INTERNATIONAL STANDARD ISO 3847

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Liquid flow measurement in open channels by weirs and flumes — End-depth method for estimation of flow in rectangular channels with a free overfall

Mesure de débit des liquides dans les canaux découverts au moyen de déversoirs et de canaux jaugeurs — Méthode d'évaluation du débit par détermination de la profondeur en bout des chenaux rectangulaires à déversement dénoyé

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FOREWORD

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Draft International Standards adopted by the technical committees are circulated to the member bodies for approval before their acceptance as International Standards by the ISO Council.

International Standard ISO 3847 was developed by Technical Committee ISO/TC 113, *Measurement of liquid flow in open channels*, and was circulated to the member bodies in July 1975.

It has been approved by the member bodies of the following countries :

Austria	Italy	Sweden
Belgium	Japan	Switzerland
Canada	Netherlands	Turkey
Czechoslovakia	Norway	United Kingdom
France	Pakistan	U.S.A.
Germany	Romania	U.S.S.R.
India	South Africa, Rep. of	Yugoslavia

The member body of the following country expressed disapproval of the document on technical grounds :

Australia

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0 INTRODUCTION

Free overfall occurs in many hydraulic structures when the bottom of a flat channel is abruptly discontinued. Such an overfall forms a control section and offers an approximate means for the estimation of flow. The flow at the brink is curvilinear and therefore the depth at the drop or end is not equal to the critical depth as computed by the principle based on the parallel flow assumption. However, the ratio between the end depth and the critical depth (as in the case of the assumption of parallel flow) has a unique value for each condition of the nappe, namely confined and unconfined. Therefore, from the depth measured at the end, the flow may be estimated.

1 SCOPE AND FIELD OF APPLICATION

This International Standard specifies a method for the estimation of sub-critical flow of clear water in smooth, straight, rectangular prismatic open channels with a vertical drop and discharging freely. Using the measured depth at the end, the flow in rectangular channels (horizontal or sloping) with confined nappe and unconfined nappe may be estimated.

The advantages and disadvantages of this device and other types of weirs and flumes, as well as the relative accuracies of each of these devices, are given in the annex.

2 REFERENCE

ISO 772, *Liquid flow measurement in open channels — Vocabulary and symbols.*

3 DEFINITIONS

For the purposes of this International Standard, in addition to the definitions given in ISO 772, the following definitions apply :

3.1 confined nappe : The jet formed by the flow where the guide walls of the structure extend to at least six times the end depth at maximum flow beyond the crest (or edge) and where the nappe is sufficiently ventilated to ensure atmospheric pressure below the nappe (see figure 1).

3.2 unconfined nappe : The jet formed by the flow where the guide walls of the structure end at the crest (or edge) and permit free lateral expansion of flow and where the nappe is sufficiently ventilated to ensure atmospheric pressure below the nappe (see figure 2).

