

**National Rivers Authority
River Flow Forecasting System**

IH Technical Note No. 17

**Flow over weirs using upstream and
downstream levels**

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Summary

The theory of flow over compound Crump and Flat-vee weirs under non-modular conditions is presented. This theory is employed to develop software for weir flow estimation using upstream and downstream (or crest) measurements of river level. Application of the software to 19 weirs in the Yorkshire Region is demonstrated for the flood of 26-29 August 1986. First, it is used to assess the severity of backwater effects at each site. Second, the software is used to explore the prospect of developing a single rating relation, based on upstream levels only, under non-modular flow conditions.

A set of Appendices provides details of the software, weir configuration data and a guide to how the software may be used.

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Notation

A	upstream cross-sectional area
b	width of crest
d	depth of upstream bed below minimum crest level
f	drowned flow reduction factor
f_l, f_u	lower and upper limits on f for Flat-V weir
g	acceleration due to gravity
h_1	upstream level relative to low point of crest
H_1	total head upstream (including k_h)
h_2	downstream level relative to low point of crest
H_2	total head downstream (including k_h)
h_{max}	maximum upstream level for in-structure flow
h_p	pressure head in separation pocket behind crest
k_h	head correction due to crest boundary layer
m	slope of channel/structure walls (1 vertical to m horizontal)
n	cross-slope of Flat-V weir crest (1 vertical to n horizontal)
P_v	depth of V in Flat-V weir crest ($=b/n$)
Q, Q_C, Q_V	flow over single weir crest, Crump and Flat-V respectively
Q_M, Q_{CM}, Q_{VM}	modular flow as above
V_A	velocity at upstream gauging position
α	Coriolis coefficient in total head calculation

1. Introduction

During flood events, gauging structures may become drowned because the flow backs up from a downstream restriction or confluence. Under such conditions the flow is said to be non-modular and an estimate of flow from a theoretical rating curve will be unreliable, tending to overpredict the actual flow. Improved estimates can be obtained, at least in part, by using observations of downstream levels in theoretical weir flow calculations. The issue is complicated by the fact that high flows may exceed the limits of the structure. A summary of the situation which may arise is given below:

	Flow in structure	Flow out-of-structure
Normal flow	Theoretical rating curve	Empirical rating curve
Backing up	Weir theory using downstream levels	Empirical rating curve, provided downstream controls are fixed or Weir theory and downstream levels, with approximations for out-of-structure flow

The weir flow software described in this report computes flow over compound Crump or Flat-V weirs using measurements of the upstream and downstream (or crest) levels, together with a description of the weir configuration. The theory is based entirely on the formulae and figures in Reference 1, and is summarised in Section 2. Application of the weir flow software is demonstrated in Section 3 where it is used to examine the importance of backwater effects within the Yorkshire Region for the event of 26 to 29 August 1986 using the weir flow.

A set of appendices provides details of the software and how it is used. The transfer of weir configuration data, levels and flows between the external data structure, the host routine, and the weir flow routines is accomplished by two interfaces (subroutine argument lists) described in Appendix A. Two host environments are considered. The test environment, described in Appendix B, interfaces to a weir configuration file, and provides an interactive user with flows computed from levels that may be typed in, or retrieved from a database. The RFFS (River Flow Forecasting System) calibration environment, described in Appendix C, interfaces to the IH database, and provides the model calibration routines with flow histories computed from upstream and downstream levels. This environment is structurally similar to the RFFS shell environment and will provide the basis from which integration into the operational RFFS system will be achieved by Logica. The weir flow software is not configured as an RFFS model algorithm.

The format of the weir configuration table is described in Appendix D along with a table of weir configuration data for Crump and Flat-V gauging stations in the

Yorkshire Region. The database organisation and format conversion procedure used at IH is described in Appendix E. Appendix F gives a list of program and data files associated with the weir flow routines.

Reference 1. Ackers, P., White, W.R., Perkins, J.A. & Harrison, A.J.M., 1978. Weirs and Flumes for Flow Measurement, Wiley, New York.

2. Weir Theory

The theoretical background for the calculations described here is contained in Reference 1, which should be consulted for an explanation of the basic fluid dynamics and dimensional analysis which lead to the equations presented below.

2.1 General

The purpose of a weir is to act as a control structure at which there exists a unique relationship between level and flow. This is achieved by allowing the flow just downstream of the weir crest to accelerate to a critical-flow condition. The general form of a relationship between flow and total head (relative to the minimum crest level) can then be obtained from Bernoulli's equation, although empirical calibration constants for a particular class of structure are required to account for streamline curvature and boundary-layer effects.

