream of the low crest (see Figure 11.2).

In an effort to improve the accuracy of the discharge measurement with compound weirs without dividing walls, different analyzing techniques were applied. One of the more successful attempts is described below in section 12.3.

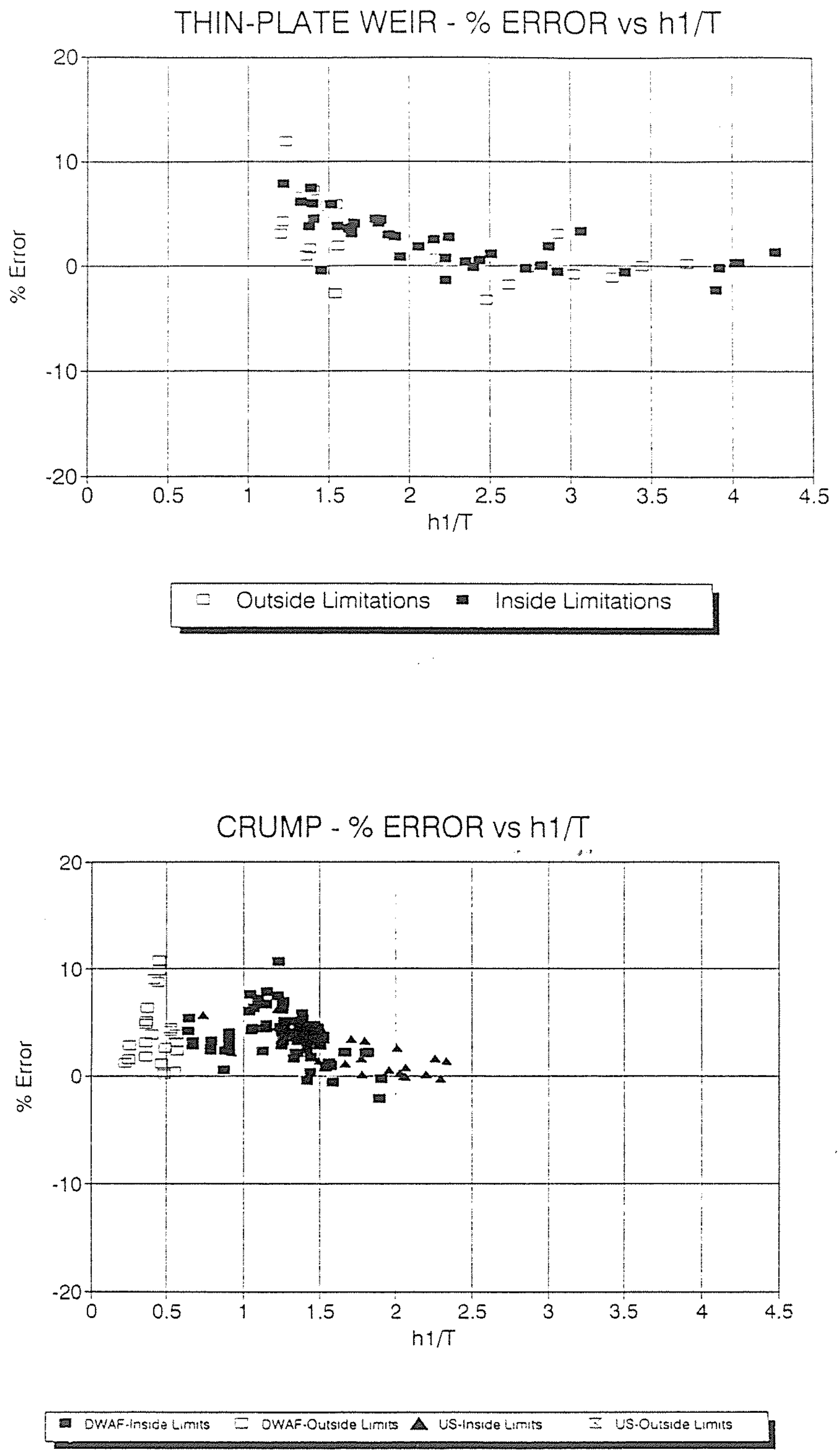


Figure 12.1: **Percentage Error *vs* h/T for Thin-Plate and Crump Weirs *Without Dividing Walls* - h measured upstream of low crest**

12.3 IMPROVED ACCURACY WITH ALTERNATIVE ANALYSIS PROCEDURE

12.3.1 THIN PLATE WEIR

In the standard analysis procedure described in paragraph 12.2 above, two discharge coefficients were calculated, one for the low crest and one for the high crest. These discharge coefficients are functions of the energy head H relative to the weir crest and the pool depth. With a compound weir these two parameters vary across the weir as is illustrated in Figure 12.2.

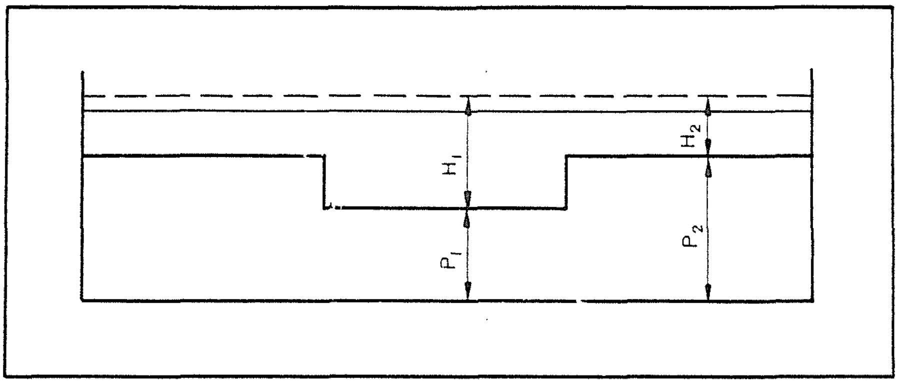


Figure 12.2: Variation in H and P for a compound weir

To eliminate the need for two discharge coefficients in the calculation, the weir was treated as a single structure with an effective pool depth and energy head being defined as follows:

$$P_e = \frac{P_1 \cdot L_1 + P_2 \cdot L_2}{(L_1 + L_2)} \quad \text{with } P_2 = P_1 + T \quad \mathit{for}\ h_1 > T$$

$$= \frac{P_1 \cdot L_1 + (P_1 + h_1) \cdot L_2}{(L_1 + L_2)} \quad \mathit{for}\ h_1 < T$$

$$H_e = \frac{H_1 \cdot L_1 + H_2 \cdot L_2}{(L_1 + L_2)} \quad \text{and } H_2 = H_1 - T \quad \mathit{for}\ h_1 > T$$

$$= H_1 \quad \mathit{for} \quad h_1 < T$$

This definition was found to be very useful especially for cases where either P_1 or H_2 became very small and fell outside the limits for which the standard discharge coefficients have been calibrated. This aspect will be expanded upon in section 13 where the effect of pool siltation is discussed.

The procedure that was followed in the calibration of these weirs was to substitute the values for Q and H in the equation below and to determine C_D as follows:

$$Q = C_D \cdot \frac{2}{3} \sqrt{2g} \left\{ L_1 H_1^{3/2} + L_2 (H_1 - T)^{3/2} \right\}$$

Since h_l is recorded as well as Q in the supply pipe, it is a simple matter to convert h_l to H_l since

$$v = \frac{Q}{(L_1 + L_2)(P_1 + h_1)}$$

$$\text{and } H_1 = h_1 + \frac{v^2}{2g}$$

In this way a C_D value was determined for each test. A sample calculation for test S01 is given in Appendix B7.

The relationship between C_D and H_e/P_e was now determined as $C_D = 0,607 + 0,0419\ H_e/P_e$. Graphical representation of this relationship is shown in Figure 12.3.

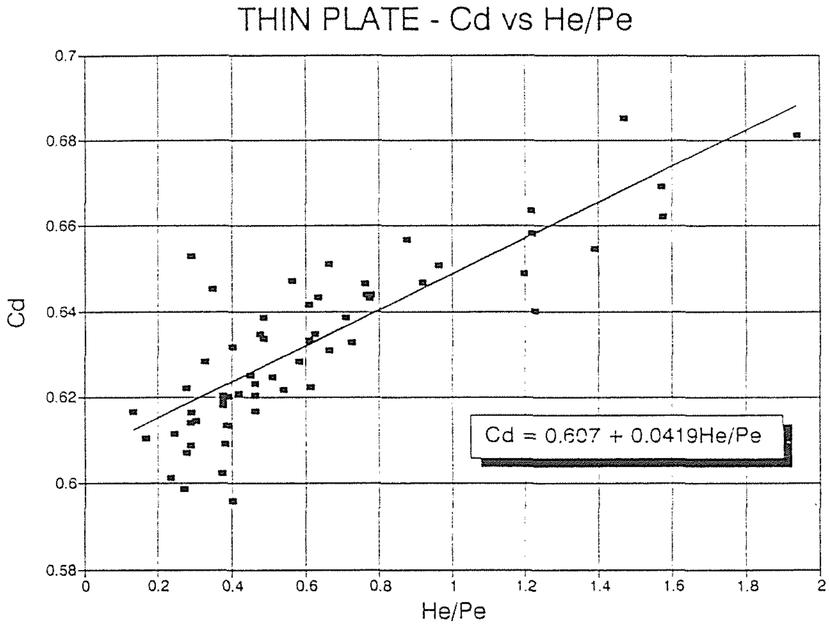


Figure 12.3: C_D as a Function of H_e/P_e for Thin-Plate Weir Without Dividing Walls

The percentage error in the discharge, if the discharge is calculated as described in section 12.2 using $C_D = 0,607 + 0,042\ H_e/P_e$ instead of $= 0,627 + 0,018$ H/P as was used before. The results are given in Appendix table C7 and are shown as a function of H_e/P_e in Figure 12.4.

The mean error is now 0 with a standard deviation of 1,75%. This means that the error is 3,5% at the 95% confidence level and the largest error that was recorded in the tests was 5%.

Although other approaches gave similar accuracies for the test results without the dividing walls, the advantages of the method described here will become obvious in section 13 where the effect of pool siltation is investigated.

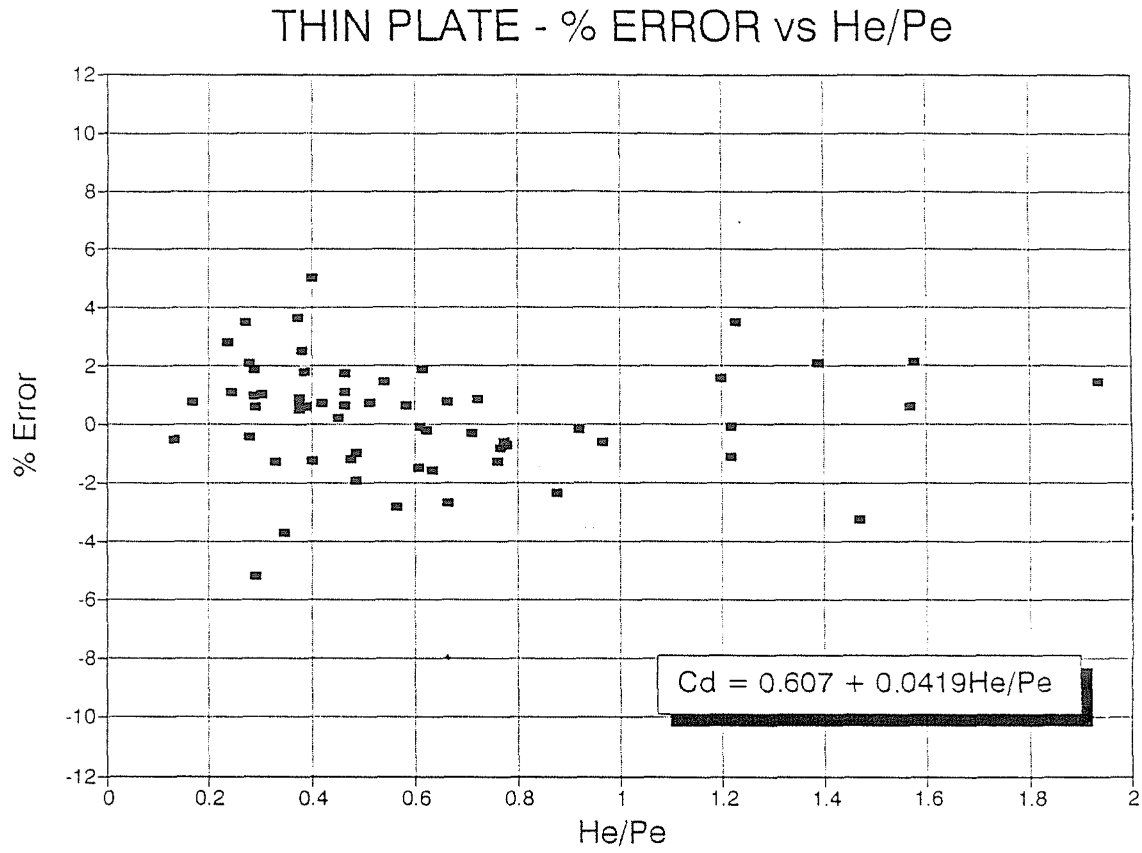


Figure 12.4: Percentage Error as a Function of H_e/P_e for Thin Plate Weir *Without Dividing Walls* (C_D = 0,607 + 0,042 H_e/P_e)

12.3.2 CRUMP WEIR

An identical approach to that described in section 12.3.1 for the thin-plate weir, was also attempted for the Crump weir using the data from both the DWAF and Stellenbosch tests. The analysis was first performed only for the tests where flow occurred over both crests (i.e. h/T > 1). This procedure was then repeated for the tests where flow only occurred over the low crest (i.e. h/T < 1) using H_e and P_e as defined in Section 12.3.1 It was found from regression analyses that the relationship

$$C_d = 1{,}09 + 0{,}083 \frac{H_e}{P_e}$$

held good for both cases. This is shown in Figure 12.5 where the results for h/T < 1 and h/T > 1 are combined.

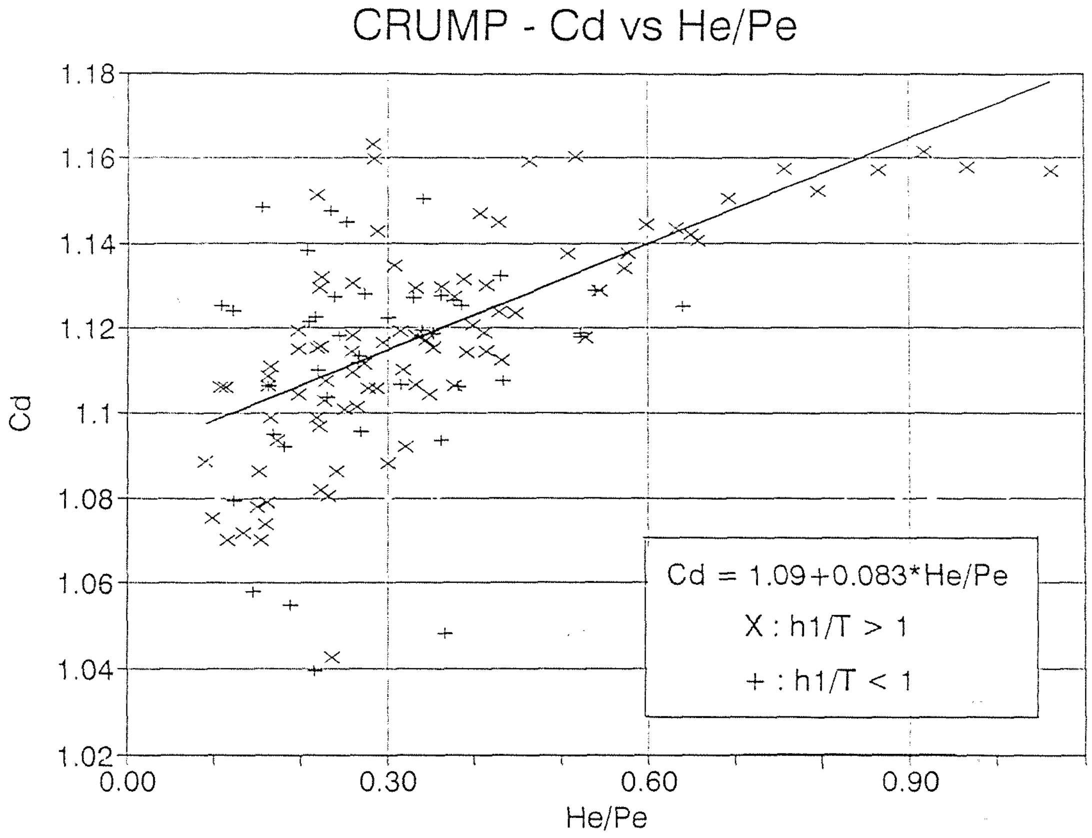


Figure 12.5: C_D as a Function of H_e/P_e for *Crump Weir Without Dividing Walls*

Using this relationship, the error in the discharge was calculated for each test. The results are shown in Appendix C8. Percentage error as a function of H_e/P_e is shown in Figure 12.6. For the 129 test results used in this exercise the mean error was found to be 0 percent with a standard deviation of 1,9%. In only 3 out of the 129 test results errors exceeding 5 percent were found.

This approach was therefore found to be very effective in eliminating the tendency for over-estimating the discharge for both the cases of flow over only one crest and for the case where the flow depth over the two crests differed substantially.

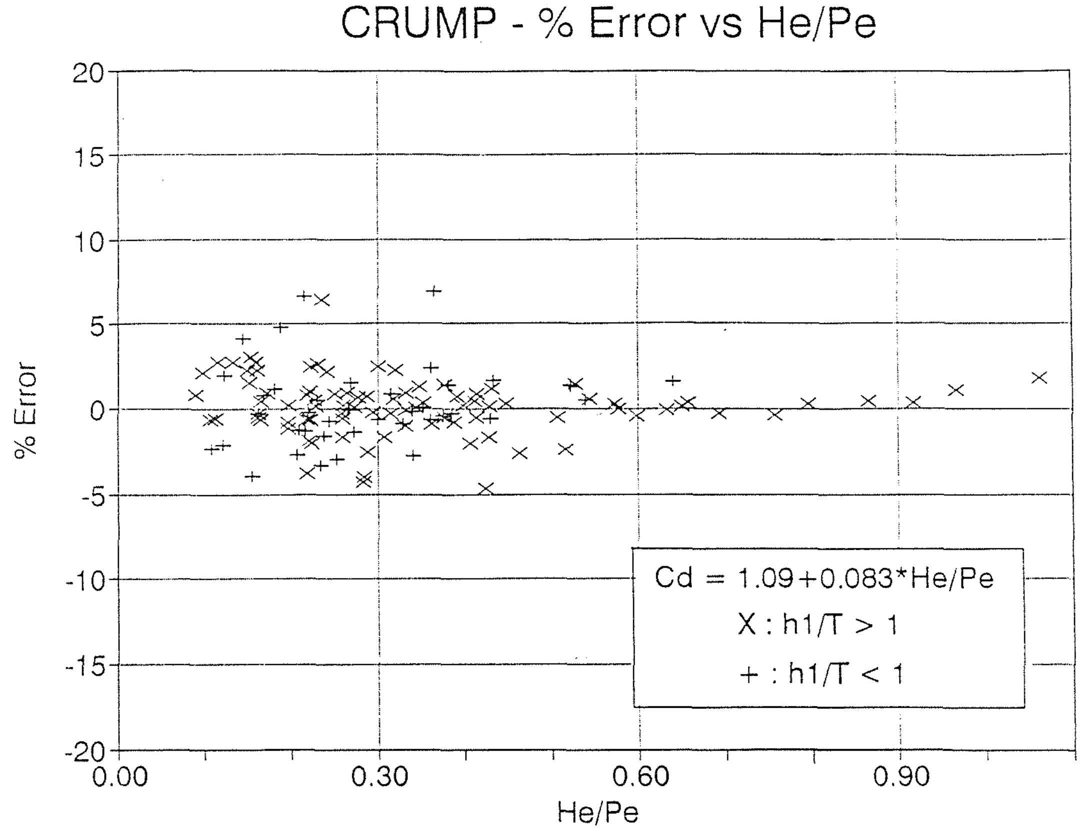


Figure 12.6: Percentage Error as a Function of H_e/P_e for a *Crump Weir Without Dividing Walls* (C_d =1,09 + 0,083 H_e/P_e)

13. EFFECT OF VERY SHALLOW AND IRREGULAR POOLS ON THE ACCURACY OF SHARP-CRESTED WEIRS

As described in section 8.2.2, a few tests were conducted towards the end of the test program in order to determine the influence of siltation in the pools on the accuracy of discharge measurement with compound thin-plate weirs without dividing walls. All these tests were done with only one set of values of the low crest, high crest and step height. The pool configurations used are shown in Figure 8.2 and in Table 8.3.

With especially the irregular pools, the definition of the effective pool depth was found to be a simple yet effective way of characterizing the pool. As before, the effective pool depth is defined as the total pool area below the crest of the weir, divided by the total width of the weir as illustrated in Figure 13.1 below.