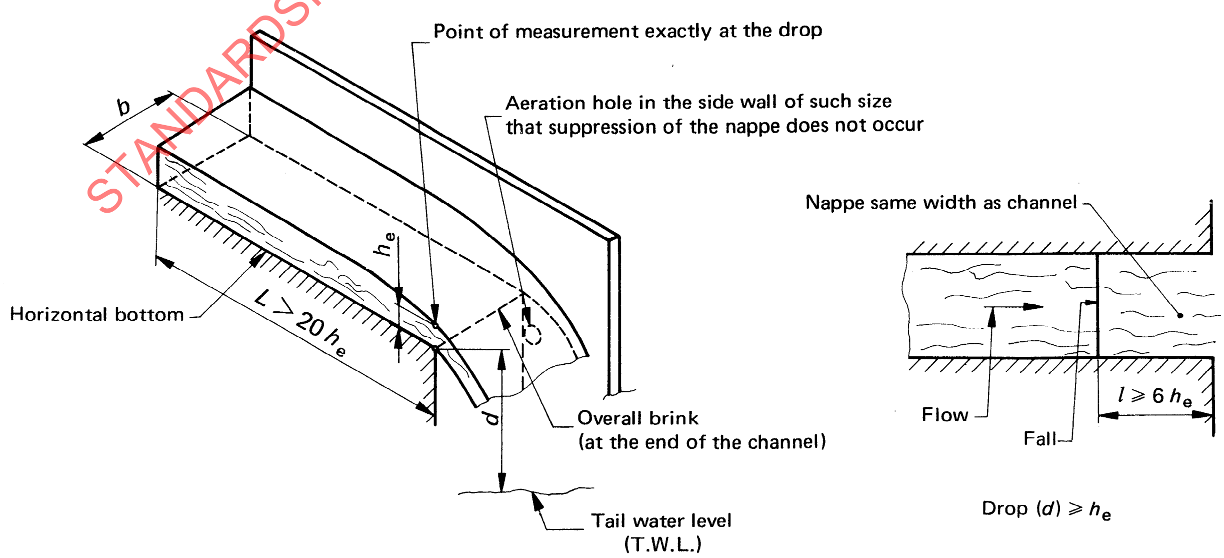

FIGURE 1 — **Confined nappe (nappe to be aerated)**

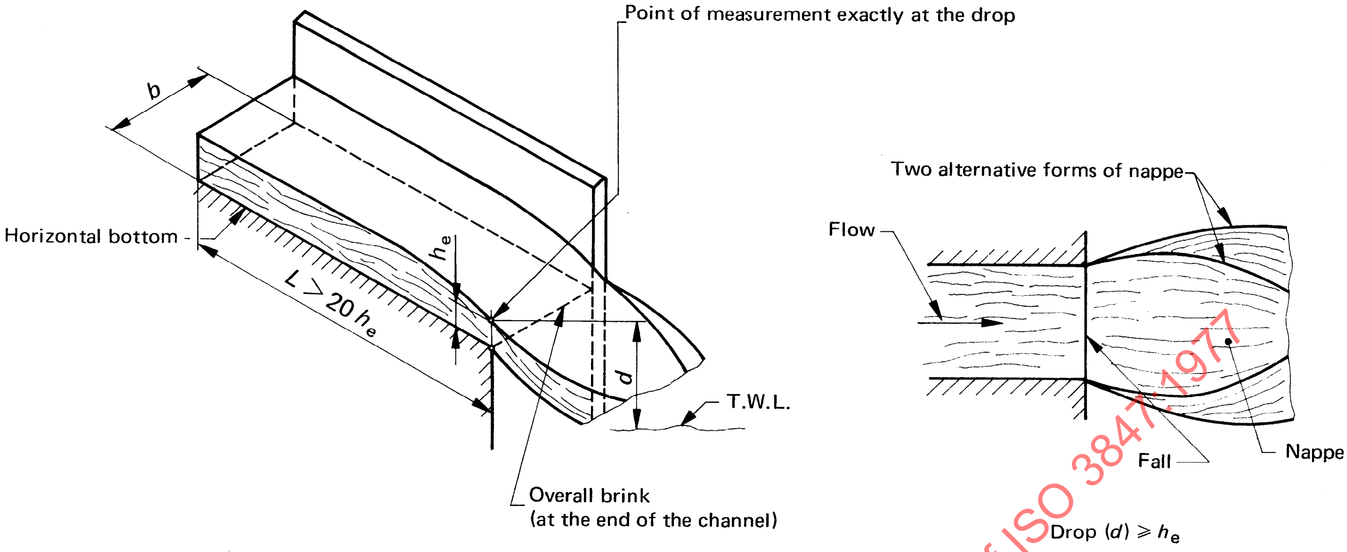

FIGURE 2 — **Unconfined nappe**

4 UNITS OF MEASUREMENT

The units of measurement used in this International Standard are seconds and metres.

5 SELECTION OF SITE

A preliminary survey shall be made of the physical and hydraulic features of the proposed site, to check that it conforms (or may be made to conform) to the requirements necessary for measurement by the end-depth method.

Particular attention shall be paid to the following features in selecting the site and ensuring the flow conditions :

a) an adequate straight length (at least 20 h_e, where h_e is the end depth corresponding to the maximum discharge anticipated) of channel of regular cross-section shall be available;

b) velocity distribution seen by inspection or measurement shall be practically uniform;

c) the flow shall be sub-critical and practically uniform upstream of the drop;

d) the side walls as well as the bottom shall be smooth as far as possible (in this specification a smooth surface shall correspond to a neat cement finish);

NOTE — The finish of the structure must be well maintained; changes in wall roughness due to various forms of deposition will change the discharge relationship.

e) the end of the channel shall be cut off normal to its centre line and the water shall be allowed to fall freely beyond this point;

f) in the case of confined nappe, the downstream side walls shall be extended to a distance not less than six times the maximum end depth; in the case of unconfined nappe, the side walls shall end at the drop;

g) the nappe shall be fully aerated.