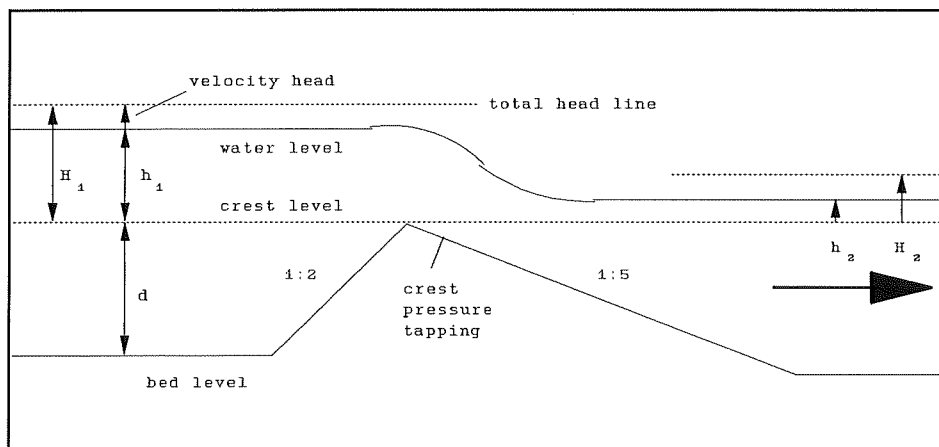


Figure 1 Alongstream section through low point of weir crest.

The theory described here applies to triangular-profile weirs for which the upstream slope is 1:2, the downstream slope is 1:5 and the crest is perpendicular to the flow (Figure 1). The crest may be either of uniform height (a Crump weir), or in the form of a symmetrical shallow V (the Flat-V weir). The relationship between flow and total head, H , for each of these weirs is given in sections 2.2 and 2.3, and will be denoted by $Q_C(H)$ and $Q_V(H)$ respectively.

Total head at a single-crested weir

The quantity actually measured at the weir is the upstream level, h_1 , relative to the minimum crest level (Figure 1). Assuming that the velocity V_A is uniform across an upstream cross-section of area A and that there are no losses, the total head at the crest is given by the Bernoulli equation, with a small correction, K_h , due to the crest boundary layer

$$H_1 = h_1 + \frac{V_a^2}{2g} - k_h = h_1 + \frac{Q^2}{2Ag} - k_h \quad (1)$$

where g is the acceleration due to gravity. The form of the equation for the flow Q means that this equation must be solved iteratively for a Flat-V weir and analytically for a Crump weir.

In practice, the velocity in the upstream channel is non-uniform, and an empirical coefficient, α , called the energy or Coriolis coefficient must be introduced, giving

$$H_1 = h_1 + \frac{\alpha Q^2}{2Ag} - k_h \quad (2)$$

An accurate value of α is important only for steep rivers, and a value of unity is likely to be acceptable in most cases.

Drowned flow

If the level downstream of the weir rises to such an extent that it interferes with or prevents the occurrence of critical flow over the crest then the weir is said to be drowned. If this tailwater level depends only on the flow rate (due to a downstream constriction such as a bridge) then there may still be a unique relationship between upstream level and flow, but its form must be determined by experiment. More usually, for example, when the river backs up from a downstream confluence, the flow depends on both upstream head H_1 and downstream head H_2 (Figure 1).

The tailwater level h_2 may be measured directly, taking care that it is adjusted to the same datum as h_1 , and the upstream velocity head applied to calculate H_2

$$H_2 = h_2 + H_1 - h_1 \quad (3)$$

The drowned, or non-modular, flow rate is then computed as the product of the undrowned, or modular, flow rate Q_M and a reduction factor f which is an empirical function of ratio of downstream to upstream heads, H_2/H_1 ; that is

$$Q = f(H_2/H_1)Q_M(H_1) \quad (4)$$

However, the downstream head is sensitive to the downstream geometry, energy losses over the weir, and inaccurate measurement in turbulent conditions. A more reliable quantity to measure is the pressure in the separation pocket just downstream of the crest (expressed as a head h_p relative to the minimum crest level). The

reduction factor is then given as a (different) empirical function of h_p/H_1 . Fouling of the crest tapping can be a significant problem with this method.

Equations for the reduction factor are given under the headings for each type of weir. For severe drowning ($f < 0.8$) the reduction factor can be very unreliable, due to its sensitivity to the accuracy of the level measurements and the details of the weir geometry (the crest tapping method is considerably superior to the downstream level method in this respect). Values of f less than 0.4 are not based on any experimental results, and are intended simply to provide reasonable behaviour at very high tailwater levels. The modular limit between undrowned (modular) and drowned (non-modular) flow is taken to be the ratio H_2/H_1 at which the reduction factor f equals 0.99.