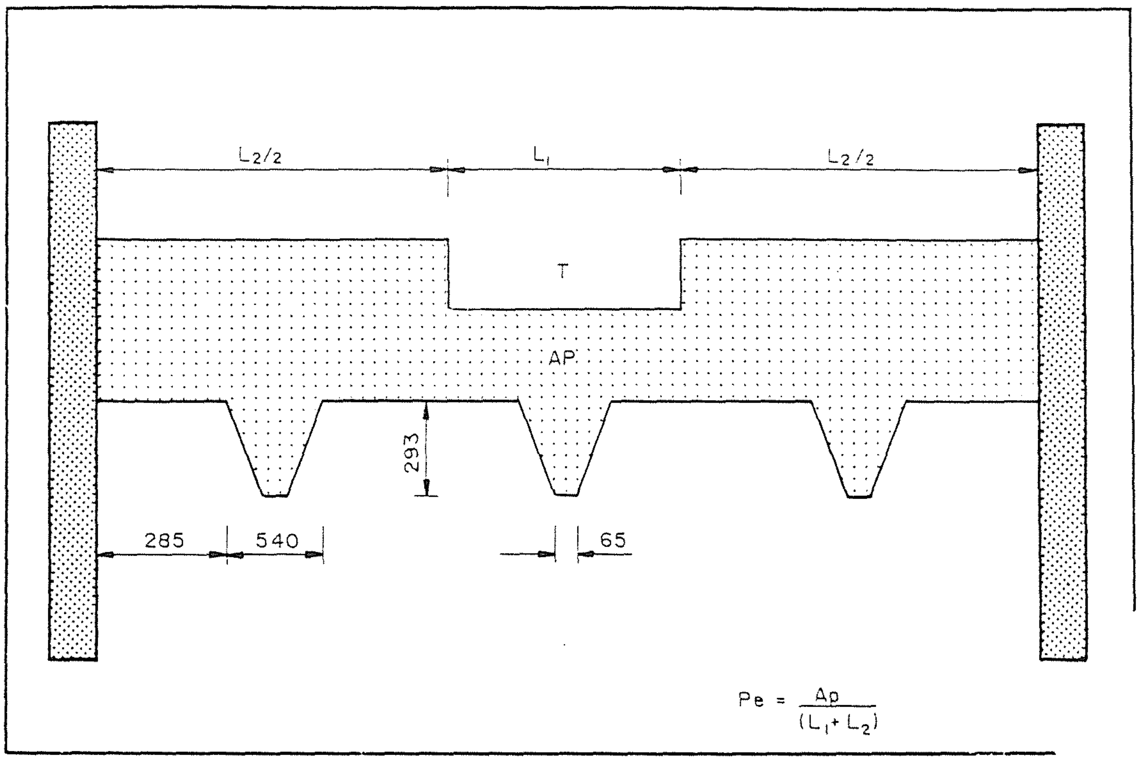
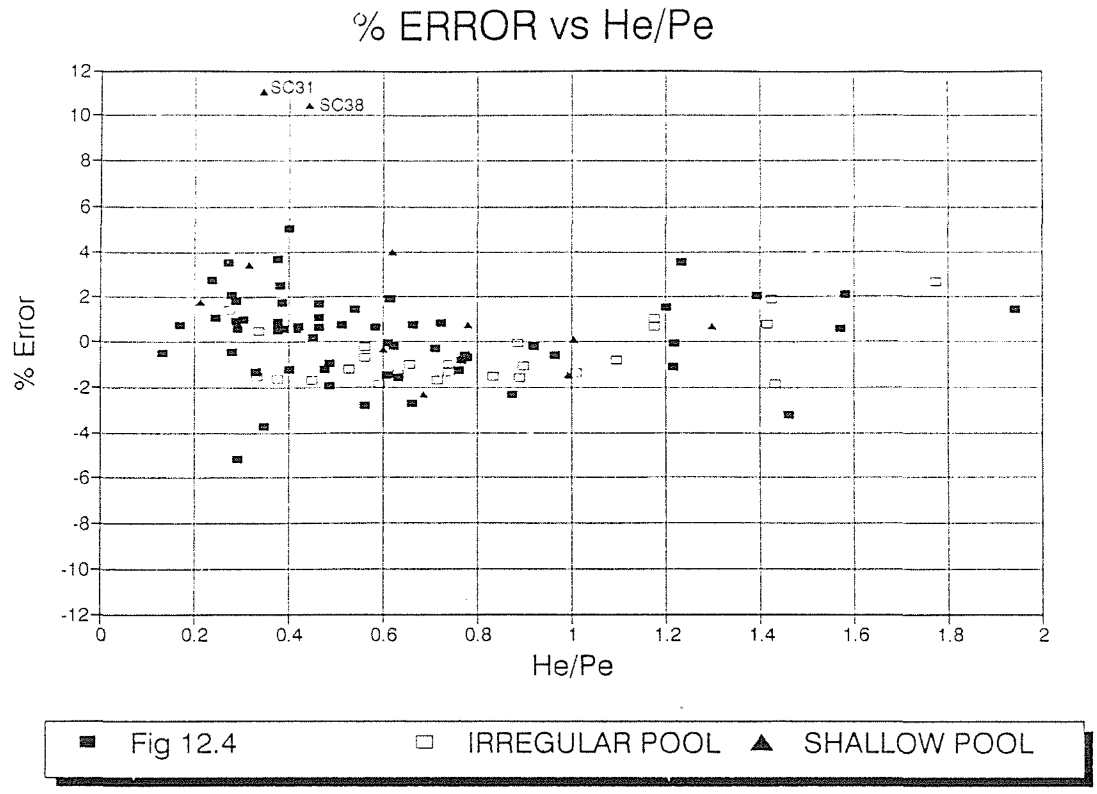


Figure 13.1: Definition of Effective Pool Depth

The process of calculating the discharge from the recorded water level was identical to the iterative process described in section 12.3 except that one discharge coefficient i.e. $C_D = 0{,}607 + 0{,}042\ H_e/P_e$ was used for both weirs. The error in the discharge was calculated as before.

The results of this analysis are given in Appendix Table C9 and are summarized in Figure 13.2. The results of the previous tests on the thin-plate weirs without dividing walls are also included in this figure.



% ERROR vs He/Pe

Figure 13.2: Percentage Error as Function of H_e/P_e for Thin-Plate Weirs with Shallow and Irregular Pool ($C_D = 0,607 + 0,042\ H_e/P_e$)

The results in general are very satisfactory. Errors even with the pools silted up to the level of the low weir are all less than 6 per cent, except in two cases i.e. test SC31 and SC38 where errors between 10 and 11% are made. In these two tests virtually all the water flowed over the low crest (i.e. h/T equaled 1,08 in both cases) and no pool or channel existed upstream of the low crest. As the discharge over the high weir increases, the pool upstream of the high weir becomes effective and the error reduces rapidly.

It is also interesting to note that if one of the channels connects up to the low weir such as is the case test SC9 (LMR) and SC20(M), the extent of the pool formed in the channel is sufficient to ensure that the error becomes insignificant.

These tests proved that accuracies to within 4% can be achieved at the 95% confidence level even if the pools become very shallow. These accuracies only apply for the case where only two crest heights are used and flow takes place over both crests.

14. CONCLUSIONS

(i) By far the most significant conclusion of this study is that accurate flow gauging by means of compound sharp-crested and Crump weirs without dividing walls is possible within the limits that were tested in the study. If the standard discharge coefficients for these weirs as published in BSI (1981) are used, there is a tendency for the flow to be over-estimated in the range $2 > h/T > 1$. This over-estimation varies from an average of 7% at $h/T \approx 1$ to 0 at $h/T \geq 2$.

If the discharge coefficient is adjusted in terms of H_e/P_e, the over-estimation can be eliminated and accuracies at the 95% confidence level are improved to approximately 4% for both weir types. This relationship was found to be reliable even for very shallow and irregular pool forms. It also served well to eliminate over-estimations in discharge when flow occurred only over one crest.

(ii) The recommendation in BSI (1981) to use dividing walls with compound weirs and to base the energy level upstream of all the weirs on the energy level at the weir where the water level is recorded, can lead to errors in discharge recording. The South African practice of recording upstream of the low crest can cause an under-estimation of up to 15 to 20 per cent in the flow rate under certain conditions. The under-estimation is at its worst for large step heights T and small pool depths P (i.e. $T/P > 1$) combined with large differences in overflow depths above adjacent weirs $1{,}5 > h/T > 1{,}0$. If step heights are limited to 300 mm and pool depths are 600 mm or more, these under-estimations will not exceed 10 per cent.

(iii) For wide rivers where compound weirs with many different crest heights are used and especially for cases where the pool is not straight and roughly rectangular, the only sure way to ensure accurate flow gauging would be to build dividing walls and to record water levels upstream of each crest.

15. RECOMMENDATIONS

15.1 ANALYSIS WITHOUT DIVIDING WALLS

(i) The following formulae are recommended:

Thin plate weir:

$$Q = C_D \cdot \frac{2}{3}\sqrt{2g}\left\{L_1 H_1^{3/2} + L_2(H_1 - T_1)^{3/2} + L_3(H_1 - T_1 - T_2)^{3/2} + \ldots\right\}$$

with $C_D = 0{,}607 + 0{,}042\dfrac{H_e}{P_e}$ for $2 > \dfrac{H_e}{P_e} > 0$

Crump weir

$$Q = C_D \cdot \frac{2}{3}\sqrt{\frac{2}{3}g}\left\{L_1 H_1^{3/2} + L_2(H_1 - T_1)^{3/2} + L_3(H_1 - T_1 - T_2)^{3/2} + \ldots\right\}$$

with $$C_D = 1{,}09 + 0{,}083\frac{H_e}{P_e} \quad \text{for} \quad 0 \le \frac{H_e}{P_e} \le 0{,}88$$

and $$C_D = 1{,}163 \quad \text{for} \quad \frac{H_e}{P_e} > 0{,}88$$

The definitions of H_e, P_e, etc are given in Chapter 12.3.1.

Only those sections of the weir that are overtopped should be used in determining H_e and P_e.

(ii) The discharge Q should be calculated from the water level recorded upstream of the low weir by means of the iteration process described in Appendix B5 and B6.

(iii) The range of applicability of this procedure as specified above should cover virtually all the conditions normally encountered with these types of weir in South Africa.

15.2 ANALYSIS WITH DIVIDING WALLS

The present procedure used for the analysis of discharge with dividing walls is acceptable. The crest where the water level is recorded is used to determine the energy head and this energy head can be applied to all the crests. Standard discharge formulae and discharge coefficients are used in the analysis i.e. for each weir section, the following equations can be used.

Thin-plate weir

$$Q = C_D \cdot \frac{2}{3}\sqrt{2g}\; L\, H^{3/2} .$$

with $$C_D = 0{,}627 + 0{,}018\,\frac{H}{P}$$

Crump weir

$$Q = C_D \cdot \frac{2}{3}\sqrt{\frac{2}{3}g}\, L\, H^{3/2}$$

with $$C_D = 1{,}163\left(1 - \frac{0{,}0003}{h}\right)^{3/2}$$

For the section of the structure where T/P > 0,5 the flow may be underestimated by up to 20% for the flow range where 1,5 > h/T > 1 if the energy level is based on measurement upstream of the low crest. With most of the prototype structures T/P will only be in this range if serious pool siltation occurs. The effect of this under-estimation on the total flow record will also be limited since only sections of the weir will fall in this critical range for limited periods.

15.3 CONSTRUCTION OF NEW WEIRS

Sharp-crested and Crump weirs can be constructed without dividing walls in all cases where relatively straight pools can be created and where the number of crest sections and the width of the weir is not excessive. In very wide rivers, where flow conditions in the pool vary considerably across the pool, the use of dividing walls with water level recorders upstream of a number of the weir sections, will lead to better accuracy. This approach may be warranted for the more important gauging stations where the accuracy of discharge determination is of major importance.

The possibility of in situ or model calibration of such important gauging stations is an alternative to the approach of dividing walls with multiple water level recording. Where major changes are expected in the approach flow conditions in the pool, say due to siltation, the use of dividing walls and multiple water level recording is however to be preferred.

15.4 MAINTENANCE OF STRUCTURES

Accurate estimates of discharge based on weir structures can only be made if the approach velocity can be estimated with reasonable accuracy, especially where this velocity is high. It is therefore not only important to maintain the upstream pool at an acceptable depth, but also to monitor the pool cross section at all times. Regular surveys of the pool are therefore important in pools where siltation poses problems. The importance of these surveys increases with reduction in pool depth. (The reader is referred to the internal guidelines on pool maintenance and surveys of the Hydrology Division, Dept. of Water Affairs and Forestry).

15.5 FURTHER RESEARCH

Whilst a number of the most serious problems which have been encountered in river flow gauging in the past, have been addressed, further research should be considered.
The main topics which require attention are:

(i) The impacts of horizontal contractions on the discharge coefficients of compound weirs;

(ii) Renewed research into the optimization of gauging networks. Such research would aim at determining the optimum number of river gauging stations and their positions in order to satisfy future data requirements.

16. REFERENCES

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APPENDIX A: TEST RESULTS

A1	Thin plate weir with dividing walls. Stellenbosch tests - first series
A2	Thin plate weir without dividing walls. Stellenbosch tests - first series
A3	Thin plate weir without dividing walls. Stellenbosch tests - second series (Shallow and irregular pools)
A4	Crump weir with dividing walls - DWAF tests
A5	Crump weir without dividing walls - DWAF tests
A6	Crump weir with dividing walls - Stellenbosch tests
A7	Crump weir without dividing walls - Stellenbosch tests

APPENDIX A1

THIN PLATE WEIR WITH DIVIDING WALLS
STELLENBOSCH TESTS - FIRST SERIES

Test No						Discharge		Left				Centre				Right			
	L1 (m)	L2 (m)	P (m)	T (m)	H_{max} (m)	Qm (m3/s)	Qr (m3/s)	0H (m)	2H (m)	4H (m)	6H (m)	0H (m)	2H (m)	4H (m)	6H (m)	0H (m)	2H (m)	4H (m)	6H (m)
S01	1.177	1.759	0.040	0.050	0.193	0.050	0.051	0.067	0.070	0.070	0.070	0.053	0.060	0.060	0.060	0.067	0.070	0.071	0.070
S02	1.177	1.759	0.040	0.050	0.193	0.200	0.202	0.121	0.132	0.132	0.132	0.100	0.112	0.111	0.114	0.121	0.133	0.133	0.132
S03	1.177	1.759	0.040	0.050	0.193	0.303	0.304	0.147	0.161	0.162	0.162	0.123	0.138	0.135	0.136	0.148	0.162	0.162	0.164
S04	1.177	1.759	0.091	0.050	0.197	0.050	0.058	0.070	0.073	0.072	0.074	0.060	0.070	0.070	0.070	0.070	0.073	0.074	0.074
S05	1.177	1.759	0.091	0.050	0.197	0.200	0.200	0.123	0.134	0.134	0.135	0.110	0.125	0.126	0.126	0.123	0.134	0.134	0.134
S06	1.177	1.759	0.091	0.050	0.197	0.400	0.392	0.170	0.188	0.188	0.188	0.155	0.180	0.174	0.177	0.172	0.189	0.188	0.184
S10	1.177	1.759	0.193	0.050	0.200	0.201	0.206	0.122	0.135	0.135	0.135	0.114	0.133	0.133	0.133	0.122	0.135	0.134	0.135
S11	1.177	1.759	0.193	0.050	0.200	0.300	0.297	0.149	0.166	0.167	0.167	0.141	0.164	0.165	0.165	0.151	0.167	0.166	0.167
S12	1.177	1.759	0.193	0.050	0.200	0.401	0.393	0.173	0.193	0.194	0.196	0.166	0.191	0.193	0.194	0.174	0.193	0.194	0.194
S13	1.176	1.760	0.193	0.100	0.200	0.102	0.104	0.117	0.121	0.121	0.121	0.101	0.117	0.118	0.117	0.116	0.122	0.121	0.122
S14	1.174	1.761	0.193	0.100	0.227	0.202	0.207	0.153	0.170	0.166	0.166	0.138	0.159	0.160	0.160	0.148	0.165	0.165	0.166
S15	1.174	1.761	0.193	0.100	0.230	0.399	0.395	0.207	0.225	0.226	0.226	0.190	0.218	0.219	0.219	0.207	0.226	0.226	0.227
S16	1.174	1.761	0.290	0.103	0.230	0.196	0.199	0.156	0.172	0.169	0.165	0.139	0.162	0.161	0.162	0.156	0.166	0.165	0.165
S17	1.174	1.761	0.290	0.103	0.230	0.301	0.301	0.186	0.201	0.205	0.200	0.168	0.195	0.196	0.196	0.187	0.200	0.201	0.200
S18	1.174	1.761	0.290	0.103	0.230	0.400	0.394	0.206	0.227	0.232	0.227	0.190	0.220	0.222	0.222	0.206	0.208	0.228	0.227
S19	0.735	2.196	0.050	0.050	0.174	0.051	0.052	0.075	0.079	0.079	0.079	0.060	0.070	0.069	0.071	0.075	0.079	0.079	0.074
S20	0.735	2.196	0.050	0.050	0.174	0.201	0.203	0.122	0.141	0.141	0.140	0.108	0.121	0.121	0.121	0.127	0.14	0.138	0.141
S21	0.735	2.196	0.050	0.050	0.174	0.300	0.299	0.153	0.169	0.169	0.169	0.130	0.144	0.142	0.142	0.153	0.169	0.169	0.165
S22	0.738	2.186	0.100	0.050	0.206	0.051	0.052	0.074	0.079	0.079	0.079	0.065	0.074	0.074	0.075				
S22H	0.739	2.196	0.1	0.05	0.206	0.049	0.05	0.072	0.078	0.077	0.078	0.063	0.075	0.073	0.074				
S23	0.738	2.186	0.100	0.050	0.206	0.202	0.206	0.130	0.144	0.143	0.144	0.118	0.133	0.133	0.135				
S23H	0.739	2.196	0.1	0.05	0.206	0.201	0.201	0.129	0.143	0.143	0.144	0.117	0.135	0.132	0.135				
S24	0.738	2.186	0.100	0.050	0.206	0.399	0.396	0.166	0.187	0.188	0.189	0.154	0.173	0.170	0.181				
S24H	0.739	2.196	0.1	0.05	0.206	0.4	0.394	0.178	0.198	0.198	0.199	0.164	0.188	0.182	0.19				

APPENDIX A1

THIN PLATE WEIR WITH DIVIDING WALLS
STELLENBOSCH TESTS - FIRST SERIES

Test						Discharge		Left				Centre				Right			
No:	L1 (m)	L2 (m)	P (m)	T (m)	H_{max} (m)	Qm (m3/s)	Qr (m3/s)	0H (m)	2H (m)	4H (m)	6H (m)	0H (m)	2H (m)	4H (m)	6H (m)	0H (m)	2H (m)	4H (m)	6H (m)
S25	0.738	2.190	0.100	0.100	0.238	0.100	0.100	0.132	0.138	0.137	0.138	0.108	0.124	0.124	0.123				
S26	0.738	2.218	0.100	0.100	0.238	0.200	0.202	0.167	0.180	0.180	0.180	0.140	0.161	0.162	0.161				
S27	0.738	2.218	0.100	0.100	0.238	0.399	0.402	0.220	0.240	0.240	0.239	0.174	0.208	0.209	0.213				
S28	0.735	2.203	0.1	0.199	0.294	0.2	0.201	0.238	0.244	0.243	0.242	0.181	0.208	0.196	0.196				
S29	0.735	2.203	0.1	0.199	0.294	0.301	0.301	0.27	0.281	0.28	0.28	0.205	0.223	0.225	0.227				
S30	0.735	2.203	0.1	0.199	0.294	0.399	0.397	0.296	0.311	0.31	0.31	0.223	0.248	0.25	0.254				
S31	0.736	2.202	0.205	0.051	0.209	0.099	0.102	0.098	0.099	0.106	0.106	0.089	0.103	0.103	0.103				
S32	0.736	2.202	0.205	0.051	0.209	0.200	0.204	0.133	0.141	0.146	0.147	0.123	0.143	0.143	0.143				
S33	0.736	2.202	0.205	0.051	0.209	0.399	0.397	0.184	0.199	0.206	0.206	0.173	0.199	0.201	0.200				
S34	0.740	2.196	0.205	0.100	0.245	0.099	0.099	0.131	0.138	0.137	0.138	0.113	0.132	0.131	0.131				
S35	0.740	2.196	0.205	0.100	0.245	0.199	0.200	0.169	0.181	0.181	0.181	0.149	0.172	0.173	0.172				
S36	0.740	2.196	0.205	0.100	0.245	0.398	0.393	0.222	0.242	0.242	0.242	0.199	0.227	0.224	0.227				
S37	0.740	2.196	0.206	0.201	0.304	0.197	0.199	0.237	0.244	0.244	0.244	0.197	0.223	0.221	0.220				
S38	0.740	2.196	0.206	0.201	0.304	0.297	0.299	0.269	0.280	0.280	0.281	0.222	0.253	0.252	0.255				
S39	0.740	2.196	0.206	0.201	0.304	0.400	0.396	0.297	0.313	0.314	0.313	0.246	0.282	0.275	0.284				
S40	0.740	2.196	0.305	0.101	0.260	0.200	0.201	0.170	0.182	0.182	0.182	0.151	0.175	0.175	0.174				
S41	0.740	2.196	0.305	0.101	0.260	0.299	0.301	0.199	0.215	0.217	0.217	0.180	0.207	0.209	0.209				
S42	0.740	2.196	0.305	0.101	0.260	0.101	0.103	0.134	0.140	0.141	0.141	0.118	0.137	0.137	0.136				
S46	0.496	2.44	0.049	0.049	0.194	0.101	0.102	0.098	0.107	0.107	0.107	0.081	0.093	0.093	0.093				
S47	0.496	2.44	0.049	0.049	0.194	0.2	0.202	0.103	0.143	0.144	0.144	0.108	0.119	0.127	0.124				
S48	0.496	2.44	0.048	0.049	0.194	0.301	0.3	0.154	0.175	0.172	0.171	0.129	0.145	0.15	0.152				
S49	0.495	2.438	0.101	0.05	0.213	0.05	0.05	0.077	0.083	0.082	0.082	0.068	0.077	0.078	0.078				
S50	0.495	2.438	0.101	0.05	0.213	0.201	0.205	0.133	0.147	0.147	0.147	0.119	0.135	0.137	0.139				
S51	0.495	2.438	0.101	0.05	0.213	0.399	0.398	0.18	0.201	0.202	0.202	0.16	0.184	0.181	0.189				