6 MEASUREMENT OF DEPTH

The depth shall be measured exactly at the end (drop) of the channel with a point gauge or other suitable measuring device.

NOTE — The flow at the drop is fully curvilinear and any small error in the location of the gauge will result in large errors in the measurement of discharge.

7 GENERAL EQUATION FOR SUB-CRITICAL FLOW

7.1 General equation

The general equation for sub-critical flow is

$$Q = C\sqrt{g}\,b\,h_e^{3/2} \qquad \ldots (1)$$

where

Q is the discharge;

C is the non-dimensional coefficient of discharge;

g is the acceleration due to gravity;

b is the width of the channel;

h_e is the measured depth at the end of the channel.

7.2 Coefficient of discharge

7.2.1 *Confined nappe*

In principle, the discharge coefficient depends on the slope and the roughness of the channel. The coefficient for a horizontal channel is given by

$$C = 1{,}66$$

This value can also be used for sloping channels, but then its accuracy is less.

7.2.2 *Unconfined nappe*

In principle, the discharge coefficient depends on the slope and the roughness of the channel. The coefficient for a horizontal channel is given by

$$C = 1{,}69$$

This value can also be used for sloping channels, but then its accuracy is less.

7.3 Limitations

For the application of the method, the following limitations shall apply :

a) Drop (d). The drop d — the vertical distance from channel bottom to the downstream water surface — shall be greater than h_e.

b) Width of channel (b). The width shall be greater than 0,3 m.

c) End depth (h_e). The end depth shall be greater than 0,04 m.

7.4 Uncertainty of measurement

The overall uncertainty of flow measurement by this method depends on the uncertainty of the depth measurement, of the measurement of width of the channel and of the coefficient of discharge.

With reasonable care and skill in the construction and installation of the structure, the tolerance in the coefficient of discharge for a horizontal channel may be of the order of ± 2 %; for other slopes of the channel the tolerance is greater and can attain values up to ± 7 %.

The method by which the errors in the coefficient shall be combined with other sources of errors is given in clause 8.

In general, calibration experiments have been carried out on model structures of small dimensions and when transferred to larger structures there may be small changes in the discharge coefficients due to scale effect.

8 UNCERTAINTIES IN FLOW MEASUREMENT

8.1 General

8.1.1 The total uncertainty of any flow measurement can be estimated if the uncertainties from various sources are combined. In general, these contributions to the total uncertainty may be assessed and will indicate whether the discharge can be measured with sufficient accuracy for the purpose in hand. This clause is intended to provide sufficient information for the user of this International Standard to estimate the uncertainty in a measurement of discharge.

8.1.2 The error may be defined as the difference between the actual rate of flow and that calculated in accordance with the equation for the type of drop at a site selected in accordance with this International Standard. The term uncertainty will be used to denote the deviation from the true rate of flow within which the measurement is expected to lie some nineteen times out of twenty (the 95 % confidence limits).

The uncertainty shall be calculated according to the method in this clause and quoted under this reference term whenever a measurement is claimed to be in conformity with this International Standard.

8.2 Sources of error

8.2.1 The sources of error in the discharge measurement may be identified by considering a generalized form of discharge equation for weirs :

$$Q = C\sqrt{g}\, b\, h_e^{3/2}$$

g, the acceleration due to gravity, varies from place to place, but in general the variation is small enough to be neglected in flow measurement.

8.2.2 The only sources of error which need to be considered further are :

a) the discharge coefficient C (numerical estimates of uncertainties are given in clause 7);

b) the dimensional measurement of the structure, for example the width of the channel b;

c) the measured end depth h_e.

8.2.3 The uncertainty in b and h_e must be estimated by the user. The uncertainty in dimension will depend upon the accuracy to which the device as constructed can be measured; in practice this uncertainty may prove to be insignificant in comparison with other uncertainties. The uncertainty in the end depth will depend upon the accuracy of the depth-measuring device, the determination of the gauge zero, the precise location of the instrument and upon the technique used. This uncertainty may be small if a vernier or micrometer instrument is used with a zero determination of comparable comparison.