Compound weirs

The flow over a compound weir is simply the sum of the flows over the individual crests, computed from their geometries and the total head relative to the low point of each crest. Alternative methods for calculating the total head at each crest are compared in Chapter 12 of Ref.[1], and the recommended procedure is used here.

It is assumed that the total head is constant across the upstream section, so that the total head relative to the n 'th crest is given by the total head at the first crest, H_1 , minus the step height from the first to the n 'th crest level.

$$H_1^{(n)} = H_1 - \delta^{(n)} . \quad (5)$$

The total head at the first crest is calculated as if the weir was single-crested, with an upstream width equal to the first crest width. Mixed crest geometries (Crump and Flat-V) are not explicitly allowed, but it may be noted that a Crump weir is equivalent to a very shallow Flat-V weir (say 1:100, as extremely small slopes may introduce rounding errors). The assumption of independent flow over the crests is obviously best if the crests are separated by piers, but the method may still be applied if piers are not present, although the computed flow will be less reliable.

It may be possible to improve flow estimates for out-of-structure levels by introducing extra, artificial, crests and side walls which approximate to the out-of-structure cross-section. Clearly this provides only a very crude approximation which, since critical flow is unlikely out-of-structure, will probably over-estimate the true flow.

2.2 Crump Weir

The Crump weir crest is defined by its width and its height above the upstream bed level (Figure 2). The channel walls are assumed vertical.

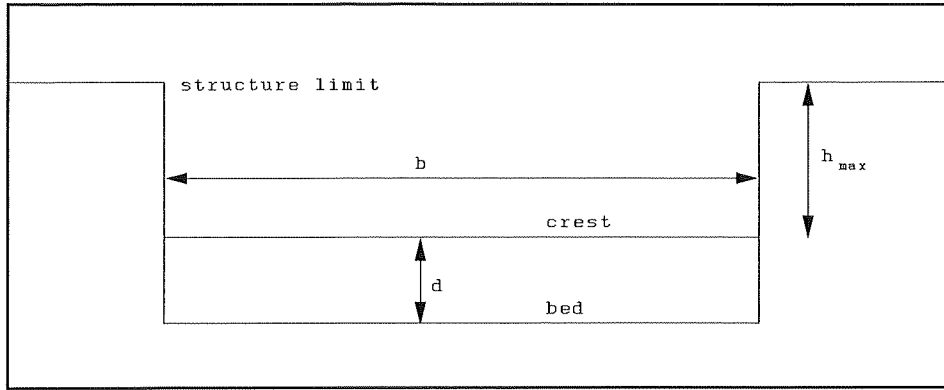


Figure 2 Cross-section of Crump weir crest

Modular flow

The area at the upstream cross-section is

$$A = b(h_1 + d) \quad (6)$$

where b is the crest width, h_1 is the water level above the crest and d is the depth of approach. The modular discharge equation for a Crump weir (Equation 4.1 in Ref.[1]) is

$$Q_{CM} = C_{de} b \sqrt{g} H_1^{3/2} \quad (7)$$

where the discharge coefficient, C_{de} , has a recommended value of 0.633. The head correction k_h is constant at 0.0003m, and is essentially negligible.

Drowned flow reduction factor

The reduction factor as a function of the crest pressure head h_p is given by (Equation 4.12 in Ref.[1])

$$f = \begin{cases} 1.04 \left[0.945 - \left(\frac{h_p}{H_1} \right)^{1.5} \right]^{0.256} & \frac{h_p}{H_1} < 0.946 \\ 7.4826 \left[1.0 - \frac{h_p}{H_1} \right] & \frac{h_p}{H_1} > 0.946 \end{cases} \quad (8)$$

As a function of the tailwater ratio H_2/H_1 the reduction factor is given by (Equations 4.13 and 4.14 in Ref.[1])

$$f = \begin{cases} 1.35 \left[0.817 - \left(\frac{H_2}{H_1} \right)^4 \right]^{0.0647} & \frac{H_2}{H_1} < 0.93 \\ 8.686 - 8.403 \left(\frac{H_2}{H_1} \right) & 0.93 < \frac{H_2}{H_1} < 0.986 \\ 28.571 \left(1.0 - \frac{H_2}{H_1} \right) & \frac{H_2}{H_1} > 0.986 \end{cases} \quad (9)$$

2.3 Flow over Flat-V Weirs

The flat-V weir crest is defined by its width, the height of the minimum crest level above the upstream bed, and the cross-slope (Figure 3). The channel walls may be sloping.