APPENDIX A1

THIN PLATE WEIR WITH DIVIDING WALLS
STELLENBOSCH TESTS - FIRST SERIES

Test						Discharge		Left				Centre				Right			
No:	L1 (m)	L2 (m)	P (m)	T (m)	H_{max} (m)	Qm (m3/s)	Qr (m3/s)	0H (m)	2H (m)	4H (m)	6H (m)	0H (m)	2H (m)	4H (m)	6H (m)	0H (m)	2H (m)	4H (m)	6H (m)
S52	0.493	2.443	0.1	0.1	0.251	0.1	0.101	0.14	0.152	0.148	0.148	0.117	0.134	0.134	0.13				
S53	0.493	2.443	0.1	0.1	0.251	0.2	0.201	0.177	0.19	0.19	0.19	0.147	0.17	0.167	0.167				
S54	0.493	2.443	0.1	0.1	0.251	0.401	0.396	0.22	0.248	0.248	0.248	0.192	0.218	0.215	0.218				
S55	0.495	2.442	0.099	0.200	0.318	0.200	0.203	0.257	0.267	0.267	0.268	0.197	0.220	0.219	0.223				
S56	0.495	2.442	0.099	0.200	0.318	0.300	0.301	0.287	0.303	0.303	0.303	0.219	0.249	0.251	0.254				
S57	0.495	2.442	0.099	0.200	0.318	0.398	0.398	0.312	0.331	0.331	0.332	0.240	0.269	0.277	0.280				
S58	0.495	2.44	0.2	0.049	0.213	0.101	0.101	0.1	0.109	0.109	0.109	0.091	0.106	0.107	0.106				
S59	0.495	2.44	0.2	0.049	0.213	0.201	0.202	0.135	0.149	0.15	0.149	0.125	0.145	0.145	0.145				
S60	0.495	2.44	0.2	0.049	0.213	0.398	0.396	0.186	0.207	0.208	0.209	0.174	0.2	0.202	0.203				
S61	0.495	2.442	0.201	0.100	0.254	0.050	0.050	0.116	0.119	0.120	0.119	0.098	0.114	0.114	0.114				
S62	0.495	2.442	0.201	0.100	0.254	0.200	0.202	0.1[illegible]	0.190	0.191	0.190	0.155	0.179	0.180	0.179				
S63	0.495	2.442	0.201	0.100	0.254	0.399	0.399	0.229	0.251	0.252	0.251	0.204	0.234	0.233	0.236				
S64	0.495	2.446	0.199	0.202	0.326	0.200	0.201	0.257	0.266	0.267	0.266	0.210	0.240	0.238	0.248				
S64F	0.495	2.446	0.199	0.202	0.326	0.199	0.203	0.257	0.267	0.267	0.266	0.210	0.239	0.239	0.248				
S65	0.495	2.446	0.199	0.202	0.326	0.300	0.298	0.287	0.303	0.302	0.303	0.235	0.271	0.263	0.282				
S66	0.495	2.446	0.199	0.202	0.326	0.399	0.400	0.314	0.333	0.333	0.333	0.258	0.290	0.292	0.311				

APPENDIX A2:

THIN PLATE WEIR WITHOUT DIVIDING WALLS
STELLENBOSCH TESTS - FIRST SERIES

Test						Discharge		Left				Centre				Right			
No:	L1	L2	P	T	Hmax	Qm	Qr	0H	2H	4H	6H	0H	2H	4H	6H	0H	2H	4H	6H
	(m)	(m)	(m)	(m)	(m)	(m3/s)	(m3/s)	(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)
S01	1.177	1.759	0.040	0.050	0.193	0.050	0.052	0.066	0.069	0.069	0.069	0.056	0.067	0.068	0.069	0.066	0.069	0.069	0.069
S02	1.177	1.759	0.040	0.050	0.193	0.200	0.198	0.117	0.127	0.127	0.127	0.104	0.122	0.124	0.125	0.117	0.127	0.127	0.126
S03	1.177	1.759	0.040	0.050	0.193	0.298	0.299	0.142	0.155	0.154	0.154	0.127	0.148	0.151	0.153	0.142	0.155	0.154	0.153
S04	1.177	1.759	0.091	0.050	0.197	0.049	0.050	0.067	0.070	0.069	0.069	0.058	0.068	0.069	0.069	0.066	0.069	0.069	0.069
S05	1.177	1.759	0.091	0.050	0.197	0.200	0.203	0.120	0.132	0.131	0.131	0.110	0.129	0.131	0.131	0.120	0.132	0.132	0.132
S06	1.177	1.759	0.091	0.050	0.197	0.394	0.388	0.169	0.186	0.187	0.187	0.159	0.183	0.186	0.186	0.169	0.186	0.187	0.187
S10	1.177	1.759	0.193	0.050	0.200	0.201	0.200	0.125	0.137	0.137	0.138	0.116	0.136	0.136	0.137	0.124	0.137	0.137	0.137
S11	1.177	1.759	0.193	0.050	0.200	0.299	0.300	0.151	0.168	0.167	0.168	0.145	0.167	0.167	0.167	0.152	0.168	0.168	0.167
S12	1.177	1.759	0.193	0.050	0.200	0.402	0.392	0.176	0.195	0.196	0.196	0.168	0.194	0.196	0.197	0.175	0.195	0.196	0.196
S13	1.174	1.761	0.193	0.100	0.227	0.100	0.102	0.117	0.122	0.121	0.122	0.102	0.121	0.121	0.122	0.117	0.121	0.121	0.121
S14	1.174	1.761	0.193	0.100	0.227	0.200	0.203	0.153	0.165	0.164	0.165	0.139	0.162	0.164	0.164	0.154	0.164	0.165	0.164
S15	1.174	1.761	0.193	0.100	0.227	0.399	0.392	0.205	0.223	0.223	0.223	0.194	0.221	0.222	0.222	0.207	0.222	0.223	0.223
S16	1.174	1.761	0.290	0.103	0.230	0.200	0.204	0.158	0.168	0.172	0.167	0.142	0.166	0.167	0.168	0.156	0.167	0.167	0.168
S17	1.174	1.761	0.290	0.103	0.230	0.302	0.304	0.188	0.202	0.207	0.202	0.171	0.200	0.200	0.201	0.186	0.202	0.202	0.202
S18	1.174	1.761	0.290	0.103	0.230	0.400	0.399	0.211	0.232	0.235	0.230	0.195	0.228	0.229	0.229	0.209	0.229	0.230	0.230
S19	0.740	2.192	0.050	0.050	0.174	0.051	0.052	0.074	0.078	0.078	0.078	0.064	0.077	0.078	0.077				
S20	0.740	2.192	0.050	0.050	0.174	0.201	0.201	0.127	0.138	0.138	0.138	0.116	0.135	0.137	0.137				
S21	0.740	2.192	0.050	0.050	0.174	0.297	0.298	0.151	0.165	0.165	0.165	0.139	0.161	0.163	0.163				
S22	0.738	2.181	0.100	0.050	0.206	0.050	0.052	0.074	0.078	0.078	0.079	0.065	0.078	0.077	0.079				
S22H	0.739	2.196	0.101	0.05	0.206	0.05	0.051	0.073	0.077	0.078	0.078	0.065	0.076	0.077	0.077				
S23	0.738	2.181	0.100	0.050	0.206	0.202	0.207	0.132	0.142	0.142	0.144	0.120	0.141	0.142	0.144				
S23H	0.739	2.196	0.101	0.05	0.206	0.2	0.201	0.13	0.142	0.142	0.142	0.119	0.14	0.141	0.141				
S24	0.738	2.181	0.100	0.050	0.206	0.399	0.401	0.166	0.187	0.188	0.189	0.159	0.186	0.187	0.189				
S24H	0.739	2.196	0.101	0.05	0.206	0.4	0.399	0.176	0.195	0.196	0.196	0.168	0.194	0.195	0.194				

APPENDIX A2:

THIN PLATE WEIR WITHOUT DIVIDING WALLS
STELLENBOSCH TESTS - FIRST SERIES

Test						Discharge		Left				Centre				Right			
No:	L1 (m)	L2 (m)	P (m)	T (m)	H_{max} (m)	Qm (m3/s)	Qr (m3/s)	0H (m)	2H (m)	4H (m)	6H (m)	0H (m)	2H (m)	4H (m)	6H (m)	0H (m)	2H (m)	4H (m)	6H (m)
S25	0.738	2.190	0.100	0.100	0.238	0.100	0.103	0.132	0.139	0.139	0.139	0.115	0.138	0.139	0.139				
S26	0.738	2.190	0.100	0.100	0.238	0.200	0.203	0.168	0.179	0.179	0.179	0.150	0.178	0.179	0.179				
S27	0.738	2.190	0.100	0.100	0.238	0.399	0.398	0.218	0.237	0.237	0.236	0.201	0.234	0.235	0.236				
S28	0.736	2.197	0.099	0.199	0.294	0.202	0.204	0.24	0.246	0.246	0.246	0.209	0.243	0.246	0.246				
S29	0.736	2.197	0.099	0.199	0.294	0.301	0.3	0.269	0.28	0.28	0.28	0.239	0.276	0.279	0.28				
S30	0.736	2.197	0.099	0.199	0.294	0.4	0.399	0.294	0.309	0.31	0.309	0.264	0.305	0.308	0.309				
S31	0.736	2.202	0.205	0.051	0.209	0.098	0.100	0.098	0.099	0.106	0.104	0.090	0.105	0.105	0.106				
S32	0.736	2.202	0.205	0.051	0.209	0.200	0.200	0.133	0.140	0.146	0.147	0.125	0.145	0.146	0.151				
S33	0.736	2.202	0.205	0.051	0.209	0.399	0.399	0.184	0.198	0.205	0.250	0.176	0.204	0.205	0.205				
S34	0.740	2.196	0.205	0.100	0.245	0.101	0.104	0.134	0.141	0.140	0.140	0.120	0.140	0.140	0.140				
S35	0.740	2.196	0.205	0.100	0.245	0.199	0.201	0.169	0.181	0.181	0.181	0.154	0.180	0.181	0.181				
S36	0.740	2.196	0.205	0.100	0.245	0.399	0.396	0.222	0.241	0.240	0.240	0.207	0.239	0.240	0.241				
S37	0.740	2.196	0.206	0.201	0.304	0.197	0.200	0.239	0.246	0.246	0.246	0.214	0.244	0.245	0.246				
S38	0.740	2.196	0.206	0.201	0.304	0.301	0.300	0.271	0.283	0.283	0.283	0.247	0.280	0.282	0.284				
S39	0.740	2.196	0.206	0.201	0.304	0.398	0.397	0.298	0.313	0.313	0.312	0.273	0.311	0.312	0.313				
S40	0.740	2.196	0.306	0.101	0.260	0.202	0.205	0.172	0.184	0.184	0.184	0.152	0.183	0.184	0.185				
S41	0.740	2.196	0.306	0.101	0.260	0.302	0.300	0.201	0.217	0.217	0.217	0.187	0.215	0.217	0.217				
S42	0.740	2.196	0.306	0.101	0.260	0.099	0.099	0.134	0.140	0.139	0.139	0.120	0.139	0.139	0.140				
S46	0.496	2.433	0.048	0.049	0.194	0.101	0.102	0.097	0.105	0.106	0.112	0.083	0.104	0.106	0.105				
S47	0.496	2.433	0.048	0.049	0.194	0.201	0.203	0.13	0.143	0.142	0.142	0.12	0.14	0.143	0.142				
S48	0.496	2.433	0.048	0.049	0.194	0.301	0.3	0.154	0.169	0.169	0.17	0.143	0.167	0.169	0.169				
S49	0.495	2.438	0.101	0.05	0.213	0.047	0.049	0.076	0.08	0.08	0.082	0.069	0.081	0.082	0.082				
S50	0.495	2.438	0.101	0.05	0.213	0.202	0.204	0.133	0.146	0.147	0.147	0.124	0.145	0.146	0.146				
S51	0.495	2.438	0.101	0.05	0.213	0.398	0.395	0.181	0.2	0.201	0.201	0.174	0.2	0.202	0.201				

APPENDIX A2:

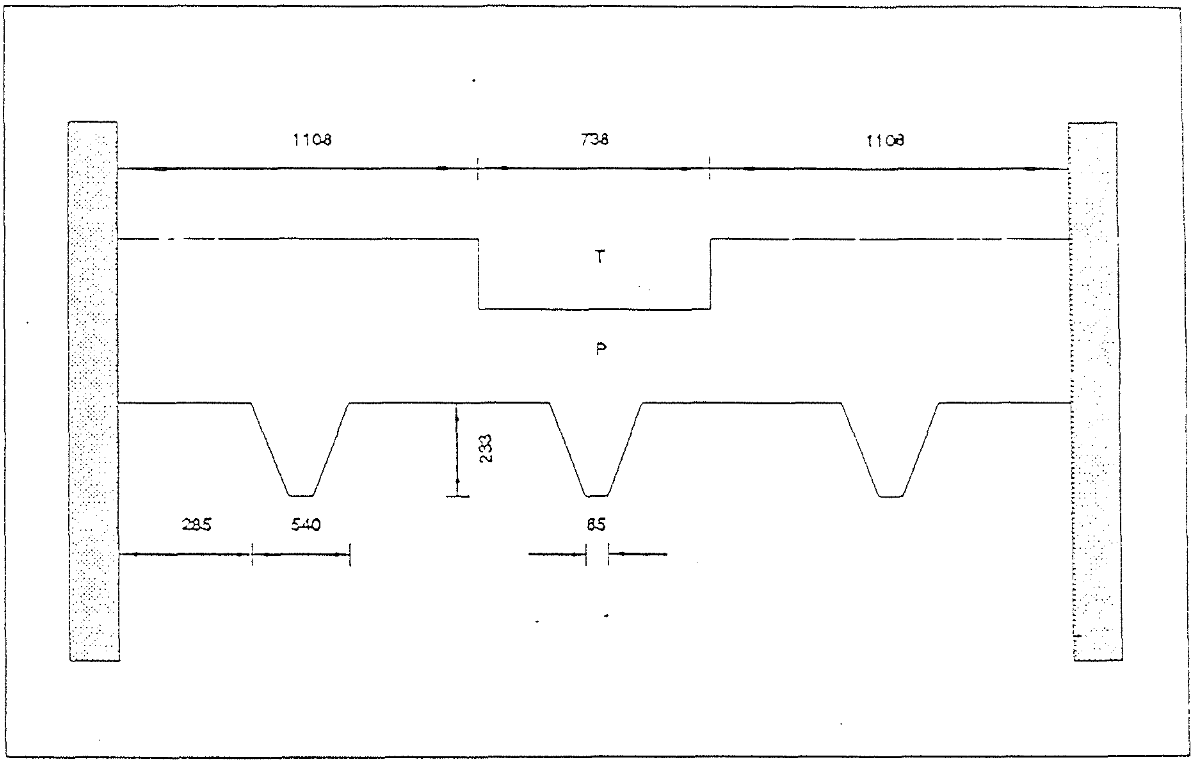
THIN PLATE WEIR WITHOUT DIVIDING WALLS
STELLENBOSCH TESTS - FIRST SERIES

Test						Discharge		Left				Centre				Right			
No:	L1 (m)	L2 (m)	P (m)	T (m)	H_{max} (m)	Qm (m3/s)	Qr (m3/s)	0H (m)	2H (m)	4H (m)	6H (m)	0H (m)	2H (m)	4H (m)	6H (m)	0H (m)	2H (m)	4H (m)	6H (m)
S52	0.495	2.437	0.101	0.101	0.251	0.101	0.102	0.142	0.149	0.148	0.148	0.126	0.147	0.147	0.148				
S53	0.495	2.437	0.101	0.101	0.251	0.201	0.203	0.177	0.188	0.188	0.189	0.161	0.187	0.189	0.19				
S54	0.495	2.437	0.101	0.101	0.251	0.399	0.397	0.226	0.245	0.246	0.246	0.212	0.244	0.246	0.246				
S55	0.494	2.446	0.099	0.201	0.318	0.200	0.202	0.257	0.266	0.267	0.266	0.233	0.264	0.265	0.266				
S56	0.494	2.446	0.099	0.201	0.318	0.300	0.302	0.287	0.301	0.301	0.301	0.263	0.299	0.300	0.301				
S57	0.494	2.446	0.099	0.201	0.318	0.400	0.400	0.312	0.329	0.330	0.330	0.291	0.327	0.328	0.330				
S58	0.494	2.438	0.200	0.049	0.213	0.101	0.102	0.101	0.110	0.110	0.110	0.094	0.109	0.110	0.110				
S59	0.494	2.438	0.200	0.049	0.213	0.200	0.202	0.136	0.150	0.150	0.150	0.128	0.149	0.150	0.150				
S60	0.494	2.438	0.200	0.049	0.213	0.399	0.399	0.187	0.208	0.209	0.209	0.180	0.208	0.209	0.209				
S61	0.492	2.438	0.200	0.100	0.253	0.050	0.050	0.116	0.120	0.120	0.120	0.103	0.120	0.120	0.120				
S62	0.492	2.438	0.200	0.100	0.253	0.202	0.203	0.178	0.192	0.191	0.192	0.165	0.191	0.191	0.191				
S63	0.492	2.438	0.200	0.100	0.253	0.399	0.400	0.229	0.251	0.251	0.252	0.218	0.251	0.251	0.252				
S64	0.495	2.434	0.199	0.201	0.326	0.199	0.201	0.257	0.268	0.268	0.268	0.236	0.267	0.267	0.268				
S65	0.495	2.434	0.199	0.201	0.326	0.300	0.301	0.288	0.304	0.305	0.304	0.268	0.303	0.304	0.304				
S66	0.495	2.434	0.199	0.201	0.326	0.399	0.400	0.314	0.334	0.334	0.334	0.294	0.332	0.333	0.334				

APPENDIX A3:

THIN PLATE WEIR WITHOUT DIVIDING WALLS.

STELLENBOSCH TESTS - SECOND SERIES
(Shallow and irregular pools)



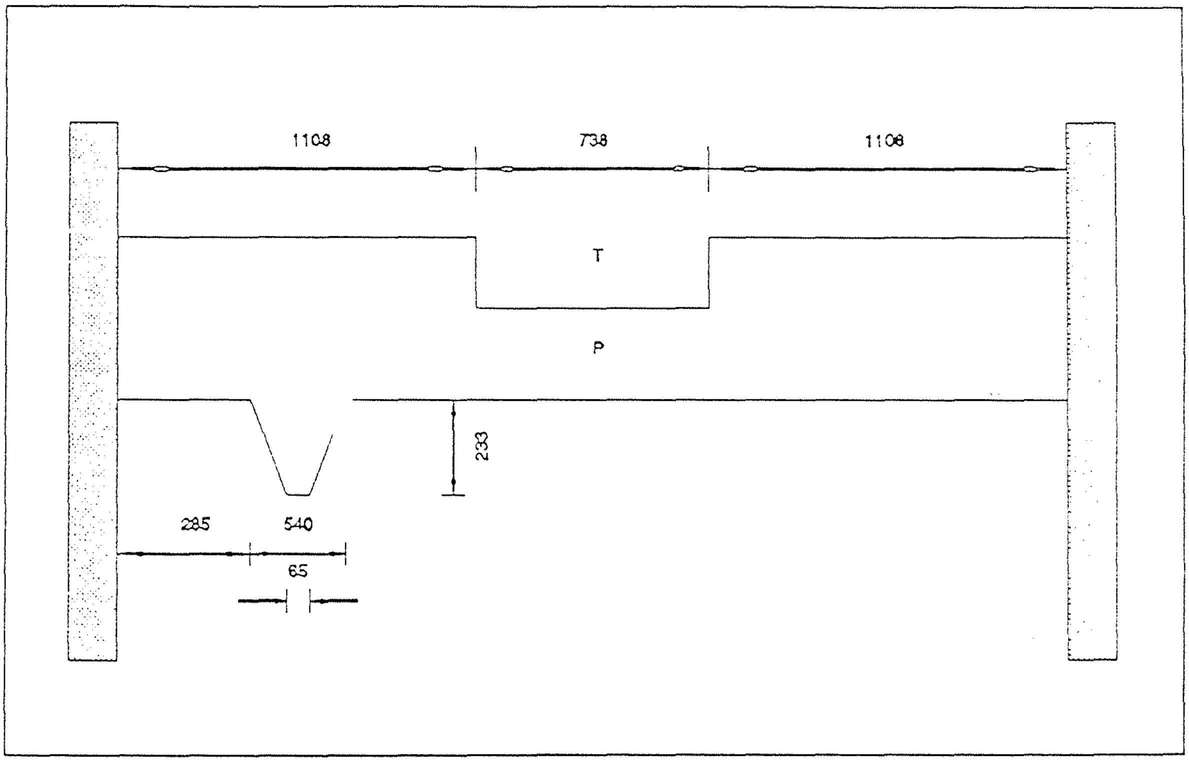
P mm	T mm	Q_m l/s	h at 4H (mm)		
			Left	Centre	Right
85	104	100	141	141	141
85	104	201	182	181	182
85	104	301	215	213	214
85	104	398	241	240	242
16	103	100	139	138	138
16	103	200	179	178	180
16	103	301	210	209	211
16	103	400	237	235	238
0	105	50	110	110	111
0	105	100	140	140	141
0	105	200	180	178	181

CHANNEL CONFIGURATION: LMR

APPENDIX A3:

THIN PLATE WEIR WITHOUT DIVIDING WALLS.