8.3 Kinds of error

8.3.1 Errors may be classified as random or systematic, the former affecting the reproducibility (precision) of measurement and the latter affecting its true accuracy.

8.3.2 The standard deviation of a set of measurements under steady conditions may be estimated from the equation :

$$S_y = \left[\frac{\sum_{i=1}^{n} (y_i - \bar{y})}{n-1} \right]^{1/2}$$

where $\bar{y}$ is the arithmetic mean of n measurements.

The standard deviation of the mean is then given by :

$$S_{\bar{y}} = \frac{S_y}{\sqrt{n}}$$

and the uncertainty of the mean is twice $S_{\bar{y}}$ (for 95 % probability)[1]. This uncertainty is the contribution of random errors in any series of experimental measurements to the total uncertainty.

8.3.3 A measurement may also be subject to systematic error; the mean of very many measured values would thus still differ from the true value of the quantity being measured. An error in setting the zero of a water level gauge to channel bottom, for example, produces a systematic difference between the true mean measured depth and the actual value. As repetition of the measurement does not eliminate systematic errors, the actual value could only be determined by an idependent measurement known to be more accurate.

8.4 Uncertainties in coefficient values

8.4.1 All errors in this category are systematic.

8.4.2 The value of the discharge coefficient C quoted in this International Standard is based on an appraisal of experiments, which may be presumed to have been carefully carried out, with sufficient repetition of the readings to ensure adequate precision. However, when measurements are made on other similar installations, systematic discrepancies between coefficients of discharge may well occur, which may be attributed to variations in the surface finish, the approach conditions, the scale effect between model and site structures, etc.

8.4.3 The uncertainty in the coefficients quoted in the preceding clauses of this International Standard are based on a consideration of the deviation of experimental data from various sources from the equations given. The suggested uncertainties thus represent the accumulation of evidence and experience available.

8.5 Uncertainties in measurements made by the user

8.5.1 Both random and systematic errors will occur in measurements made by the user.

8.5.2 Since neither the methods of measurement nor the way in which they are to be made are specified, no numerical values for uncertainties in this category can be given; they must be estimated by the user. For example, consideration of the method of measuring the channel width should permit the user to determine the uncertainty in this quantity.

8.5.3 The uncertainty of the gauged depth shall be determined from an assessment of the individual sources of error, for example the zero error, the gauge sensitivity, backlash in the indication mechanism, the residual random uncertainty in the mean of a series of measurements, etc. The uncertainty on the gauge depth is the square root of the sum of the squares of the individual uncertainties.

8.6 Combination of uncertainties to give overall uncertainty on discharge

8.6.1 The total uncertainty is the resultant of several contributory uncertainties, which may themselves be composite uncertainties (see 8.5.3).

When partial uncertainties, the combination of which gives the total uncertainty, are independent of one another, are small and numerous, and have a Gaussian distribution, there is a probability of 0,95 that the true error is less than the total uncertainty.

8.6.2 The uncertainty on the rate of flow shall be calculated from the following equation.

$$X = \pm \sqrt{\left(X_C^2 + X_b^2 + 1{,}5^2 \, X_{h_e}^2 \right)}$$

where

X_C is the percentage uncertainty in C;

X_b is the percentage uncertainty in b;

X_{h_e} is the percentage uncertainty in h_e.

In the above,

$$X_b = \pm\, 100 \times \frac{\epsilon_b}{b}$$

and

$$X_{h_e} = \pm \frac{100 \left({}_1\epsilon_{h_e}^2 + {}_2\epsilon_{h_e}^2 + \ldots + 4\, S_{\bar{h}_e}^2 \right)^{1/2}}{\bar{h}_e}$$

where

ϵ_b is the uncertainty in width measurement;

1) The factor of two assumes that n is large. For $n = 6$ the factor should be 2,6; $n = 8$ requires 2,4; $n = 10$ requires 2,3; $n = 15$ requires 2,1.

$_1\epsilon_{h_e}$, $_2\epsilon_{h_e}$, etc. are uncertainties in depth measurement (see 8.5.3);

$2\,S_{\overline{h_e}}$ is the uncertainty of the mean if a series of readings of the end depth measurement are taken (see 8.3.2, including foot-note).

8.6.3 It should be realized that the uncertainty X is not single-valued for a given device, but will vary with discharge. It may, therefore, be necessary to consider the uncertainty at several discharges covering the required range of measurement.

8.6.4 *Example*

The following is an example of the application of the formula to a single determination of discharge using the end-depth method under sub-critical flow in the channel. The width of the channel is 1,0 m and the uncertainty in width may be taken as ± 1 mm. The depth at the end section is 0,1 m and the uncertainty in depth measurement may be taken as ± 3 mm.

Then :

percentage uncertainty in depth measurement

$$X_{h_e} = \pm\, 100 \times \frac{0{,}003}{0{,}1}$$

$$= \pm\, 3\ \%$$

percentage uncertainty in width

$$X_b = \pm\, 100 \times \frac{0{,}001}{1}$$

$$= \pm\, 0{,}1\ \%$$

percentage uncertainty in the coefficient

$$X_C = \pm\, 4{,}5\ \%\ \text{(assumed)}$$

Therefore, the total uncertainty in Q is

$$X = \pm\left[4{,}5^2 + 0{,}1^2 + (1{,}5^2 \times 3^2)\right]^{1/2}$$

$$= \pm\, 6{,}4\ \%$$

ANNEX

GUIDE FOR THE SELECTION OF WEIRS AND FLUMES FOR THE MEASUREMENT OF THE DISCHARGE OF WATER IN OPEN CHANNELS

A.1 PURPOSE

The purpose of this annex is to provide guidelines for the selection of weirs and flumes for the measurement of discharge in open channels. Consideration is limited to the steady, uniform flow of water at ordinary temperatures (approximately 5 to 30 °C).

Despite the great number of types of weirs and flumes available, some of which may offer advantage for specific purposes, only the following types are presently standardized. Criteria for selection from among the standard types are given in clause A.3.

A.2 TYPES OF STANDARD WEIRS AND FLUMES

A.2.1 Thin-plate weir

A weir constructed with a crest of vertical thin plate, shaped in such a manner that the nappe springs clear of the crest, the discharge being determined by the head on the weir and the width of the crest (or the angle of the notch).

The following types are included :

- rectangular full-width weir;
- rectangular-notch weir;
- triangular-notch (V-notch) weir.

A.2.2 Broad-crested weir

A weir with substantial crest dimension in the direction of flow formed in such a manner that critical flow occurs on the crest of the weir within the breadth, the discharge being determined by the head on the weir and the width of the crest.

The following types are included :

- rectangular-profile weir with sharp upstream edge;
- rectangular-profile weir with rounded upstream edge.

A.2.3 Triangular-profile weir

A weir having a triangular profile in the direction of flow, the discharge being determined by the head over the weir and the width of the crest.

The following type is included :

- triangular-profile weir having 1/2 slope upstream and 1/5 slope downstream.

A.2.4 Standing-wave flume (free flow)

A flume with side contractions with or without bottom contractions, within which the flow changes from sub-critical to super-critical, the discharge being determined by the cross-sectional area and velocity of flow at critical depth within the throat of the flume.

The following types are included :

- with rectangular throat;
- with trapezoidal throat;
- with U-throat.

A.2.5 Free overfall

An abrupt drop in the floor of a rectangular channel, the discharge being determined by the depth at the brink of the drop and the width of the channel at the brink section.

A.3 CRITERIA FOR SELECTION OF STANDARD WEIRS OR FLUMES

The essential criteria for selection from among the standard weirs and flumes are given below :

A.3.1 Available difference in water levels

Thin-plate weirs and free overfalls require a sufficient difference between upstream and downstream water levels which will ensure free, fully ventilated flow under conditions of maximum discharge.

Broad-crested weirs may be used with relatively smaller differences in water level; triangular-profile weirs and standing-wave flumes may be used with even smaller differences in water level.

For all types of weirs and flumes included in this International Standard the discharge should be free or independent of the downstream water level.