STELLENBOSCH TESTS - SECOND SERIES
(Shallow and irregular pools)

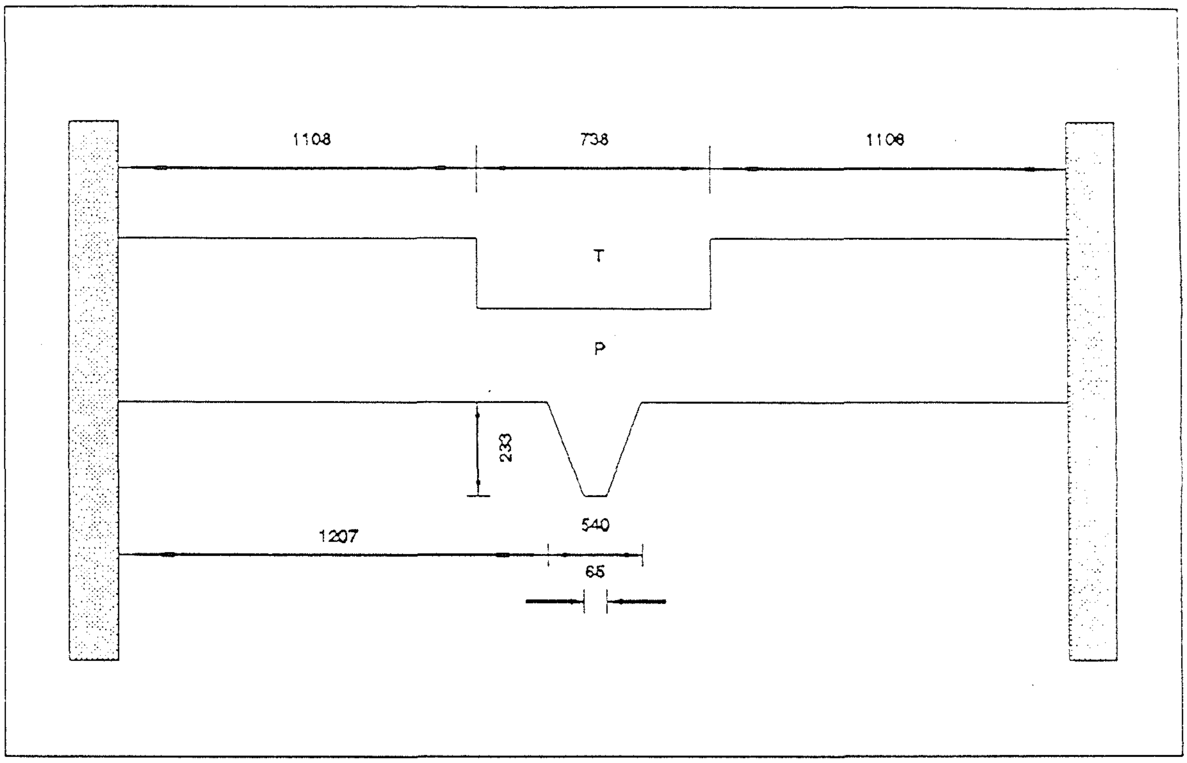


P mm	T mm	Q_m l/s	h at 4H (mm) Left	 Centre	 Right
85	104	100	141	140	140
85	104	200	181	180	180
85	104	300	212	211	209
85	104	400	239	238	237
16	103	100	139	137	137
16	103	200	179	176	177
16	103	301	210	206	207
16	103	399	235	230	231
0	105	50	113	113	113
0	105	100	141	140	140
0	105	200	178	176	178

CHANNEL CONFIGURATION: L

APPENDIX A3:

THIN PLATE WEIR WITHOUT DIVIDING WALLS.



P	T	Q_m	h at 4H (mm)		
mm	mm	l/s	Left	Centre	Right
85	104	100	138	139	140
85	104	199	179	180	182
85	104	299	211	211	213
85	104	398	237	237	239
16	103	100	138	137	138
16	103	200	177	176	177
16	103	300	208	206	204
16	103	399	232	231	232
0	105	50	111	110	111
0	105	100	139	138	138
0	105	200	176	175	176

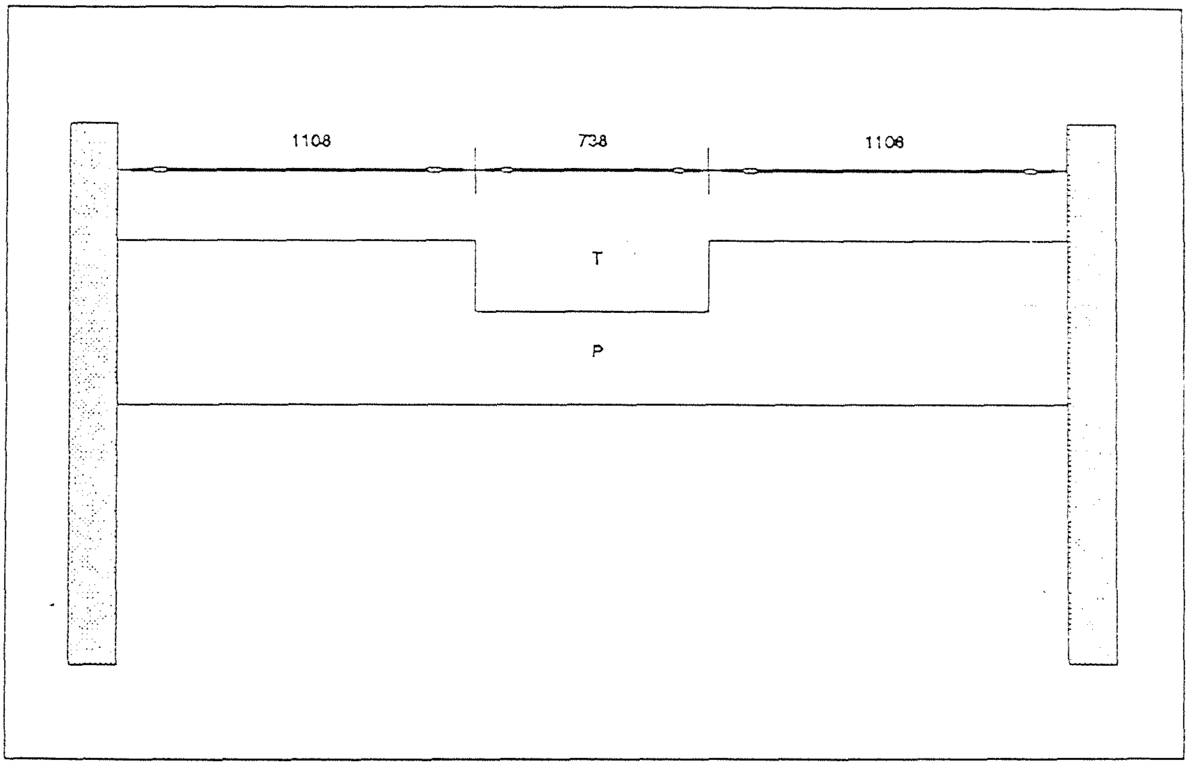
CHANNEL CONFIGURATION: M

APPENDIX A3:

THIN PLATE WEIR WITHOUT DIVIDING WALLS.

STELLENBOSCH TESTS - SECOND SERIES

(Shallow and irregular pools)



P mm	T mm	Q_m l/s	h at 4H (mm) Left	Centre	Right
16	103	100	138	136	138
16	103	200	175	173	175
16	103	301	203	200	203
16	103	400	230	226	230
0	105	50	113	112	112
0	105	100	139	137	138
0	105	200	176	173	175

CHANNEL CONFIGURATION: NO CHANNEL

APPENDIX B: SAMPLE CALCULATIONS

B1	Thin plate weir with dividing walls - based on water level upstream of both crests
B2	Crump weir with deviding walls - water level measured upstream of both low and high crests
B3	Thin plate weir with dividing walls - discharge based on water level upstream of low crest only
B4	Crump weir with dividing walls - discharge based on water level upstream of low crest
B5	Thin plate weirs without dividing walls - discharge based on water level upstream of low crest
B6	Crump weir without dividing walls - discharge based on water level upstream of low crest
B7	Thin plate weir without dividing walls - calculation of C_D based on water level upstream of low weir

APPENDIX B1:

THIN PLATE WEIR WITH DIVIDING WALLS - BASED ON WATER LEVEL UPSTREAM OF BOTH CRESTS

Test S01

$L_1 = 1{,}177\,m$ $L_2 = 1{,}759\,m$ $\mathrm{P} = 0{,}040m$ $\mathrm{T} = 0{,}050m$

$\mathrm{Q_{man}} = 0{,}050\,\mathrm{m}^3\,/\,\mathrm{s}$ $h_1 = 0{,}060\,m$ $h_2 = 0{,}070\,m$

$Q = C_D \cdot \frac{2}{3}\sqrt{2g}\,LH^{3/2}$ with $\mathrm{C_D} = 0{,}627 + 0{,}018\frac{H}{P}$

Low crest

$Q_L = C_D \cdot \frac{2}{3}\sqrt{2g}\,L_1{H_1}^{3/2}$ and $C_D = 0{,}627 + 0{,}018\frac{H_1}{P_1}$

First iteration

Take $H_1 = h_1 = 0{,}060\ m$

$$C_{D_1} = 0{,}627 + 0{,}018 \times \frac{0{,}060}{0{,}040} = 0{,}654$$

$$Q_1 = 0{,}654 \times \frac{2}{3} \times \sqrt{2g} \times 1{,}117 \times 0{,}060^{3/2} = 0{,}0317\ m^3\,/\,s$$

$$V = \frac{Q}{A} = \frac{Q}{L_1 \times (P + h)} = \frac{0{,}0317}{1{,}117\left(0{,}040\quad 0{,}060\right)} = 0{,}2838\,m\,/\,s$$

$$\therefore\quad H_1 = h_1 + \frac{V^2}{2g} = 0{,}060 + \frac{\left(0{,}2838\right)^2}{2g} = 0{,}0641m$$

Second iteration

Repeat with $H_1 = 0{,}0641\,m$

$$\therefore\ Q_1 = 0{,}656 \times \frac{2}{3}\sqrt{2g} \times 1{,}117 \times 0{,}0641^{3/2} = 0{,}0351m^3\,/\,s$$

$$\mathrm{V} = \frac{0{,}0351}{1{,}117\left(0{,}040 + 0{,}060\right)} = 0{,}3144\ m\,/\,s$$

$$\therefore H_1 = 0{,}060\frac{0{,}3144^2}{2g} = 0{,}0650\,m$$

Third and further iterations

Proceed until Q_1 remains constant from one iteration to the next.

High crest

$$Q_H = C_D \cdot \frac{2}{3}\sqrt{2g}\,L_s\,H_2{}^{3/2} \qquad \text{with} \qquad C_D = 0{,}627 + 0{,}018\frac{H_2}{P2}$$

First iteration

$$\begin{aligned}
\text{Take } H_2 &= (h_2 - T) = 0{,}070 - 0{,}050 = 0{,}020m\\
P_2 &= P + T = 0{,}040 + 0{,}050 = 0{,}090m\\
\therefore C_D &= 0{,}627 + 0{,}018 \times \frac{0{,}020}{0{,}090} = 0{,}631\\
Q &= 0{,}631 \times \frac{2}{3}\sqrt{2g} \times 1{,}759 \times 0{,}020^{3/2} = 0{,}0093\,m^3/s\\
\mathrm{v} &= \frac{Q}{A} = \frac{Q}{L_2 \times (P + h_2)} = \frac{0{,}0093}{1{,}759 \times (0{,}040 + 0{,}070)}\\
&= 0{,}0479m/s\\
\therefore H_2 &= \left(h_2 + \frac{\mathrm{V}_2^2}{2\mathrm{g}}\right) - T = 0{,}070 + \frac{0{,}0479^2}{2g} - 0{,}050 = 0{,}0201m
\end{aligned}$$

Second iteration

$$\begin{aligned}
H_2 &= 0{,}0201\\
C_D &= 0{,}627 + 0{,}018 \times \frac{0{,}0201}{0{,}09} = \quad \text{etc.}
\end{aligned}$$

APPENDIX B2:

CRUMP WEIR WITH DIVIDING WALLS - WATER LEVEL MEASURED UPSTREAM OF BOTH LOW AND HIGH CRESTS

Test C3

$L_1 = 1{,}197\ m$ $\quad L_2 = 1{,}780\ m$ $\quad P = 0{,}1711\ m$ $\quad T = 0{,}1069\ m$

$h_1 = 0{,}1232\ m$ $\quad h_2 = (0{,}1316 - T)\ m$ $\quad Q_{man} = 0{,}120\ m^3/s$

$$Q = C_D \cdot \frac{2}{3}\sqrt{\frac{2}{3}g}\ LH^{3/2} \qquad C_D = 1{,}163\left(1 - \frac{0{,}0003}{h}\right)^{3/2}$$

Low crest

$$Q_1 = C_D \cdot \frac{2}{3}\sqrt{\frac{2}{3}g}\ L_1 H_1^{3/2} \qquad C_{D_1} = 1{,}163\left(1 - \frac{0{,}0003}{h_1}\right)^{3/2}$$

$$C_{D_1} = 1{,}163\left(1 - \frac{0{,}0003}{0{,}1232}\right)^{3/2} = 1{,}159$$

First iteration

Set $H_1 = h_1 = 0{,}1232\ m$

$$\therefore\ Q_1 = 1{,}159 \times \frac{2}{3}\sqrt{\frac{2}{3}g} \times 1{,}197 \times 0{,}1232^{3/2} = 0{,}102\ m^3/s$$

$$V = \frac{Q}{A} = \frac{Q}{L_1(P + h_1)} = \frac{0{,}0854}{1{,}197 \times (0{,}1711 + 0{,}1232)}$$

$$= 0{,}2425\ m/s$$

$$\therefore\ H_1 = h_1 + \frac{V^2}{2g} = 0{,}1232 + \frac{0{,}2425^2}{2g} = 0{,}1262m$$

Second iteration

$$H_1 = 0{,}1262m$$

$$\therefore\ Q_1 = 1{,}159 \times \frac{2}{3}\sqrt{\frac{2}{3}g} \times 1{,}197 \times 0{,}1262^{3/2} = 0{,}1060\ m^3/s$$

$$\therefore V = \frac{Q}{L_1(P_1 + h_1)} = \frac{0{,},1060}{1{,}197 \times (0{,}1711 + 0{,}1232)}$$

$$= 0{,}3010\ m/s$$

$$\therefore\ H_1 = h_1 + \frac{V^2}{2g} = 0{,}1232 + \frac{0{,}3010^2}{2g} = 0{,}1278m$$

Third iteration

High crest

$$Q_2 = C_D \cdot \frac{2}{3} \cdot \sqrt{\frac{2}{3} g}\ L_2 H_2{}^{3/2} \qquad C_{D_2} = 1{,}163\left(1 - \frac{0{,}0003}{h_2}\right)^{3/2}$$

$$C_{D_2} = 1{,}163\left(1 - \frac{0{,}0003}{(0{,}1316 - 0{,}1069)}\right)^{3/2} = 1{,}1419$$

First iteration

Take $H_2 = h_2$

$$Q_2 = 1{,}1419 \times \frac{2}{3} \times \sqrt{\frac{2}{3} g} \times 1{,}780 \times (0{,}1316 - 0{,}1069)^{3/2}$$

$$= 0{,}0135 m/s$$

$$V = \frac{Q}{A} = \frac{Q}{(P + h_2) \cdot L_2} = \frac{0{,}0135}{(1{,}1711 + 0{,}1316) \times 1{,}780}$$

$$= 0{,}0250 m/s$$

$$H_2 = h_2 + \frac{V^2}{2g} = (0{,}1316 - 0{,}1069) + \frac{0{,}0250^2}{2g} = 0{,}0247 m$$

Second iteration

$$H_2 = 0{,}0247 m$$

$$\therefore Q_2 = 1{,}1419 + \frac{2}{3}\sqrt{\frac{2}{3} g} \times 1{,}780 \times 0{,}0247^{3/2} = 0{,}0135\ m^3/s$$

$v = 0{,}025 m/s$ as before

$$H_2 = h_2 + \frac{v^2}{2g} = 0{,}0247 m$$

No third iteration required because Q and H remain constant

APPENDIX B3:

THIN PLATE WITH DIVIDING WALLS - DISCHARGE BASED ON WATER LEVEL UPSTREAM OF LOW CREST ONLY

Test S01:

$L_1 = 1,777m$ $L_2 = 1,759m$ $\mathrm{P} = 0,040m$

$\mathrm{T} = 0,050m$ $Q_{man} = 0,050\,m^3/s$ $h_1 = 0,060\,m$

$$Q = C_D \cdot \frac{2}{3}\sqrt{2g}\ LH^{3/2} \qquad \mathrm{C_D} = 0,627 + 0,018\frac{H}{P}$$

Low crest

Iteration process and numerical values identical to thoseof appendix B1.

High crest

We now assume

$$\mathrm{H}_2 = H_1 - T$$

$$C_D = 0,627 + 0,018\frac{H_2}{P_2}$$

There is no iteration process involved in calculating Q_2.

Total discharge

$$Q_T = Q_1 + Q_2$$

$$\%\ \text{error} = \frac{Q_w - Q_{man}}{Q_{man}} \times 100\%$$

APPENDIX B4:

CRUMP WEIR WITH DIVIDING WALLS - DISCHARGE BASED ON WATER LEVEL UPSTREAM OF LOW CREST

Test C3

$$Q = C_D \cdot \frac{2}{3}\sqrt{\frac{2}{3}g}\; LH^{3/2} \quad \text{with} \quad C_D = 1{,}163\left(1 - \frac{0{,}0003}{h}\right)^{3/2}$$

Low crest

Iteration process and numerical values identical to those in Appendix B2.

High crest

We now assume that

$$H_2 = H_1 - T$$

To be able to calculate C_D we also assume $h_2 = (h_1 - T)$

$$\therefore C_{D_2} = 1{,}163\left(1 - \frac{0{,}0003}{(0{,}1232 - 0{,}1069)}\right)^{3/2} = 1{,}131$$

$$\therefore Q_2 = C_{D_2} \cdot \frac{2}{3}\sqrt{\frac{2}{3}g}\; L_2 H_2^{3/2}$$

$$= 1{,}131 \times \frac{2}{3}\sqrt{\frac{2}{3}g}\; 1{,}780 \times (\cdots - 0{,}1069)^{3/2}$$

There is no iteration process involved in calculating Q_2.