A.3.2 Accuracy of measurement

The accuracy in a single determination of discharge depends upon the estimation of the components uncertainties involved but approximate ranges of uncertainties for the weirs and flumes (at 95 % confidence levels) are as follows :

- rectangular thin-plate weirs (full-width and notch) : 1 to 4 %;

- triangular-notch weirs (notch angles between $\pi/9$ and $5\pi/9$ rad) : 1 to 2 %;
- broad-crested weirs : 3 to 5 %;
- triangular-profile weirs : 2 to 5 %;
- standing-wave flumes : 2 to 5 %;
- free overfall : 5 to 10 %.

Deviations from standard construction, installation or use may result in larger measurement errors. The larger figures given above are recommended conservative values for use under conditions of strict conformance with standard specifications. The smallest values can only be obtained for weirs under rigorous control, such as may be built and installed in well-equipped laboratories. Under field conditions, thin-plate weirs are specially subject to errors caused by natural hazards.

A.3.3 Dimensions and shape of open channel

Rectangular full-width weirs and notch weirs (both rectangular and triangular), of large size relative to the size of the approach channel, should be located in vertical-walled level-floored rectangular channels, or in weir boxes of rectangular cross-section for a distance extending upstream not less than 10 times the width of the nappe at maximum head. For thin-plate weirs of small size relative to the size of the approach channel, especially if the velocity of approach is negligible, the size and shape of the channel is of no importance.

Broad-crested weirs are best used in rectangular channels, but they can be used with good accuracy in non-rectangular channels if a smooth, rectangular approach channel extends upstream from the weir a distance not less than twice the maximum head.

Flumes can be used in channels of any shape if flow conditions in the approach channel are reasonably uniform and steady.

For weirs and flumes of all types the size and shape of the downstream channel are of no significance except that they must permit free, fully ventilated flow under all conditions of use.

A.3.4 Flow conditions in the approach channel

For weirs of all types, flow in the approach channel shall be sub-critical, uniform and steady. Ideally, especially for relatively high velocities of approach, the velocity distribution should approximate that in a channel of sufficient length to develop normal (resistance-controlled) flow in straight, smooth channels. For relatively low velocities of approach and for flumes, flow conditions in the channel are of less importance. In short channels and weir boxes, baffles and flow-straighteners may be used to simulate normal velocity distribution. Care should be taken to ensure that erosion and/or deposition upstream of the weir or flume do not significantly alter the velocity of approach or velocity distribution to the measurement structure.

Sub-critical flow is ensured when

$$\bar{v} < \sqrt{\frac{gA}{B_s}}$$

where

$\bar{v}$ is the average velocity, in metres per second in the approach channel;

g is the acceleration due to gravity, in metres per second squared;

A is the cross-sectional area in square metres of the channel;

B_s is the width of the channel, in metres, at the water surface.

A.3.5 Flow with sediment load

For flows with suspended load, the use of thin-plate weirs should be avoided because the crest edge may be damaged or worn by the suspended materials. On streams with bed load use of measurement structures which significantly reduce the stream velocity is not recommended as it may result in changing deposition-scour dependent on flow regime. Flumes will generally perform better than weirs on streams with sediment load.

A.3.6 Flow with floating debris

Broad-crested weirs, triangular-profile weirs, standing wave flumes and free overfall structures will normally pass floating debris more effectively than thin plate weirs. The use of the triangular-notch (V-notch) weir in particular should be avoided unless a debris trap is installed upstream.

A.3.7 Magnitude of discharge to be measured

For reasons related to accuracy and construction, thin-plate weirs are best used for the measurement of relatvely small discharges. Broad-crested weirs, triangular-profile weirs and flumes are best used for large discharges.

A.3.8 Range of dicharge to be measured

For best overall accuracy over a wide range of small discharges, a triangular-notch (V-notch) weir should be used in preference to a rectangular-notch or rectangular full-width weir. For wide range of larger discharges, a trapezoidal-throat or U-throat flumes should be used in preference to a broad-crested weir, free overfall, rectangular-throated flume or a triangular-profile weir.

A.3.9 Construction

Thin-plate weirs must be constructed with precision tools under machine-stop conditions. Flumes, broad-crested weirs, triangular-profile weirs and free overfalls can be constructed satisfactorily in the field. In all cases, great care must be exercised in making the structures conform with standard specifications.

Broad-crested weirs, triangular-profile weirs, free overfalls and flumes are inherently stronger and more easily maintained under conditions of high heads in large channels.