$\therefore$ **Total discharge**

$$Q_{weir} = Q_1 + Q_2$$

$$\%\ error = \frac{Q_{weir} - Q_{man}}{Q_{man}} \times 100\%$$

APPENDIX B5:

THIN PLATE WEIRS WITHOUT DIVIDING WALLS - DISCHARGE BASED ON WATER LEVEL UPSTREAM OF LOW CREST

Test S01

$L_1 = 1{,}777m$ $L_2 = 1{,}759m$ $\mathrm{P} = 0{,}040m$

$\mathrm{T} = 0{,}050m$ $Q_{man} = 0{,}050\, m^3 / s$ $h_1 = 0{,}068\, m$

$$Q \;=\; C_D \cdot \frac{2}{3}\sqrt{2g}\;\; LH^{3/2} \qquad \mathrm{C_D} = 0{,}627 + 0{,}018\,\frac{H}{P}$$

First iteration

Set $H_1 = h_1$

Assume $H_2 = H_1 - T$

$\therefore$ **Low weir**

$$C_{D_1} = 0{,}627 + 0{,}018\, x\, \frac{0{,}068}{0{,}040} \;=\; 0{,}6576$$

$$Q_1 = 0{,}6576 \times \frac{2}{3}\sqrt{2g} \times 1{,}177 \times 0{,}068^{3/2}$$

High weir

$$C_D = 0{,}627 + 0{,}018\,\left(\frac{0{,}068 - 0{,}050}{0{,}040 + 0{,}050}\right) = 0{,}6306$$

$$\therefore Q_2 = 0{,}6306 \times \frac{2}{3}\sqrt{2g} \times 1{,}759 \times \left(0{,}068 - 0{,}050\right)^{3/2}$$

∴ **Total**

$$Q = Q_1 + Q_2$$

$$\mathrm{V} = \frac{\mathrm{Q}}{\mathrm{A}} = \frac{Q}{(L_1 + L_2) \times (h_1 + P)}$$

$$\therefore H_1 = h_1 + \frac{\mathrm{v}^2}{2\mathrm{g}}$$

$$\therefore H_2 = H_1 - T$$

Iteration onwards

Proceed until A_1 and Q_w remains constant.

$$\% \text{ error } = \frac{Q_{weir} - Q_{man}}{Q_{man}} \times 100\%$$

$$\frac{Q_w - Q_m}{Q_m} \times 100\%$$

APPENDIX B6:

CRUMP WEIR WITHOUT DIVIDING WALLS - DISCHARGE BASED ON WATER LEVEL UPSTREAM OF LOW CREST

$$Q = C_D \cdot \frac{2}{3}\sqrt{\frac{2}{3}g}\ LH^{3/2} \qquad \mathrm{C_D} = 1{,}163\ \left(1 - \frac{0{,}0003}{h}\right)^{3/2}$$

First iteration

Set $H_1 = h_1$

Assume $H_2 = H_1 - T$

Low weir

$$C_{D_1} = 1{,}163\left(1 - \frac{0{,}0003}{h}\right)^{3/2}$$

$$Q_1 = C_{D_1}\frac{2}{3}\sqrt{\frac{2}{3}g}\ L_1 {H_1}^{3/2}$$

High weir

$$C_{D_2} = 1{,}163\left(1 - \frac{0{,}0003}{h_1 - T}\right)^{3/2}$$

$Q_2 =$

Total

$$Q_w = Q_1 + Q_2$$

$$\mathrm{v} = \frac{\mathrm{Q}}{\mathrm{A}} = \frac{Q}{(L_1 + L_2)\ (h_1 + P)}$$

$$H_1 = h_1 + \frac{\mathrm{v}^2}{2g}$$

$$H_2 = H_1 - T$$

Second iteration onwards

Proceed until A_1 and Q_w remains constant.

$$\%\ \text{error} = \frac{Q_w - Q_m}{Q} \times 100\%$$

APPENDIX B7:

THIN PLATE WEIR WITHOUT DIVIDING WALLS - CALCULATION OF C_D BASED ON WATER LEVEL UPSTREAM OF LOW CREST

Test S01

$L_1 = 1{,}777m$ $L_2 = 1{,}759m$ $\mathrm{P} = 0{,}040m$

$\mathrm{T} = 0{,}050m$ $Q_{man} = 0{,}050\,m^3/s$ $h_1 = 0{,}067mm$

Formulas used

$$Q_m = C_D \cdot \frac{2}{3}\sqrt{2g}\left(L_1 {H_1}^{3/2} + L_2 {H_2}^{3/2}\right)$$

$$H_1 = h_1 + \frac{\mathrm{v}^2}{2\mathrm{g}}$$

$$H_2 = H_1 - T$$

Calculation of C_D

$$\mathrm{v} = \frac{\mathrm{Q}}{\mathrm{A}} = \frac{Q_m}{(L_1 + L_2)\,(h_1 + P)}$$

$$= \frac{0{,}050}{(1{,}177 + 1{,}759)(0{,}067 + 0{,}040)}$$

$$H_1 = h_1 + \frac{\mathrm{v}^2}{2\mathrm{g}}$$

$$H_2 = H_1 - T$$

$$\therefore C_D = \frac{Q_m}{\left[\frac{2}{3}\cdot\sqrt{2g}\left(L_1 H_1^{\ 3/2} + L_2 {H_2}^{3/2}\right)\right]}$$

$$= \frac{0{,}050}{\left[\frac{2}{3}\sqrt{g}\left(1{,}77 \times (\cdots)^{3/2} + 1{,}759 \times (\cdots)^{3/2}\right)\right]}$$

Calculation of H_e and P_e

$$H_e = \frac{L_1 \cdot H_1 + L_2 \cdot H_2}{(L_1 + L_2)}$$

$$P_2 = \frac{L_1 \cdot P_1 + L_2 (P_1 + T)}{(L_1 + L_2)}$$

APPENDIX C: RESULTS

C1 Thin plate weir with dividing walls - Water level upstream of low and high crest - Stellenbosch first series

C2 Crump weir with dividing walls - Water level upstream of both crests - Stellenbosch first series

C3 Thin plate weir with dividing walls - Water level observed upstream of low crest - Stellenbosch first series

C4 Crump weir with dividing walls - Water level observed upstream of low crest - DWAF and Stellenbosch tests

C5 Thin plate weir without dividing walls - Standard analysis procedure i.e $Cd = 0.627 + 0.018\ H/P$

C6 Crump tests without dividing walls (Stellenbosch and DWAF) Standard Analysis procedure using $Cd = 1,163(1 - 0,0003/h)^{3/2}$

C7 Thin plate weir without dividing walls - Stellenbosch tests - First series - Analyses using improved discharge coefficient i.e. $Cd = 0,607 + 0,042\ H_e/P_e$

C8 Crump weir without deviding walls - DWAF and Stellenbosch tests - Analyses using improved dischrage coefficient i.e. $C_D = 1,09 + 0,083\ H_e/P_e$

C9 Thin plate weirs without dividing walls - Stellenbosch tests - Second series - Shallow and irregular pools

APPENDIX C1
THIN PLATE WEIR WITH DIVIDE WALLS
WATERLEVEL UPSTREAM OF LOW AND HIGH CREST
STELLENBOSCH FIRST SERIES

$Cd=K1+K2*H/P$
K1 = 0.627
K2 = 0.018

OBSERVED VALUES								CALCULATED VALUES		
TEST Nr	L1 (m)	L2 (m)	P (m)	T (m)	Qm (m^3/s)	Left h2 (m)	Middle h1 (m)	h1/T	Qw (m^3/s)	%-Error
S01	1.177	1.759	0.04	0.050	0.050	0.070	0.060	1.20	0.047	-5.08
S02	1.177	1.759	0.04	0.050	0.200	0.132	0.111	2.22	0.199	-0.46
S03	1.177	1.759	0.04	0.050	0.303	0.162	0.135	2.70	0.313	3.41
S04	1.177	1.759	0.091	0.050	0.050	0.072	0.070	1.40	0.054	8.87
S05	1.177	1.759	0.091	0.050	0.200	0.134	0.126	2.52	0.198	-0.87
S06	1.177	1.759	0.091	0.050	0.400	0.188	0.174	3.48	0.384	-3.90
S10	1.177	1.759	0.193	0.050	0.201	0.135	0.133	2.66	0.196	-2.30
S11	1.177	1.759	0.193	0.050	0.300	0.167	0.165	3.30	0.296	-1.30
S12	1.177	1.759	0.193	0.050	0.401	0.194	0.193	3.86	0.395	-1.60
S13	1.174	1.761	0.193	0.100	0.102	0.121	0.118	1.18	0.103	1.47
S14	1.174	1.761	0.193	0.100	0.202	0.166	0.160	1.60	0.208	2.95
S15	1.174	1.761	0.193	0.100	0.399	0.226	0.219	2.19	0.404	1.32
S16	1.174	1.761	0.29	0.103	0.196	0.169	0.161	1.56	0.204	4.03
S17	1.174	1.761	0.29	0.103	0.301	0.205	0.196	1.90	0.310	3.03
S18	1.174	1.761	0.29	0.103	0.400	0.232	0.222	2.16	0.401	0.30
S19	0.735	2.196	0.05	0.050	0.051	0.079	0.069	1.38	0.049	-3.09
S20	0.735	2.196	0.05	0.050	0.201	0.141	0.121	2.42	0.200	-0.35
S21	0.735	2.196	0.05	0.050	0.300	0.169	0.142	2.84	0.296	-1.47
S22H	0.739	2.196	0.1	0.050	0.049	0.077	0.073	1.46	0.047	-3.42
S23H	0.739	2.196	0.1	0.050	0.201	0.143	0.132	2.64	0.199	-1.08
S24H	0.739	2.196	0.1	0.050	0.400	0.198	0.182	3.64	0.390	-2.60
S25	0.738	2.198	0.1	0.100	0.100	0.137	0.124	1.24	0.098	-2.05
S26	0.738	2.198	0.1	0.100	0.200	0.180	0.162	1.62	0.203	1.49
S27	0.738	2.198	0.1	0.100	0.399	0.240	0.209	2.09	0.397	-0.54
S28	0.735	2.203	0.1	0.199	0.200	0.243	0.196	0.98	0.187	-6.37
S29	0.735	2.203	0.1	0.199	0.301	0.280	0.225	1.13	0.287	-4.63
S30	0.735	2.203	0.1	0.199	0.399	0.310	0.250	1.26	0.388	-2.84
S31	0.736	2.202	0.205	0.051	0.099	0.106	0.103	2.02	0.101	1.57
S32	0.736	2.202	0.205	0.051	0.200	0.146	0.143	2.80	0.202	1.11
S33	0.736	2.202	0.205	0.051	0.399	0.206	0.201	3.94	0.401	0.39
S34	0.74	2.196	0.205	0.100	0.099	0.137	0.131	1.31	0.098	-0.67
S35	0.74	2.196	0.205	0.100	0.199	0.181	0.173	1.73	0.203	2.20
S36	0.74	2.196	0.205	0.100	0.398	0.242	0.224	2.24	0.391	-1.79
S37	0.74	2.196	0.206	0.201	0.197	0.244	0.221	1.10	0.197	-0.14
S38	0.74	2.196	0.206	0.201	0.297	0.280	0.252	1.25	0.290	-2.22
S39	0.74	2.196	0.206	0.201	0.400	0.314	0.275	1.37	0.388	-3.05
S40	0.74	2.196	0.305	0.101	0.200	0.182	0.175	1.73	0.201	0.48
S41	0.74	2.196	0.305	0.101	0.299	0.217	0.209	2.07	0.304	1.82
S42	0.74	2.196	0.305	0.101	0.101	0.141	0.137	1.36	0.105	3.97
S46	0.496	2.44	0.049	0.049	0.101	0.107	0.093	1.90	0.099	-1.50
S47	0.496	2.44	0.049	0.049	0.200	0.144	0.127	2.59	0.204	2.23
S48	0.496	2.44	0.049	0.049	0.301	0.172	0.150	3.06	0.306	1.60
S49	0.495	2.438	0.101	0.050	0.050	0.082	0.078	1.56	0.048	-4.32
S50	0.495	2.438	0.101	0.050	0.201	0.147	0.137	2.74	0.200	-0.69
S51	0.495	2.438	0.101	0.050	0.399	0.202	0.181	3.62	0.386	-3.17
S52	0.493	2.443	0.1	0.100	0.100	0.148	0.134	1.34	0.101	0.56
S53	0.493	2.443	0.1	0.100	0.200	0.190	0.167	1.67	0.203	1.46
S54	0.493	2.443	0.1	0.100	0.401	0.248	0.215	2.15	0.396	-1.26
S55	0.495	2.442	0.099	0.200	0.200	0.267	0.219	1.10	0.203	1.29
S56	0.495	2.442	0.099	0.200	0.300	0.303	0.251	1.26	0.312	3.93
S57	0.495	2.442	0.099	0.200	0.398	0.331	0.277	1.39	0.414	3.98
S58	0.495	2.44	0.2	0.049	0.101	0.109	0.107	2.18	0.101	0.28
S59	0.495	2.44	0.2	0.049	0.201	0.150	0.145	2.96	0.205	1.82
S60	0.495	2.44	0.2	0.049	0.398	0.208	0.202	4.12	0.398	0.01
S61	0.495	2.442	0.201	0.100	0.050	0.120	0.114	1.14	0.050	0.15
S62	0.495	2.442	0.201	0.100	0.200	0.191	0.180	1.80	0.204	2.05
S63	0.495	2.442	0.201	0.100	0.399	0.252	0.233	2.33	0.398	-0.22
S64	0.495	0.2446	0.199	0.202	0.200	0.267	0.238	1.18	0.198	-1.25
S64F	0.495	2.446	0.1991	0.202	0.199	0.267	0.239	1.18	0.198	-0.32
S65	0.495	2.446	0.1991	0.202	0.300	0.302	0.263	1.30	0.290	-3.50
S66	0.495	2.446	0.1991	0.202	0.399	0.333	0.292	1.45	0.392	-1.83

APPENDIX C2:
CRUMP WEIR WITH DIVIDING WALLS
WATER LEVEL UPSTREAM OF BOTH CRESTS
STELLENBOSCH FIRST SERIES

Cd = 1.163(1-0.0003/h)^1.5

OBSERVED VALUES								CALCULATED VALUES		
Test Nr	L1 (m)	L2 (m)	P (m)	T (m)	Qm (m^3/s)	Middle h1 (m)	Left h2 (m)	h1/T	Qw (m^3/s)	%-Error
c1	1.197	1.78	0.1711	0.1069	0.049	0.0755	0.0783	0.71	0.05	2.76
c2	1.197	1.78	0.1711	0.1069	0.072	0.0959	0.1011	0.90	0.073	1.67
c3	1.197	1.78	0.1711	0.1069	0.120	0.1232	0.1316	1.15	0.122	1.41
c4	1.197	1.78	0.1711	0.1069	0.151	0.1353	0.145	1.27	0.152	0.57
c5	1.197	1.78	0.1711	0.1069	0.200	0.1536	0.1653	1.44	0.204	1.58
c6	1.197	1.78	0.1711	0.1069	0.300	0.1834	0.1987	1.72	0.304	1.35
c7	1.197	1.78	0.1711	0.1069	0.399	0.208	0.2261	1.95	0.399	0.07
c8	0.735	2.242	0.1711	0.1061	0.150	0.1523	0.1619	1.44	0.152	1.14
c9	0.735	2.242	0.1711	0.1061	0.200	0.1708	0.1813	1.61	0.204	1.91
c10	0.735	2.242	0.1711	0.1061	0.300	0.2001	0.2139	1.89	0.305	1.62
c11	0.735	2.242	0.1711	0.1061	0.400	0.2266	0.241	2.14	0.404	1.05
c12	0.479	2.498	0.1711	0.107	0.199	0.177	0.1921	1.65	0.202	1.18
c13	0.479	2.498	0.1711	0.107	0.301	0.2049	0.2246	1.91	0.302	0.56
c14	0.479	2.498	0.1711	0.107	0.400	0.2305	0.2519	2.15	0.401	0.38
c15	0.479	2.498	0.0885	0.107	0.070	0.1206	0.1372	1.13	0.07	0.41
c16	0.479	2.498	0.0885	0.107	0.101	0.1339	0.153	1.25	0.102	1.53
c17	0.479	2.498	0.0885	0.107	0.200	0.1685	0.1912	1.57	0.202	0.56
c18	0.479	2.498	0.0885	0.107	0.300	0.1949	0.222	1.82	0.3	0.08
c19	0.479	2.498	0.0885	0.107	0.400	0.2212	0.2487	2.07	0.402	0.62
c20	0.735	2.242	0.0885	0.1069	0.080	0.1145	0.1303	1.07	0.079	-1.81
c21	0.735	2.242	0.0885	0.1069	0.120	0.1313	0.1499	1.23	0.119	-1.31
c22	0.735	2.242	0.0885	0.1069	0.200	0.1575	0.1807	1.47	0.197	-1.58
c23	0.735	2.242	0.0885	0.1069	0.300	0.1836	0.2112	1.72	0.293	-2.47
c24	0.735	2.242	0.0885	0.1069	0.401	0.2073	0.2387	1.94	0.392	-2.03
c25	1.197	1.78	0.089	0.1069	0.150	0.1258	0.1449	1.18	0.146	-3.08
c26	1.197	1.78	0.089	0.1069	0.200	0.1449	0.1632	1.36	0.199	-0.78
c27	1.197	1.78	0.089	0.1069	0.300	0.1748	0.195	1.64	0.301	0.4
c28	1.197	1.78	0.089	0.1069	0.401	0.1989	0.2233	1.86	0.402	0.42

APPENDIX C3
THIN PLATE WEIR WITH DIVIDING WALLS
WATERLEVEL UPSTREAM OF LOW CREST
STELLENBOSCH FIRST SERIES

Cd=K1-K2*H/P
K1 = 0.627
K2 = 0.018

OBSERVED VALUES							CALCULATED VALUES		
TEST Nr	L1 (m)	L2 (m)	P (m)	T (m)	Qm (m^3/s)	Middle h1 (m)	h1/T	Qw (m^3/s)	%-Error
S01	1.177	1.759	0.04	0.050	0.050	0.060	1.20	0.0443	-11.35
S02	1.177	1.759	0.04	0.050	0.200	0.111	2.22	0.1936	-3.20
S03	1.177	1.759	0.04	0.050	0.303	0.135	2.70	0.3149	3.94
S04	1.177	1.759	0.091	0.050	0.050	0.070	1.40	0.0549	9.81
S05	1.177	1.759	0.091	0.050	0.200	0.126	2.52	0.1981	-0.95
S06	1.177	1.759	0.091	0.050	0.400	0.174	3.48	0.3832	-4.20
S10	1.177	1.759	0.193	0.050	0.201	0.133	2.66	0.1984	-1.29
S11	1.177	1.759	0.193	0.050	0.300	0.165	3.30	0.3013	0.43
S12	1.177	1.759	0.193	0.050	0.401	0.193	3.86	0.4055	1.12
S13	1.174	1.761	0.193	0.100	0.102	0.118	1.18	0.1037	1.70
S14	1.174	1.761	0.193	0.100	0.202	0.160	1.60	0.2085	3.23
S15	1.174	1.761	0.193	0.100	0.399	0.219	2.19	0.4129	3.48
S16	1.174	1.761	0.29	0.103	0.196	0.161	1.56	0.1986	1.32
S17	1.174	1.761	0.29	0.103	0.301	0.196	1.90	0.3048	1.25
S18	1.174	1.761	0.29	0.103	0.400	0.222	2.16	0.3960	-1.00
S19	0.735	2.196	0.05	0.050	0.051	0.069	1.38	0.0447	-12.44
S20	0.735	2.196	0.05	0.050	0.201	0.121	2.42	0.1903	-5.32
S21	0.735	2.196	0.05	0.050	0.300	0.142	2.84	0.2799	-6.70
S22H	0.739	2.196	0.1	0.050	0.049	0.073	1.46	0.0459	-6.42
S23H	0.739	2.196	0.1	0.050	0.201	0.132	2.64	0.1919	-4.53
S24H	0.739	2.196	0.1	0.050	0.400	0.182	3.64	0.3808	-4.81
S25	0.738	2.198	0.1	0.100	0.100	0.124	1.24	0.0929	-7.09
S26	0.738	2.198	0.1	0.100	0.200	0.162	1.62	0.1970	-1.51
S27	0.738	2.198	0.1	0.100	0.399	0.209	2.09	0.3777	-5.35
S28	0.735	2.203	0.1	0.199	0.200	0.196	0.98	0.1617	-19.13
S29	0.735	2.203	0.1	0.199	0.301	0.225	1.13	0.2493	-17.17
S30	0.735	2.203	0.1	0.199	0.399	0.250	1.26	0.3478	-12.83
S31	0.736	2.202	0.205	0.051	0.099	0.103	2.02	0.0990	-0.04
S32	0.736	2.202	0.205	0.051	0.200	0.143	2.80	0.2033	1.66
S33	0.736	2.202	0.205	0.051	0.399	0.201	3.94	0.4039	1.23
S34	0.74	2.196	0.205	0.100	0.099	0.131	1.31	0.0959	-3.17
S35	0.74	2.196	0.205	0.100	0.199	0.173	1.73	0.2015	1.24
S36	0.74	2.196	0.205	0.100	0.398	0.224	2.24	0.3742	-5.99
S37	0.74	2.196	0.206	0.201	0.197	0.221	1.10	0.1848	-6.18
S38	0.74	2.196	0.206	0.201	0.297	0.252	1.25	0.2723	-8.31
S39	0.74	2.196	0.206	0.201	0.400	0.275	1.37	0.3505	-12.37
S40	0.74	2.196	0.305	0.101	0.200	0.175	1.73	0.1960	-2.01
S41	0.74	2.196	0.305	0.101	0.299	0.209	2.07	0.3000	0.33
S42	0.74	2.196	0.305	0.101	0.101	0.137	1.36	0.1031	2.09
S46	0.496	2.44	0.049	0.049	0.101	0.093	1.90	0.0918	-9.11
S47	0.496	2.44	0.049	0.049	0.200	0.127	2.59	0.2048	2.40
S48	0.496	2.44	0.049	0.049	0.301	0.150	3.06	0.3153	4.73
S49	0.495	2.438	0.101	0.050	0.050	0.078	1.56	0.0465	-7.09
S50	0.495	2.438	0.101	0.050	0.201	0.137	2.74	0.1949	-3.02
S51	0.495	2.438	0.101	0.050	0.399	0.181	3.62	0.3595	-9.79
S52	0.493	2.443	0.1	0.100	0.100	0.134	1.34	0.0948	-5.20
S53	0.493	2.443	0.1	0.100	0.200	0.167	1.67	0.1870	-6.49
S54	0.493	2.443	0.1	0.100	0.401	0.215	2.15	0.3716	-7.33
S55	0.495	2.442	0.099	0.200	0.200	0.219	1.10	0.1739	-13.07
S56	0.495	2.442	0.099	0.200	0.300	0.251	1.26	0.2883	-3.88
S57	0.495	2.442	0.099	0.200	0.398	0.277	1.39	0.4072	2.31
S58	0.495	2.44	0.2	0.049	0.101	0.107	2.18	0.1015	0.45
S59	0.495	2.44	0.2	0.049	0.201	0.145	2.96	0.2016	0.30
S60	0.495	2.44	0.2	0.049	0.398	0.202	4.12	0.3990	0.24
S61	0.495	2.442	0.201	0.100	0.050	0.114	1.14	0.0472	-5.59
S62	0.495	2.442	0.201	0.100	0.200	0.180	1.80	0.1971	-1.46
S63	0.495	2.442	0.201	0.100	0.399	0.233	2.33	0.3790	-5.02
S64	0.495	2.446	0.1991	0.202	0.200	0.238	1.18	0.1758	-12.09
S64F	0.495	2.446	0.1991	0.202	0.199	0.239	1.18	0.1785	-10.32
S65	0.495	2.446	0.1991	0.202	0.300	0.263	1.30	0.2489	-17.02
S66	0.495	2.446	0.1991	0.202	0.399	0.292	1.45	0.3501	-12.25

APPENDIX C4
CRUMP WEIR WITH DIVIDING WALLS
WATERLEVEL OBSERVED UPSTREAM OF LOW CREST
DWAF AND STELLENBOSCH TESTS

Cd = 1.163(1-0.0003/h)^1.5

OBSERVED VALUES							CALCULATED VALUES		
Test Nr	L1 (m)	L2 (m)	P (m)	T (m)	Qm (m^3/s)	Middle h1 (m)	h1/T	Qw (m^3/s)	% Error
WMOD1-1s	1.597	2.416	0.269	0.097	0.02	0.0345	0.36	0.020	0.52
WMOD1-1s	1.597	2.416	0.269	0.097	0.05	0.0636	0.66	0.051	1.78
WMOD1-1s	1.597	2.416	0.269	0.097	0.08	0.0858	0.88	0.081	0.71
WMOD1-1s	1.597	2.416	0.269	0.097	0.12	0.107	1.10	0.119	-0.74
WMOD1-1s	1.597	2.416	0.269	0.097	0.15	0.119	1.23	0.151	0.89
WMOD1-1s	1.597	2.416	0.269	0.097	0.177	0.1265	1.30	0.174	-1.64
WMOD1-2s	1.597	2.416	0.176	0.097	0.02	0.0352	0.36	0.021	3.05
WMOD1-2s	1.597	2.416	0.176	0.097	0.05	0.0635	0.65	0.051	2.61
WMOD1-2s	1.597	2.416	0.176	0.097	0.08	0.0853	0.88	0.081	1.39
WMOD1-2s	1.597	2.416	0.176	0.097	0.12	0.1076	1.11	0.124	3.51
WMOD1-2s	1.597	2.416	0.176	0.097	0.15	0.1177	1.21	0.153	1.82
WMOD1-2s	1.597	2.416	0.176	0.097	0.177	0.1268	1.31	0.181	2.65
WMOD1-3s	1.597	2.416	0.085	0.097	0.02	0.036	0.37	0.022	8.57
WMOD1-3s	1.597	2.416	0.085	0.097	0.05	0.0616	0.64	0.051	1.62
WMOD1-3s	1.597	2.416	0.085	0.097	0.08	0.0829	0.85	0.082	2.1
WMOD1-3s	1.597	2.416	0.085	0.097	0.12	0.1014	1.05	0.119	-1.12
WMOD1-3s	1.597	2.416	0.085	0.097	0.15	0.1127	1.16	0.153	1.84
WMOD1-3s	1.597	2.416	0.085	0.097	0.177	0.1214	1.25	0.183	3.34
WMOD2-3s	1.23	2.792	0.089	0.098	0.02	0.0423	0.43	0.022	7.02
WMOD2-3s	1.23	2.792	0.089	0.098	0.05	0.0718	0.73	0.050	-0.69
WMOD2-3s	1.23	2.792	0.089	0.098	0.08	0.0946	0.97	0.078	-3.3
WMOD2-3s	1.23	2.792	0.089	0.098	0.12	0.11	1.12	0.114	-4.73
WMOD2-3s	1.23	2.792	0.089	0.098	0.15	0.1206	1.23	0.147	-1.96
WMOD2-3s	1.23	2.792	0.089	0.098	0.177	0.1269	1.29	0.169	-4.6
WMOD2-2s	1.23	2.792	0.173	0.098	0.02	0.0433	0.44	0.022	8.68
WMOD2-2s	1.23	2.792	0.173	0.098	0.05	0.0742	0.76	0.050	0.46
WMOD2-2s	1.23	2.792	0.173	0.098	0.08	0.0995	1.02	0.081	0.7
WMOD2-2s	1.23	2.792	0.173	0.098	0.12	0.1172	1.20	0.122	1.83
WMOD2-2s	1.23	2.792	0.173	0.098	0.15	0.1272	1.30	0.152	1.07
WMOD2-2s	1.23	2.792	0.173	0.098	0.177	0.1345	1.37	0.175	-0.93
WMOD2-1s	1.23	2.792	0.268	0.098	0.02	0.0433	0.44	0.022	9.36
WMOD2-1s	1.23	2.792	0.268	0.098	0.05	0.0748	0.76	0.050	0.63
WMOD2-1s	1.23	2.792	0.268	0.098	0.08	0.0998	1.02	0.079	-1.1
WMOD2-1s	1.23	2.792	0.268	0.098	0.12	0.1172	1.20	0.117	-2.19
WMOD2-1s	1.23	2.792	0.268	0.098	0.15	0.1283	1.31	0.148	-1.09
WMOD2-1s	1.23	2.792	0.268	0.098	0.177	0.1365	1.39	0.174	-1.75
WMOD3-1s	0.999	3.005	0.268	0.098	0.02	0.0473	0.48	0.020	1.6
WMOD3-1s	0.999	3.005	0.268	0.098	0.05	0.085	0.87	0.050	-0.59
WMOD3-1s	0.999	3.005	0.268	0.098	0.08	0.1071	1.09	0.077	-3.27
WMOD3-1s	0.999	3.005	0.268	0.098	0.12	0.1227	1.25	0.114	-5.15
WMOD3-1s	0.999	3.005	0.268	0.098	0.15	0.133	1.36	0.143	-4.72
WMOD3-1s	0.999	3.005	0.268	0.098	0.177	0.1413	1.44	0.169	-4.6
WMOD3-2s	0.999	3.005	0.185	0.098	0.02	0.0486	0.50	0.021	6.51
WMOD3-2s	0.999	3.005	0.185	0.098	0.05	0.085	0.87	0.050	0.73
WMOD3-2s	0.999	3.005	0.185	0.098	0.08	0.1074	1.10	0.080	0.58
WMOD3-2s	0.999	3.005	0.185	0.098	0.12	0.1229	1.25	0.119	-1.02
WMOD3-2s	0.999	3.005	0.185	0.098	0.15	0.1333	1.36	0.150	-0.16
WMOD3-2s	0.999	3.005	0.185	0.098	0.177	0.1416	1.44	0.177	0.07
WMOD3-3s	0.999	3.005	0.103	0.098	0.02	0.0454	0.46	0.020	-2.36
WMOD3-3s	0.999	3.005	0.103	0.098	0.05	0.08	0.82	0.047	-5.06
WMOD3-3s	0.999	3.005	0.103	0.098	0.08	0.0988	1.01	0.068	-15.07
WMOD3-3s	0.999	3.005	0.103	0.098	0.12	0.1136	1.16	0.104	-13.72
WMOD3-3s	0.999	3.005	0.103	0.098	0.15	0.1222	1.25	0.129	-14.21
WMOD3-3s	0.999	3.005	0.103	0.098	0.177	0.1304	1.33	0.156	-12.12
WMOD4-2s	0.804	3.2	0.183	0.098	0.005	0.0228	0.23	0.005	7.99
WMOD4-2s	0.804	3.2	0.183	0.098	0.01	0.0352	0.36	0.010	4.74
WMOD4-2s	0.804	3.2	0.183	0.098	0.015	0.0452	0.46	0.015	2.31
WMOD4-2s	0.804	3.2	0.183	0.098	0.02	0.0542	0.55	0.020	1.34
WMOD4-2s	0.804	3.2	0.183	0.098	0.05	0.0962	0.98	0.049	-1.68
WMOD4-2s	0.804	3.2	0.183	0.098	0.08	0.1134	1.16	0.080	-0.33
WMOD4-2s	0.804	3.2	0.183	0.098	0.12	0.1284	1.31	0.119	-1.12
WMOD4-2s	0.804	3.2	0.183	0.098	0.15	0.1384	1.41	0.149	-0.5
WMOD4-2s	0.804	3.2	0.183	0.098	0.177	0.1456	1.49	0.173	-2.08
WMOD4-3s	0.804	3.2	0.103	0.098	0.01	0.0338	0.34	0.010	-0.44
WMOD4-3s	0.804	3.2	0.103	0.098	0.02	0.0523	0.53	0.020	-2.06

OBSERVED VALUES							CALCULATED VALUES		
Test Nr	L1 (m)	L2 (m)	P (m)	T (m)	Qm (m^3/s)	Middle h1 (m)	h1/T	Qw (m^3/s)	% Error
WMOD4-3s	0.804	3.2	0.103	0.098	0.05	0.0915	0.93	0.047	-5.39
WMOD4-3s	0.804	3.2	0.103	0.098	0.08	0.1058	1.08	0.070	-12.67
WMOD4-3s	0.804	3.2	0.103	0.098	0.12	0.1187	1.21	0.102	-14.59
WMOD4-3s	0.804	3.2	0.103	0.098	0.15	0.1272	1.30	0.128	-14.56
WMOD4-3s	0.804	3.2	0.103	0.098	0.171	0.1332	1.36	0.148	-13.41
WMOD5-2s	0.672	3.332	0.183	0.099	0.005	0.0245	0.25	0.005	0.73
WMOD5-2s	0.672	3.332	0.183	0.099	0.01	0.0401	0.41	0.011	6.82
WMOD5-2s	0.672	3.332	0.183	0.099	0.015	0.052	0.53	0.016	5.98
WMOD5-2s	0.672	3.332	0.183	0.099	0.02	0.0627	0.63	0.021	5.94
WMOD5-2s	0.672	3.332	0.183	0.099	0.05	0.1029	1.04	0.049	-2.19
WMOD5-2s	0.672	3.332	0.183	0.099	0.08	0.1183	1.19	0.080	-0.32
WMOD5-2s	0.672	3.332	0.183	0.099	0.12	0.1334	1.35	0.120	0.16
WMOD5-2s	0.672	3.332	0.183	0.099	0.15	0.1425	1.44	0.149	-0.97
WMOD5-2s	0.672	3.332	0.183	0.099	0.177	0.1504	1.52	0.175	-0.94
WMOD5-3s	0.672	3.332	0.093	0.099	0.005	0.0251	0.25	0.005	5.48
WMOD5-3s	0.672	3.332	0.093	0.099	0.01	0.0388	0.39	0.010	3.37
WMOD5-3s	0.672	3.332	0.093	0.099	0.015	0.0496	0.50	0.015	1.01
WMOD5-3s	0.672	3.332	0.093	0.099	0.02	0.0596	0.60	0.020	1.04
WMOD5-3s	0.672	3.332	0.093	0.099	0.05	0.0965	0.97	0.045	-13.03
WMOD5-3s	0.672	3.332	0.093	0.099	0.08	0.1097	1.11	0.069	-13.14
WMOD5-3s	0.672	3.332	0.093	0.099	0.12	0.1237	1.25	0.107	-10.63
WMOD5-3s	0.672	3.332	0.093	0.099	0.15	0.1325	1.34	0.135	-9.68
WMOD5-3s	0.672	3.332	0.093	0.099	0.174	0.1385	1.40	0.157	-10.03
WMOD6-3s	0.67	3.332	0.121	0.071	0.01	0.0379	0.53	0.010	-1.46
WMOD6-3s	0.67	3.332	0.121	0.071	0.02	0.0594	0.84	0.020	-1.27
WMOD6-3s	0.67	3.332	0.121	0.071	0.05	0.0835	1.18	0.046	-7.92
WMOD6-3s	0.67	3.332	0.121	0.071	0.08	0.0965	1.36	0.076	-5.37
WMOD6-3s	0.67	3.332	0.121	0.071	0.12	0.11	1.55	0.114	-4.99
WMOD6-3s	0.67	3.332	0.121	0.071	0.15	0.1191	1.68	0.144	-4.26
WMOD6-3s	0.67	3.332	0.121	0.071	0.175	0.1253	1.76	0.165	-5.48
WMOD6-2s	0.67	3.332	0.211	0.071	0.011	0.0418	0.59	0.011	2.94
WMOD6-2s	0.67	3.332	0.211	0.071	0.02	0.0616	0.87	0.020	2.39
WMOD6-2s	0.67	3.332	0.211	0.071	0.05	0.0868	1.22	0.049	-1.28
WMOD6-2s	0.67	3.332	0.211	0.071	0.08	0.0999	1.41	0.079	-1.52
WMOD6-2s	0.67	3.332	0.211	0.071	0.12	0.1144	1.61	0.119	-1.09
WMOD6-2s	0.67	3.332	0.211	0.071	0.15	0.124	1.75	0.149	-0.79
WMOD6-2s	0.67	3.332	0.211	0.071	0.175	0.1309	1.84	0.172	-1.63
C1	1.197	1.78	0.1711	0.1069	0.04904	0.0755	0.71	0.050	2.76
C2	1.197	1.78	0.1711	0.1069	0.0719	0.0959	0.90	0.073	1.67
C3	1.197	1.78	0.1711	0.1069	0.1201	0.1232	1.15	0.119	-1.04
C4	1.197	1.78	0.1711	0.1069	0.1508	0.1353	1.27	0.148	-2.02
C5	1.197	1.78	0.1711	0.1069	0.2004	0.1536	1.44	0.198	-1.01
C6	1.197	1.78	0.1711	0.1069	0.2997	0.1834	1.72	0.296	-1.15
C7	1.197	1.78	0.1711	0.1069	0.3988	0.208	1.95	0.390	-2.18
C8	0.735	2.242	0.1711	0.1061	0.15	0.1523	1.44	0.148	-1.09
C9	0.735	2.242	0.1711	0.1061	0.2004	0.1708	1.61	0.202	0.86
C10	0.735	2.242	0.1711	0.1061	0.3	0.2001	1.89	0.302	0.63
C11	0.735	2.242	0.1711	0.1061	0.3995	0.2266	2.14	0.406	1.72
C12	0.479	2.498	0.1711	0.107	0.1992	0.177	1.65	0.190	-4.39
C13	0.479	2.498	0.171	0.107	0.3006	0.2049	1.91	0.285	-5.25
C14	0.479	2.498	0.171	0.107	0.3995	0.2305	2.15	0.385	-3.72
C15	0.479	2.498	0.0885	0.1069	0.0702	0.1206	1.13	0.062	-11.08
C16	0.479	2.498	0.0885	0.1069	0.1005	0.1339	1.25	0.092	-8.86
C17	0.479	2.498	0.0885	0.1069	0.2004	0.1685	1.58	0.193	-3.71
C18	0.479	2.498	0.0885	0.1069	0.3	0.1949	1.82	0.292	-2.73
C19	0.479	2.498	0.0885	0.1069	0.3995	0.2212	2.07	0.407	1.93
C20	0.735	2.242	0.0885	0.1069	0.0802	0.1145	1.07	0.072	-10.06
C21	0.735	2.242	0.0885	0.1069	0.1201	0.1313	1.23	0.109	-8.89
C22	0.735	2.242	0.0885	0.1069	0.2004	0.1575	1.47	0.185	-7.58
C23	0.735	2.242	0.0885	0.1069	0.3	0.1836	1.72	0.279	-6.96
C24	0.735	2.242	0.0885	0.1069	0.4005	0.2073	1.94	0.379	-5.38
C25	1.197	1.78	0.089	0.1069	0.1504	0.1258	1.18	0.138	-8.52
C26	1.197	1.78	0.089	0.1069	0.2001	0.1449	1.36	0.193	-3.35
C27	1.197	1.78	0.089	0.1069	0.2997	0.1748	1.64	0.300	0.22
C28	1.197	1.78	0.089	0.1069	0.4005	0.1989	1.86	0.403	0.48

APPENDIX C5:
THIN-PLATE WEIR WITHOUT DIVIDING WALLS
STANDARD ANALYSIS PROCEDURES

Cd = 0.627 + 0.018 H/P

OBSERVED VALUES							CALCULATED VALUES		
Test Nr	L1 (m)	L2 (m)	P (m)	T (m)	Qm (m^3/s)	h1 (m)	h1/T	Qw (m^3/s)	% Error
S01	1.177	1.759	0.040	0.050	0.050	0.068	1.36	0.051	1.02
S02	1.177	1.759	0.040	0.050	0.200	0.124	2.48	0.194	-3.22
S03	1.177	1.759	0.040	0.050	0.298	0.151	3.02	0.296	-0.82
S04	1.177	1.759	0.091	0.050	0.049	0.069	1.38	0.050	1.68
S05	1.177	1.759	0.091	0.050	0.200	0.131	2.62	0.197	-1.72
S06	1.177	1.759	0.091	0.050	0.394	0.186	3.72	0.395	0.28
S10	1.177	1.759	0.193	0.050	0.201	0.136	2.72	0.200	-0.28
S11	1.177	1.759	0.193	0.050	0.299	0.167	3.34	0.297	-0.62
S12	1.177	1.759	0.193	0.050	0.402	0.196	3.92	0.401	-0.18
S13	1.174	1.761	0.193	0.100	0.100	0.121	1.21	0.104	4.31
S14	1.174	1.761	0.193	0.100	0.200	0.164	1.64	0.206	3.11
S15	1.174	1.761	0.193	0.100	0.399	0.222	2.22	0.394	-1.37
S16	1.174	1.761	0.290	0.103	0.200	0.167	1.62136	0.207	3.51
S17	1.174	1.761	0.290	0.103	0.302	0.200	1.94175	0.304	0.81
S18	1.174	1.761	0.290	0.103	0.400	0.229	2.2233	0.403	0.73
S19	0.740	2.192	0.050	0.050	0.051	0.078	1.56	0.052	1.91
S20	0.740	2.192	0.050	0.050	0.201	0.137	2.74	0.201	-0.15
S21	0.740	2.192	0.050	0.050	0.297	0.163	3.26	0.294	-1.07
S22H	0.739	2.196	0.101	0.050	0.050	0.077	1.54	0.049	-2.56
S23H	0.739	2.196	0.101	0.050	0.200	0.141	2.82	0.200	-0.01
S24H	0.739	2.196	0.101	0.050	0.400	0.195	3.9	0.391	-2.26
S25	0.738	2.190	0.100	0.100	0.100	0.139	1.39	0.107	7.49
S26	0.738	2.190	0.100	0.100	0.200	0.179	1.79	0.209	4.44
S27	0.738	2.190	0.100	0.100	0.399	0.235	2.35	0.401	0.41
S28	0.736	2.197	0.099	0.199	0.202	0.246	1.23618	0.226	11.93
S29	0.736	2.197	0.099	0.199	0.301	0.279	1.40201	0.323	7.24
S30	0.736	2.197	0.099	0.199	0.400	0.308	1.54774	0.423	5.85
S31	0.736	2.202	0.205	0.051	0.098	0.105	2.05882	0.100	1.85
S32	0.736	2.202	0.205	0.051	0.200	0.146	2.86275	0.204	1.84
S33	0.736	2.202	0.205	0.051	0.399	0.205	4.01961	0.400	0.32
S34	0.740	2.196	0.205	0.100	0.101	0.140	1.4	0.107	5.92
S35	0.740	2.196	0.205	0.100	0.199	0.181	1.81	0.207	4.12
S36	0.740	2.196	0.205	0.100	0.399	0.240	2.4	0.399	-0.12
S37	0.740	2.196	0.206	0.201	0.197	0.245	1.21891	0.213	7.91
S38	0.740	2.196	0.206	0.201	0.301	0.282	1.40299	0.315	4.56
S39	0.740	2.196	0.206	0.201	0.398	0.312	1.55224	0.413	3.81
S40	0.740	2.196	0.306	0.101	0.202	0.184	1.82178	0.211	4.33
S41	0.740	2.196	0.306	0.101	0.302	0.217	2.14851	0.310	2.55
S42	0.740	2.196	0.306	0.101	0.099	0.139	1.37624	0.103	3.79
S46	0.496	2.433	0.048	0.049	0.101	0.106	2.16327	0.102	0.67
S47	0.496	2.433	0.048	0.049	0.201	0.143	2.91837	0.207	2.98
S48	0.496	2.433	0.048	0.049	0.301	0.169	3.44898	0.301	-0.01
S49	0.495	2.438	0.101	0.050	0.047	0.082	1.64	0.049	3.63
S50	0.495	2.438	0.101	0.050	0.202	0.146	2.92	0.201	-0.63
S51	0.495	2.438	0.101	0.050	0.398	0.202	4.04	0.399	0.32
S52	0.495	2.437	0.101	0.101	0.101	0.147	1.45545	0.101	-0.39
S53	0.495	2.437	0.101	0.101	0.201	0.189	1.87129	0.207	2.90
S54	0.495	2.437	0.101	0.101	0.399	0.246	2.43564	0.401	0.62
S55	0.494	2.446	0.099	0.201	0.200	0.265	1.31841	0.213	6.65
S56	0.494	2.446	0.099	0.201	0.300	0.300	1.49254	0.317	5.72
S57	0.494	2.466	0.099	0.201	0.400	0.328	1.63184	0.416	4.07
S58	0.494	2.438	0.200	0.049	0.101	0.110	2.2449	0.104	2.79
S59	0.494	2.438	0.200	0.049	0.200	0.150	3.06122	0.207	3.28
S60	0.494	2.438	0.200	0.049	0.399	0.209	4.26531	0.404	1.36
S61	0.492	2.438	0.200	0.100	0.050	0.120	1.2	0.052	3.07
S62	0.492	2.438	0.200	0.100	0.202	0.191	1.91	0.208	2.80
S63	0.492	2.438	0.200	0.100	0.399	0.251	2.51	0.404	1.20
S64	0.495	2.434	0.199	0.201	0.199	0.267	1.32836	0.211	6.11
S65	0.495	2.434	0.199	0.201	0.300	0.304	1.51244	0.318	5.86
S66	0.495	2.434	0.199	0.201	0.399	0.333	1.65672	0.415	3.99

APPENDIX C6
CRUMP WEIR WITHOUT DIVIDE WALLS-DWAF TEST & STELLENBOSCH TESTS
STANDARD ANALYSIS PROCEDURES

Cd = 1.163(1-0.0003/h)^(3/2)

OBSERVED VALUES							CALCULATED VALUES		
Test Nr	L1 (m)	L2 (m)	P (m)	T (m)	Qm (m^3/s)	h1 (m)	h1/T	Qw (m^3/s)	% Error
WMOD1-1s	1.597	2.408	0.269	0.097	0.02	0.0359	0.37	0.021	6.416
WMOD1-1s	1.597	2.408	0.269	0.097	0.05	0.0644	0.66	0.051	2.959
WMOD1-1s	1.597	2.408	0.269	0.097	0.08	0.0877	0.90	0.082	2.567
WMOD1-1s	1.597	2.408	0.269	0.097	0.12	0.1111	1.15	0.125	4.465
WMOD1-1s	1.597	2.408	0.269	0.097	0.15	0.1222	1.26	0.155	3.275
WMOD1-1s	1.597	2.408	0.269	0.097	0.177	0.1309	1.35	0.181	2.158
WMOD1-2s	1.597	2.408	0.176	0.097	0.02	0.0356	0.37	0.021	5.145
WMOD1-2s	1.597	2.408	0.176	0.097	0.05	0.0643	0.66	0.051	2.886
WMOD1-2s	1.597	2.408	0.176	0.097	0.08	0.0877	0.90	0.082	2.814
WMOD1-2s	1.597	2.408	0.176	0.097	0.12	0.111	1.14	0.126	4.794
WMOD1-2s	1.597	2.408	0.176	0.097	0.15	0.1225	1.26	0.157	4.543
WMOD1-2s	1.597	2.408	0.176	0.097	0.177	0.1311	1.35	0.183	3.323
WMOD1-3s	1.597	2.408	0.085	0.097	0.02	0.0348	0.36	0.020	1.859
WMOD1-3s	1.597	2.408	0.085	0.097	0.05	0.0642	0.66	0.052	3.207
WMOD1-3s	1.597	2.408	0.085	0.097	0.08	0.0873	0.90	0.082	2.838
WMOD1-3s	1.597	2.408	0.085	0.097	0.12	0.1091	1.12	0.123	2.282
WMOD1-3s	1.597	2.408	0.085	0.097	0.15	0.1207	1.24	0.154	2.366
WMOD1-3s	1.597	2.408	0.085	0.097	0.177	0.129	1.33	0.180	1.619
WMOD2-3s	1.23	2.773	0.089	0.098	0.02	0.0435	0.44	0.022	9.821
WMOD2-3s	1.23	2.773	0.089	0.098	0.05	0.0761	0.78	0.051	2.407
WMOD2-3s	1.23	2.773	0.089	0.098	0.08	0.1032	1.05	0.083	4.281
WMOD2-3s	1.23	2.773	0.089	0.098	0.12	0.1216	1.24	0.125	4.537
WMOD2-3s	1.23	2.773	0.089	0.098	0.15	0.1314	1.34	0.153	2.152
WMOD2-3s	1.23	2.773	0.089	0.098	0.177	0.1388	1.42	0.176	-0.400
WMOD2-2s	1.23	2.773	0.173	0.098	0.02	0.0438	0.45	0.022	10.759
WMOD2-2s	1.23	2.773	0.173	0.098	0.05	0.0767	0.78	0.052	3.278
WMOD2-2s	1.23	2.773	0.173	0.098	0.08	0.1044	1.07	0.085	6.340
WMOD2-2s	1.23	2.773	0.173	0.098	0.12	0.1232	1.26	0.128	6.846
WMOD2-2s	1.23	2.773	0.173	0.098	0.15	0.133	1.36	0.156	3.863
WMOD2-2s	1.23	2.773	0.173	0.098	0.177	0.1409	1.44	0.180	1.773
WMOD2-1s	1.23	2.773	0.268	0.098	0.02	0.0433	0.44	0.022	8.790
WMOD2-1s	1.23	2.773	0.268	0.098	0.05	0.0764	0.78	0.051	2.539
WMOD2-1s	1.23	2.773	0.268	0.098	0.08	0.1037	1.06	0.084	4.441
WMOD2-1s	1.23	2.773	0.268	0.098	0.12	0.1222	1.25	0.125	[illegible]
WMOD2-1s	1.23	2.773	0.268	0.098	0.15	0.1337	1.36	0.157	[illegible]
WMOD2-1s	1.23	2.773	0.268	0.098	0.177	0.1405	1.43	0.178	0.299
WMOD3-1s	0.999	3.005	0.268	0.098	0.02	0.0471	0.48	0.020	0.314
WMOD3-1s	0.999	3.005	0.268	0.098	0.05	0.0886	0.90	0.052	4.067
WMOD3-1s	0.999	3.005	0.268	0.098	0.08	0.1132	1.16	0.086	7.895
WMOD3-1s	0.999	3.005	0.268	0.098	0.12	0.1297	1.32	0.126	5.167
WMOD3-1s	0.999	3.005	0.268	0.098	0.15	0.14	1.43	0.156	3.678
WMOD3-1s	0.999	3.005	0.268	0.098	0.177	0.149	1.52	0.184	3.696
WMOD3-2s	0.999	3.005	0.185	0.098	0.02	0.0478	0.49	0.021	2.610
WMOD3-2s	0.999	3.005	0.185	0.098	0.05	0.0882	0.90	0.052	3.442
WMOD3-2s	0.999	3.005	0.185	0.098	0.08	0.1131	1.15	0.086	7.901
WMOD3-2s	0.999	3.005	0.185	0.098	0.12	0.1295	1.32	0.126	5.145
WMOD3-2s	0.999	3.005	0.185	0.098	0.15	0.14	1.43	0.156	4.213
WMOD3-2s	0.999	3.005	0.185	0.098	0.177	0.1486	1.52	0.183	3.594
WMOD3-3s	0.999	3.005	0.103	0.098	0.02	0.047	0.48	0.020	0.132
WMOD3-3s	0.999	3.005	0.103	0.098	0.05	0.0881	0.90	0.052	3.475
WMOD3-3s	0.999	3.005	0.103	0.098	0.08	0.1124	1.15	0.085	6.674
WMOD3-3s	0.999	3.005	0.103	0.098	0.12	0.1286	1.31	0.125	4.061
WMOD3-3s	0.999	3.005	0.103	0.098	0.15	0.1386	1.41	0.154	2.545
WMOD3-3s	0.999	3.005	0.103	0.098	0.177	0.1475	1.51	0.182	2.909
WMOD4-2s	0.804	3.2	0.183	0.098	0.005	0.0219	0.22	0.005	1.228
WMOD4-2s	0.804	3.2	0.183	0.098	0.01	0.0354	0.36	0.010	4.865
WMOD4-2s	0.804	3.2	0.183	0.098	0.015	0.0452	0.46	0.015	1.161
WMOD4-2s	0.804	3.2	0.183	0.098	0.02	0.0554	0.57	0.021	3.160
WMOD4-2s	0.804	3.2	0.183	0.098	0.05	0.1018	1.04	0.053	6.011
WMOD4-2s	0.804	3.2	0.183	0.098	0.08	0.1196	1.22	0.086	7.472
WMOD4-2s	0.804	3.2	0.183	0.098	0.12	0.1356	1.38	0.126	5.334
WMOD4-2s	0.804	3.2	0.183	0.098	0.15	0.1454	1.48	0.155	3.383
WMOD4-2s	0.804	3.2	0.183	0.098	0.177	0.153	1.56	0.179	1.215
WMOD4-3s	0.804	3.2	0.103	0.098	0.01	0.035	0.36	0.010	3.124
WMOD4-3s	0.804	3.2	0.103	0.098	0.02	0.0551	0.56	0.020	2.401
WMOD4-3s	0.804	3.2	0.103	0.098	0.05	0.1023	1.04	0.054	7.655

OBSERVED VALUES							CALCULATED VALUES		
Test Nr	L1 (m)	L2 (m)	P (m)	T (m)	Qm (m^3/s)	h1 (m)	h1/T	Qw (m^3/s)	% Error
WMOD4-3s	0.804	3.2	0.103	0.098	0.08	0.1205	1.23	0.089	10.670
WMOD4-3s	0.804	3.2	0.103	0.098	0.12	0.1354	1.38	0.127	5.786
WMOD4-3s	0.804	3.2	0.103	0.098	0.15	0.1454	1.48	0.157	4.492
WMOD4-3s	0.804	3.2	0.103	0.098	0.172	0.1506	1.54	0.173	0.812
WMOD5-2s	0.672	3.332	0.183	0.099	0.005	0.0247	0.25	0.005	1.581
WMOD5-2s	0.672	3.332	0.183	0.099	0.01	0.0409	0.41	0.011	9.032
WMOD5-2s	0.672	3.332	0.183	0.099	0.015	0.052	0.53	0.016	4.464
WMOD5-2s	0.672	3.332	0.183	0.099	0.02	0.0633	0.64	0.021	5.406
WMOD5-2s	0.672	3.332	0.183	0.099	0.05	0.1086	1.10	0.054	7.168
WMOD5-2s	0.672	3.332	0.183	0.099	0.08	0.1246	1.26	0.086	6.919
WMOD5-2s	0.672	3.332	0.183	0.099	0.12	0.1397	1.41	0.124	3.570
WMOD5-2s	0.672	3.332	0.183	0.099	0.15	0.1503	1.52	0.156	3.721
WMOD5-2s	0.672	3.332	0.183	0.099	0.177	0.1567	1.58	0.176	-0.584
WMOD5-3s	0.672	3.332	0.093	0.099	0.005	0.0249	0.25	0.005	2.858
WMOD5-3s	0.672	3.332	0.093	0.099	0.01	0.0396	0.40	0.010	3.886
WMOD5-3s	0.672	3.332	0.093	0.099	0.015	0.0519	0.52	0.016	4.230
WMOD5-3s	0.672	3.332	0.093	0.099	0.02	0.0628	0.63	0.021	4.238
WMOD5-3s	0.672	3.332	0.093	0.099	0.05	0.1084	1.09	0.053	6.890
WMOD5-3s	0.672	3.332	0.093	0.099	0.08	0.1241	1.25	0.085	6.173
WMOD5-3s	0.672	3.332	0.093	0.099	0.12	0.1396	1.41	0.125	4.368
WMOD5-3s	0.672	3.332	0.093	0.099	0.15	0.1497	1.51	0.156	3.744
WMOD5-3s	0.672	3.332	0.093	0.099	0.174	0.1559	1.57	0.176	0.999
WMOD6-3s	0.67	3.332	0.121	0.071	0.01	0.0388	0.55	0.010	0.405
WMOD6-3s	0.67	3.332	0.121	0.071	0.02	0.0622	0.88	0.020	2.394
WMOD6-3s	0.67	3.332	0.121	0.071	0.05	0.0898	1.26	0.053	5.151
WMOD6-3s	0.67	3.332	0.121	0.071	0.08	0.1037	1.46	0.084	4.710
WMOD6-3s	0.67	3.332	0.121	0.071	0.12	0.118	1.66	0.123	2.236
WMOD6-3s	0.67	3.332	0.121	0.071	0.15	0.1279	1.80	0.153	2.144
WMOD6-3s	0.67	3.332	0.121	0.071	0.177	0.134	1.89	0.173	-2.035
WMOD6-2s	0.67	3.332	0.211	0.071	0.01	0.0397	0.56	0.010	3.917
WMOD6-2s	0.67	3.332	0.211	0.071	0.02	0.0615	0.87	0.020	0.608
WMOD6-2s	0.67	3.332	0.211	0.071	0.05	0.0896	1.26	0.052	3.977
WMOD6-2s	0.67	3.332	0.211	0.071	0.08	0.1036	1.46	0.083	3.739
WMOD6-2s	0.67	3.332	0.211	0.071	0.12	0.1184	1.67	0.123	2.248
WMOD6-2s	0.67	3.332	0.211	0.071	0.15	0.1285	1.81	0.153	2.239
WMOD6-2s	0.67	3.332	0.211	0.071	0.175	0.135	1.90	0.175	-0.283
c1	1.197	1.78	0.1711	0.1069	0.04904	0.0782	0.73	0.052	5.730
c2	1.197	1.78	0.1711	0.1069	0.0719	0.0985	0.92	0.074	2.243
c3	1.197	1.78	0.1711	0.1069	0.1206	0.1305	1.22	0.126	4.610
c4	1.197	1.78	0.1711	0.1069	0.15	0.1431	1.34	0.155	3.592
c5	1.197	1.78	0.1711	0.1069	0.1998	0.1629	1.52	0.208	4.113
c6	1.197	1.78	0.1711	0.1069	0.3	0.1944	1.82	0.307	2.196
c7	1.197	1.78	0.1711	0.1069	0.3988	0.2208	2.07	0.402	0.791
c8	0.735	2.242	0.1711	0.1061	0.1504	0.1618	1.52	0.156	3.477
c9	0.735	2.242	0.1711	0.1061	0.201	0.181	1.71	0.208	3.511
c10	0.735	2.242	0.1711	0.1061	0.3006	0.2127	2.00	0.309	2.666
c11	0.735	2.242	0.1711	0.1061	0.3991	0.2394	2.26	0.406	1.684
c12	0.479	2.498	0.1711	0.107	0.1998	0.1918	1.79	0.206	3.324
c13	0.479	2.498	0.1711	0.107	0.2994	0.221	2.07	0.299	-0.124
c14	0.479	2.498	0.1711	0.107	0.3971	0.2496	2.33	0.403	1.419
c15	0.479	2.498	0.0885	0.107	0.0698	0.1362	1.27	0.073	4.580
c16	0.479	2.498	0.0885	0.107	0.1005	0.1514	1.41	0.104	3.417
c17	0.479	2.498	0.0885	0.107	0.1998	0.1894	1.77	0.203	1.651
c18	0.479	2.498	0.0885	0.107	0.3	0.2192	2.05	0.300	0.018
c19	0.479	2.498	0.0885	0.107	0.398	0.2451	2.29	0.397	-0.275
c20	0.735	2.242	0.0885	0.1069	0.0807	0.1304	1.22	0.086	6.175
c21	0.735	2.242	0.0885	0.1069	0.1201	0.1488	1.39	0.125	3.759
c22	0.735	2.242	0.0885	0.1069	0.2004	0.1783	1.67	0.203	1.169
c23	0.735	2.242	0.0885	0.1069	0.3	0.2089	1.95	0.302	0.565
c24	0.735	2.242	0.0885	0.1069	0.3988	0.235	2.20	0.399	0.139
c25	1.197	1.78	0.089	0.1069	0.1503	0.142	1.33	0.156	3.539
c26	1.197	1.78	0.089	0.1069	0.2001	0.1594	1.49	0.203	1.388
c27	1.197	1.78	0.089	0.1069	0.2995	0.1897	1.77	0.300	0.152
c28	1.197	1.78	0.089	0.1069	0.3994	0.2165	2.03	0.400	0.210

APPENDIX C7:
THIN PLATE WEIR WITHOUT DIVIDING WALLS
STELLENBOSCH TESTS - FIRST SERIES
ANALYSIS USING IMPROVED DISCHARGE COEFFICIENT

i.e Cd = 0.607 + 0.042 He/Pe

OBSERVED VALUES							CALCULATED VALUES		
Test Nr	L1 (m)	L2 (m)	P (m)	T (m)	Qm (m^3/s)	h1 (m)	He/Pe	Cd1	% Fout
S01	1.177	1.759	0.040	0.050	0.050	0.068	0.5609494	0.6305015	-2.800
S02	1.177	1.759	0.040	0.050	0.200	0.124	1.4619559	0.6682501	-3.240
S03	1.177	1.759	0.040	0.050	0.298	0.151	1.9415076	0.6883414	1.452
S04	1.177	1.759	0.091	0.050	0.049	0.069	0.3272655	0.6207111	-1.288
S05	1.177	1.759	0.091	0.050	0.200	0.131	0.873236	0.6435851	-2.321
S06	1.177	1.759	0.091	0.050	0.394	0.186	1.3930769	0.6653644	2.066
S10	1.177	1.759	0.193	0.050	0.201	0.136	0.485154	0.627326	-1.906
S11	1.177	1.759	0.193	0.050	0.299	0.167	0.6[illegible]27	0.6340332	-1.574
S12	1.177	1.759	0.193	0.050	0.402	0.196	0.7727299	0.639766	-0.589
S13	1.174	1.761	0.193	0.100	0.100	0.121	0.2435311	0.6181482	1.099
S14	1.174	1.761	0.193	0.100	0.200	0.164	0.4185138	0.6252963	0.724
S15	1.174	1.761	0.193	0.100	0.399	0.222	0.6607852	0.6351931	-2.693
S16	1.174	1.761	0.290	0.103	0.200	0.167	0.3023199	0.6205498	1.007
S17	1.174	1.761	0.290	0.103	0.302	0.200	0.3990696	0.624502	-1.228
S18	1.174	1.761	0.290	0.103	0.400	0.229	0.485066	0.6280149	-0.977
S19	0.740	2.192	0.050	0.050	0.051	0.078	0.4753686	0.6276188	-1.208
S20	0.740	2.192	0.050	0.050	0.201	0.137	1.2183294	0.6579688	-0.068
S21	0.740	2.192	0.050	0.050	0.297	0.163	1.571021	0.6723762	0.606
S22H	0.739	2.196	0.101	0.050	0.050	0.077	0.2890604	0.6200081	-5.199
S23H	0.739	2.196	0.101	0.050	0.200	0.141	0.7772044	0.6399488	-0.712
S24H	0.739	2.196	0.101	0.050	0.400	0.195	1.2148769	0.6578277	-1.119
S25	0.738	2.190	0.100	0.100	0.100	0.139	0.3737139	0.6234662	3.663
S26	0.738	2.190	0.100	0.100	0.200	0.179	0.6142991	0.6332941	1.890
S27	0.738	2.190	0.100	0.100	0.399	0.235	0.9642128	0.6475881	-0.585
S28	0.736	2.197	0.099	0.199	0.202	0.246	0.3998051	0.624532	5.026
S29	0.736	2.197	0.099	0.199	0.301	0.279	0.539392	0.6302342	1.453
S30	0.736	2.197	0.099	0.199	0.400	0.308	0.6641367	0.63533	0.772
S31	0.736	2.202	0.205	0.051	0.098	0.105	0.2769503	0.6195134	-0.441
S32	0.736	2.202	0.205	0.051	0.200	0.146	0.4510308	0.6266246	0.218
S33	0.736	2.202	0.205	0.051	0.399	0.205	0.7085485	0.6371442	-0.288
S34	0.740	2.196	0.205	0.100	0.101	0.140	0.2349565	0.617798	2.792
S35	0.740	2.196	0.205	0.100	0.199	0.181	0.3853949	0.6239434	1.764
S36	0.740	2.196	0.205	0.100	0.399	0.240	0.6069354	0.6329933	-1.483
S37	0.740	2.196	0.206	0.201	0.197	0.245	0.2690393	0.6191903	3.500
S38	0.740	2.196	0.206	0.201	0.301	0.282	0.3759098	0.6235559	0.911
S39	0.740	2.196	0.206	0.201	0.398	0.312	0.4635918	0.6271377	0.637
S40	0.740	2.196	0.306	0.101	0.202	0.184	0.2869899	0.6199235	1.868
S41	0.740	2.196	0.306	0.101	0.302	0.217	0.3759672	0.6235583	0.505
S42	0.740	2.196	0.306	0.101	0.099	0.139	0.1670938	0.6150258	0.769
S46	0.496	2.433	0.048	0.049	0.101	0.106	0.7644859	0.6394292	-0.815
S47	0.496	2.433	0.048	0.049	0.201	0.143	1.2327124	0.6585563	3.502
S48	0.496	2.433	0.048	0.049	0.301	0.169	1.5806729	0.6727705	2.126
S49	0.495	2.438	0.101	0.050	0.047	0.082	0.2864512	0.6199015	0.974
S50	0.495	2.438	0.101	0.050	0.202	0.146	0.7596802	0.6392329	-1.268
S51	0.495	2.438	0.101	0.050	0.398	0.202	1.1993313	0.6571927	1.551
S52	0.495	2.437	0.101	0.101	0.101	0.147	0.3458434	0.6223277	-3.711
S53	0.495	2.437	0.101	0.101	0.201	0.189	0.5836001	0.6320401	0.635
S54	0.495	2.437	0.101	0.101	0.399	0.246	0.9184251	0.6457177	-0.184
S55	0.494	2.446	0.099	0.201	0.200	0.265	0.3740347	0.6234793	0.680
S56	0.494	2.446	0.099	0.201	0.300	0.300	0.51143	0.6290919	0.736
S57	0.494	2.466	0.099	0.201	0.400	0.328	0.6216009	0.6335924	-0.212
S58	0.494	2.438	0.200	0.049	0.101	0.110	0.290319	0.6200595	0.591
S59	0.494	2.438	0.200	0.049	0.200	0.150	0.4621469	0.6270787	1.727
S60	0.494	2.438	0.200	0.049	0.399	0.209	0.7227319	0.6377236	0.841
S61	0.492	2.438	0.200	0.100	0.050	0.120	0.1304175	0.6135276	-0.504
S62	0.492	2.438	0.200	0.100	0.202	0.191	0.3862727	0.6239792	0.604
S63	0.492	2.438	0.200	0.100	0.399	0.251	0.6088542	0.6330717	-0.066
S64	0.495	2.434	0.199	0.201	0.199	0.267	0.276201	0.6194828	2.092
S65	0.495	2.434	0.199	0.201	0.300	0.304	0.3802665	0.6237339	2.503
S66	0.495	2.434	0.199	0.201	0.399	0.333	0.4627643	0.6271039	1.121

Average Error	0.2654177
Std deviation	1.8611728

APPENDIX C8:
CRUMP WEIR WITHOUT DIVIDING WALLS
DWAF AND STELLENBOSCH TESTS
ANALYSES USING IMPROVED DISCHARGE COEFFICIENT

e.i. Cd = 1.09 − 0.083 He/Pe

OBSERVED VALUES							CALCULATED VALUES		
Test Nr	L1(m)	L2(m)	P(m)	T(m)	Qm (m^3/s)	h1 (m)	He/Pe	Cd1	% Error
WMOD1-1s	1.597	2.416	0.269	0.097	0.02	0.0359	0.124	1.0792043	1.95
WMOD1-1s	1.597	2.416	0.269	0.097	0.05	0.0644	0.209	1.1216885	-1.27
WMOD1-1s	1.597	2.416	0.269	0.097	0.08	0.0877	0.273	1.1280828	-1.37
WMOD1-1s	1.597	2.416	0.269	0.097	0.12	0.1111	0.162	1.1064933	-0.28
WMOD1-1s	1.597	2.416	0.269	0.097	0.15	0.1222	0.196	1.1194667	-1.18
WMOD1-1s	1.597	2.416	0.269	0.097	0.177	0.1309	0.223	1.1319648	-2.07
WMOD1-2s	1.597	2.416	0.176	0.097	0.02	0.0356	0.180	1.0921338	1.18
WMOD1-2s	1.597	2.416	0.176	0.097	0.05	0.0643	0.300	1.122474	-0.67
WMOD1-2s	1.597	2.416	0.176	0.097	0.08	0.0877	0.385	1.1253745	-0.31
WMOD1-2s	1.597	2.416	0.176	0.097	0.12	0.111	0.227	1.1029493	0.53
WMOD1-2s	1.597	2.416	0.176	0.097	0.15	0.1225	0.277	1.1058339	0.65
WMOD1-2s	1.597	2.416	0.176	0.097	0.177	0.1311	0.315	1.1191543	-0.27
WMOD1-3s	1.597	2.416	0.085	0.097	0.02	0.0348	0.329	1.1270229	-0.86
WMOD1-3s	1.597	2.416	0.085	0.097	0.05	0.0642	0.522	1.1189651	1.29
WMOD1-3s	1.597	2.416	0.085	0.097	0.08	0.0873	0.640	1.1250852	1.60
WMOD1-3s	1.597	2.416	0.085	0.097	0.12	0.1091	0.362	1.1298178	-0.86
WMOD1-3s	1.597	2.416	0.085	0.097	0.15	0.1207	0.447	1.1236397	0.31
WMOD1-3s	1.597	2.416	0.085	0.097	0.177	0.129	0.508	1.1376875	-0.49
WMOD2-3s	1.23	2.792	0.089	0.098	0.02	0.0435	0.366	1.0480672	6.90
WMOD2-3s	1.23	2.792	0.089	0.098	0.05	0.0761	0.539	1.1289927	0.51
WMOD2-3s	1.23	2.792	0.089	0.098	0.08	0.1032	0.228	1.1075849	0.12
WMOD2-3s	1.23	2.792	0.089	0.098	0.12	0.1216	0.348	1.1042294	1.33
WMOD2-3s	1.23	2.792	0.089	0.098	0.15	0.1314	0.413	1.1301162	-0.51
WMOD2-3s	1.23	2.792	0.089	0.098	0.177	0.1388	0.463	1.1592029	-2.66
WMOD2-2s	1.23	2.792	0.173	0.098	0.02	0.0438	0.215	1.0392587	6.60
WMOD2-2s	1.23	2.792	0.173	0.098	0.05	0.0767	0.340	1.1195056	-0.12
WMOD2-2s	1.23	2.792	0.173	0.098	0.08	0.1044	0.152	1.0861942	1.51
WMOD2-2s	1.23	2.792	0.173	0.098	0.12	0.1232	0.231	1.080473	2.66
WMOD2-2s	1.23	2.792	0.173	0.098	0.15	0.133	0.273	1.1116164	0.09
WMOD2-2s	1.23	2.792	0.173	0.098	0.177	0.1409	0.307	1.1345793	-1.69
WMOD2-1s	1.23	2.792	0.268	0.098	0.02	0.0433	0.145	1.057943	4.17
WMOD2-1s	1.23	2.792	0.268	0.098	0.05	0.0764	0.238	1.1275344	-1.58
WMOD2-1s	1.23	2.792	0.268	0.098	0.08	0.1037	0.107	1.1061036	-0.66
WMOD2-1s	1.23	2.792	0.268	0.098	0.12	0.1222	0.162	1.1088309	-0.48
WMOD2-1s	1.23	2.792	0.268	0.098	0.15	0.1337	0.197	1.1042293	0.19
WMOD2-1s	1.23	2.792	0.268	0.098	0.177	0.1405	0.217	1.1512888	-3.76
WMOD3-1s	0.999	3.005	0.268	0.098	0.02	0.0471	0.155	1.1483021	3.95
WMOD3-1s	0.999	3.005	0.268	0.098	0.05	0.0886	0.265	1.111878	0.01
WMOD3-1s	0.999	3.005	0.268	0.098	0.08	0.1132	0.117	1.0699916	2.77
WMOD3-1s	0.999	3.005	0.268	0.098	0.12	0.1297	0.165	1.098786	0.45
WMOD3-1s	0.999	3.005	0.268	0.098	0.15	0.14	0.196	1.1152733	-0.81
WMOD3-1s	0.999	3.005	0.268	0.098	0.177	0.149	0.223	1.1156216	-0.64
WMOD3-2s	0.999	3.005	0.185	0.098	0.02	0.0478	0.217	1.1227584	-1.32
WMOD3-2s	0.999	3.005	0.185	0.098	0.05	0.0882	0.352	1.1185621	0.06
WMOD3-2s	0.999	3.005	0.185	0.098	0.08	0.1131	0.154	1.0698727	3.08
WMOD3-2s	0.999	3.005	0.185	0.098	0.12	0.1295	0.218	1.0989429	0.84
WMOD3-2s	0.999	3.005	0.185	0.098	0.15	0.14	0.260	1.1094879	0.19
WMOD3-2s	0.999	3.005	0.185	0.098	0.177	0.1486	0.294	1.1166424	-0.20
WMOD3-3s	0.999	3.005	0.103	0.098	0.02	0.047	0.340	1.1503502	-2.79
WMOD3-3s	0.999	3.005	0.103	0.098	0.05	0.0881	0.522	1.1181919	1.36
WMOD3-3s	0.999	3.005	0.103	0.098	0.08	0.1124	0.223	1.0820218	2.45
WMOD3-3s	0.999	3.005	0.103	0.098	0.12	0.1286	0.317	1.1102067	0.55
WMOD3-3s	0.999	3.005	0.103	0.098	0.15	0.1386	0.376	1.1273122	-0.54
WMOD3-3s	0.999	3.005	0.103	0.098	0.177	0.1475	0.428	1.1238829	0.15
WMOD4-2s	0.804	3.2	0.183	0.098	0.005	0.0219	0.109	1.1253605	-2.34
WMOD4-2s	0.804	3.2	0.183	0.098	0.01	0.0354	0.168	1.0949781	0.82
WMOD4-2s	0.804	3.2	0.183	0.098	0.015	0.0452	0.206	1.1382195	-2.73
WMOD4-2s	0.804	3.2	0.183	0.098	0.02	0.0554	0.244	1.1182276	-0.71
WMOD4-2s	0.804	3.2	0.183	0.098	0.05	0.1018	0.090	1.0886252	0.81
WMOD4-2s	0.804	3.2	0.183	0.098	0.08	0.1196	0.159	1.0736457	2.75
WMOD4-2s	0.804	3.2	0.183	0.098	0.12	0.1356	0.221	1.0968082	1.05
WMOD4-2s	0.804	3.2	0.183	0.098	0.15	0.1454	0.259	1.1182592	-0.60
WMOD4-2s	0.804	3.2	0.183	0.098	0.177	0.153	0.289	1.1427369	-2.51
WMOD4-3s	0.804	3.2	0.103	0.098	0.01	0.035	0.267	1.1132971	-0.10
WMOD4-3s	0.804	3.2	0.103	0.098	0.02	0.0551	0.375	1.1264581	-0.47

OBSERVED VALUES							CALCULATED VALUES		
Test Nr	L1(m)	L2(m)	P(m)	T(m)	Qm (m^3/s)	h1 (m)	He/Pe	Cd1	% Error
WMOD4-3s	0.804	3.2	0.103	0.098	0.05	0.1023	0.133	1.0717134	2.74
WMOD4-3s	0.804	3.2	0.103	0.098	0.08	0.1205	0.235	1.0425812	6.42
WMOD4-3s	0.804	3.2	0.103	0.098	0.12	0.1354	0.320	1.091988	2.25
WMOD4-3s	0.804	3.2	0.103	0.098	0.15	0.1454	0.377	1.1062794	1.36
WMOD4-3s	0.804	3.2	0.103	0.098	0.172	0.1506	0.407	1.1470162	-2.03
WMOD5-2s	0.672	3.332	0.183	0.099	0.005	0.0247	0.121	1.1241051	-2.14
WMOD5-2s	0.672	3.332	0.183	0.099	0.01	0.0409	0.188	1.0549386	4.81
WMOD5-2s	0.672	3.332	0.183	0.099	0.015	0.052	0.230	1.1036752	0.49
WMOD5-2s	0.672	3.332	0.183	0.099	0.02	0.0633	0.269	1.095511	1.53
WMOD5-2s	0.672	3.332	0.183	0.099	0.05	0.1086	0.099	1.0753022	2.13
WMOD5-2s	0.672	3.332	0.183	0.099	0.08	0.1246	0.160	1.0789101	2.26
WMOD5-2s	0.672	3.332	0.183	0.099	0.12	0.1397	0.218	1.1153195	-0.65
WMOD5-2s	0.672	3.332	0.183	0.099	0.15	0.1503	0.259	1.1145651	-0.28
WMOD5-2s	0.672	3.332	0.183	0.099	0.177	0.1567	0.283	1.1633024	-4.28
WMOD5-3s	0.672	3.332	0.093	0.099	0.005	0.0249	0.219	1.1103092	-0.19
WMOD5-3s	0.672	3.332	0.093	0.099	0.01	0.0396	0.315	1.1067944	0.84
WMOD5-3s	0.672	3.332	0.093	0.099	0.015	0.0519	0.381	1.1061301	1.40
WMOD5-3s	0.672	3.332	0.093	0.099	0.02	0.0628	0.433	1.1077215	1.64
WMOD5-3s	0.672	3.332	0.093	0.099	0.05	0.1084	0.150	1.0779693	2.27
WMOD5-3s	0.672	3.332	0.093	0.099	0.08	0.1241	0.241	1.0863194	2.18
WMOD5-3s	0.672	3.332	0.093	0.099	0.12	0.1396	0.332	1.1066524	0.98
WMOD5-3s	0.672	3.332	0.093	0.099	0.15	0.1497	0.391	1.1141406	0.75
WMOD5-3s	0.672	3.332	0.093	0.099	0.174	0.1559	0.428	1.1448706	-1.69
WMOD6-3s	0.67	3.332	0.121	0.071	0.01	0.0388	0.253	1.1448997	-2.96
WMOD6-3s	0.67	3.332	0.121	0.071	0.02	0.0622	0.360	1.1275963	-0.68
WMOD6-3s	0.67	3.332	0.121	0.071	0.05	0.0898	0.171	1.0935876	0.97
WMOD6-3s	0.67	3.332	0.121	0.071	0.08	0.1037	0.250	1.100779	0.91
WMOD6-3s	0.67	3.332	0.121	0.071	0.12	0.118	0.332	1.1293687	-1.05
WMOD6-3s	0.67	3.332	0.121	0.071	0.15	0.1279	0.389	1.1313702	-0.81
WMOD6-3s	0.67	3.332	0.121	0.071	0.177	0.134	0.424	1.180151	-4.66
WMOD6-2s	0.67	3.332	0.211	0.071	0.01	0.0397	0.163	1.1065	-0.27
WMOD6-2s	0.67	3.332	0.211	0.071	0.02	0.0615	0.235	1.1475199	-3.32
WMOD6-2s	0.67	3.332	0.211	0.071	0.05	0.0896	0.113	1.1059848	-0.60
WMOD6-2s	0.67	3.332	0.211	0.071	0.08	0.1036	0.166	1.1111681	-0.67
WMOD6-2s	0.67	3.332	0.211	0.071	0.12	0.1184	0.221	1.1293908	-1.86
WMOD6-2s	0.67	3.332	0.211	0.071	0.15	0.1285	0.259	1.1304866	-1.68
WMOD6-2s	0.67	3.332	0.211	0.071	0.175	0.135	0.284	1.1596159	-3.97
C1	1.197	1.78	0.1711	0.1069	0.04904	0.0782	0.360	1.0936327	2.40
C2	1.197	1.78	0.1711	0.1069	0.0719	0.0985	0.430	1.132276	-0.58
C3	1.197	1.78	0.1711	0.1069	0.1206	0.1305	0.288	1.1059513	0.72
C4	1.197	1.78	0.1711	0.1069	0.15	0.1431	0.343	1.117304	0.10
C5	1.197	1.78	0.1711	0.1069	0.1998	0.1629	0.431	1.1124217	1.20
C6	1.197	1.78	0.1711	0.1069	0.3	0.1944	0.572	1.1341847	0.29
C7	1.197	1.78	0.1711	0.1069	0.3988	0.2208	0.693	1.1505267	-0.26
C8	0.735	2.242	0.1711	0.1061	0.1504	0.1618	0.331	1.1183634	-0.08
C9	0.735	2.242	0.1711	0.1061	0.201	0.181	0.411	1.1188136	0.47
C10	0.735	2.242	0.1711	0.1061	0.3006	0.2127	0.544	1.128974	0.55
C11	0.735	2.242	0.1711	0.1061	0.3991	0.2394	0.658	1.1404334	0.37
C12	0.479	2.498	0.1711	0.107	0.1998	0.1918	0.398	1.120761	0.20
C13	0.479	2.498	0.171	0.107	0.2994	0.221	0.516	1.1603992	-2.38
C14	0.479	2.498	0.171	0.107	0.3971	0.2496	0.633	1.1433685	-0.07
C15	0.479	2.498	0.0885	0.1069	0.0698	0.1362	0.264	1.1015751	0.94
C16	0.479	2.498	0.0885	0.1069	0.1005	0.1514	0.352	1.1155447	0.33
C17	0.479	2.498	0.0885	0.1069	0.1998	0.1894	0.577	1.1376495	0.02
C18	0.479	2.498	0.0885	0.1069	0.3	0.2192	0.758	1.1574756	-0.40
C19	0.479	2.498	0.0885	0.1069	0.398	0.2451	0.918	1.1616194	0.39
C20	0.735	2.242	0.0885	0.1069	0.0807	0.1304	0.300	1.0880442	2.47
C21	0.735	2.242	0.0885	0.1069	0.1201	0.1488	0.414	1.1144674	0.88
C22	0.735	2.242	0.0885	0.1069	0.2004	0.1783	0.598	1.1444385	-0.42
C23	0.735	2.242	0.0885	0.1069	0.3	0.2089	0.795	1.1523087	0.32
C24	0.735	2.242	0.0885	0.1069	0.3988	0.235	0.966	1.1577884	1.07
C25	1.197	1.78	0.089	0.1069	0.1503	0.142	0.528	1.1176477	1.45
C26	1.197	1.78	0.089	0.1069	0.2001	0.1594	0.650	1.1420243	0.17
C27	1.197	1.78	0.089	0.1069	0.2995	0.1897	0.866	1.1570408	0.42
C28	1.197	1.78	0.089	0.1069	0.3994	0.2165	1.063	1.1569477	1.84
							Average error		0.17475
							Std deviation		1.93107

APPENDIX C9
THIN PLATE WEIRS WITHOUT DIVIDING WALLS
STELLENBOSCH TESTS - SECOND SERIES
SHALLOW AND IRREGULAR POOLS

TEST NR	CHANNEL CONFIG	P (m)	T (m)	L1 (m)	L2 (m)	OBSERVED VALUES		CALCULATED VALUES	
						Qm (m^3/s)	h1 (m)	Qw (m^3/s)	% Error
SC1	LMR	0.085	0.104	0.738	2.216	0.100	0.141	0.101	1.46
SC2	LMR	0.085	0.104	0.738	2.216	0.201	0.181	0.198	-1.65
SC3	LMR	0.085	0.104	0.738	2.216	0.301	0.213	0.295	-1.86
SC4	LMR	0.085	0.104	0.738	2.216	0.398	0.240	0.391	-1.68
SC5	LMR	0.016	0.103	0.738	2.216	0.100	0.138	0.098	-1.63
SC6	LMR	0.016	0.103	0.738	2.216	0.200	0.178	0.197	-1.42
SC7	LMR	0.016	0.103	0.738	2.216	0.301	0.209	0.296	-1.52
SC8	LMR	0.016	0.103	0.738	2.216	0.400	0.235	0.395	-1.35
SC9	LMR	0.000	0.105	0.738	2.216	0.050	0.110	0.051	1.79
SC10	LMR	0.000	0.105	0.738	2.216	0.100	0.140	0.101	0.58
SC11	LMR	0.000	0.105	0.738	2.216	0.200	0.178	0.195	-2.34
SC12	M	0.085	0.104	0.738	2.216	0.100	0.139	0.098	-1.52
SC13	M	0.085	0.104	0.738	2.216	0.199	0.180	0.199	-0.23
SC14	M	0.085	0.104	0.738	2.216	0.299	0.211	0.296	-0.99
SC15	M	0.085	0.104	0.738	2.216	0.398	0.237	0.392	-1.56
SC16	M	0.016	0.103	0.738	2.216	0.100	0.137	0.099	-1.19
SC17	M	0.016	0.103	0.738	2.216	0.200	0.176	0.200	-0.03
SC18	M	0.016	0.103	0.738	2.216	0.300	0.206	0.303	1.05
SC19	M	0.016	0.103	0.738	2.216	0.399	0.231	0.407	1.92
SC20	M	0.000	0.105	0.738	2.216	0.050	0.110	0.052	3.43
SC21	M	0.000	0.105	0.738	2.216	0.100	0.138	0.100	-0.34
SC22	M	0.000	0.105	0.738	2.216	0.200	0.175	0.197	-1.46
SC23	L	0.085	0.104	0.738	2.216	0.100	0.140	0.101	0.50
SC24	L	0.085	0.104	0.738	2.216	0.200	0.180	0.199	-0.73
SC25	L	0.085	0.104	0.738	2.216	0.300	0.211	0.296	-1.32
SC26	L	0.085	0.104	0.738	2.216	0.400	0.238	0.396	-1.07
SC27	L	0.016	0.103	0.738	2.216	0.100	0.137	0.099	-1.19
SC28	L	0.016	0.103	0.738	2.216	0.200	0.176	0.200	-0.03
SC29	L	0.016	0.103	0.738	2.216	0.301	0.206	0.303	0.71
SC30	L	0.016	0.103	0.738	2.216	0.399	0.230	0.402	0.80
SC31	L	0.000	0.105	0.738	2.216	0.050	0.113	0.056	11.09
SC32	L	0.000	0.105	0.738	2.216	0.100	0.140	0.104	3.99
SC33	L	0.000	0.105	0.738	2.216	0.200	0.176	0.200	0.11
SC34	NONE	0.016	0.103	0.738	2.216	0.100	0.136	0.099	-1.00
SC35	NONE	0.016	0.103	0.738	2.216	0.200	0.173	0.198	-0.78
SC36	NONE	0.016	0.103	0.738	2.216	0.301	0.200	0.296	-1.79
SC37	NONE	0.016	0.103	0.738	2.216	0.400	0.226	0.411	2.67
SC38	NONE	0.000	0.105	0.738	2.216	0.050	0.112	0.055	10.45
SC39	NONE	0.000	0.105	0.738	2.216	0.100	0.137	0.101	0.74
SC40	NONE	0.000	0.105	0.738	2.216	0.200	0.173	0.201	0.71