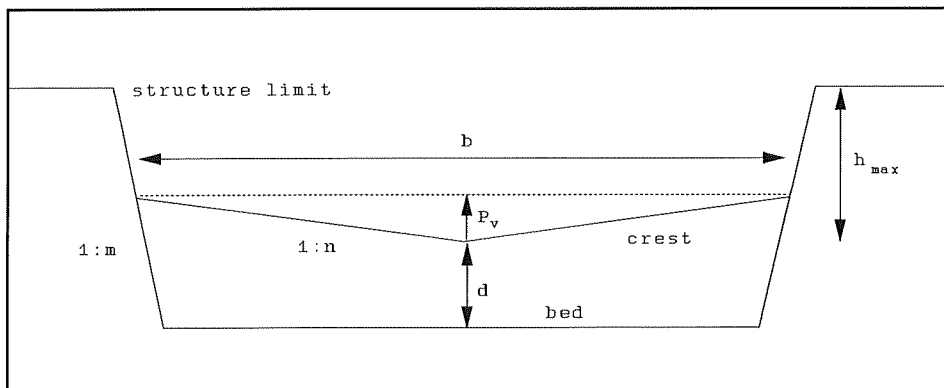


Figure 3 Cross-section of Flat-V weir crest

Modular flow

The area at the upstream cross-section is

$$A = b(h_1+d) - n(P_v+d)^2 + m(h_1-P_v)^2 \quad (10)$$

where b is the crest width, h_1 is the upstream water level above the crest, d is the depth of approach, P_v the depth of the vee, n the cross-slope of the vee and m is the slope of the section walls. For flow in the vee (Equation 5.21 in Ref.[1]) the discharge is

$$Q_{VM} = 0.8C_{de}\sqrt{g}nH_1^{5/2} \quad (11)$$

For flow out of the vee in a trapezoidal channel (Equation 5.24 in Ref.[1]) the discharge is

$$Q_{VM} = 0.8C_{de}\sqrt{g}n \left[H_1^{5/2} - \left(H_1 - \frac{b}{2m} \right)^{5/2} \right] \quad (12)$$

Ref.[1] recommends values of the discharge coefficient C_{de} between 0.615 and 0.630 according to the cross-slope n and the ratio H_1/P_v . For simplicity, a single value of discharge coefficient is used for all conditions, and a value of 0.620 is appropriate for the most common combination of crest cross-slope (1:10) and high flows ($H_1/P_v > 1.0$ or non-modular flow).

The head correction k_h is fixed at 0.0004m for cross-slopes $n > 30$, 0.0005m for $15 < n < 30$ or 0.0008m for $n < 15$ but is essentially negligible.

Drowned flow reduction factor

The reduction factor as a function of the crest pressure head h_p is given by equation (13). (equation 4.12 in Ref.[1])

$$f = 1.0783 \left[0.9085 - \left(\frac{h_p}{H_1} \right)^{1.5} \right]^{0.1827} \quad \frac{h_p}{H_1} < 0.935 \quad (13)$$

$$f = 6.1538 \left(1.0 - \frac{h_p}{H_1} \right) \quad \frac{h_p}{H_1} > 0.935$$

The relationship between reduction factor and tailwater ratio H_2/H_1 for a Flat-V weir exhibits a dependence on the V-full ratio H_1/P_v and, to a lesser extent, the depth of approach and crest cross-slope. Figure 4 (Figure 5.4b in Ref.[1]) presents this relationship as an envelope of points for a Flat-V weir with a crest cross-slope of 1:10. To provide a computable reduction factor, the outer limits of this envelope (corresponding to H_1/P_v values of 0.5 and 1.5) have been digitised and fitted to equations of the form used for the Crump weir reduction factor. The upper and lower limits on $f(H_2/H_1)$ are thus given by:

lower limit:

$$\begin{aligned}
 f_l &= 1.0756 \left[0.8453 - \left(\frac{H_2}{H_1} \right)^4 \right]^{0.118} & \frac{H_2}{H_1} < 0.9349 \\
 f_l &= 0.6 + 5.249 \left[0.973 - \frac{H_2}{H_1} \right] & 0.9349 < \frac{H_2}{H_1} < 0.973 \quad (14) \\
 f_l &= 0.4 + 16.667 \left[0.985 - \frac{H_2}{H_1} \right] & 0.973 < \frac{H_2}{H_1} < 0.985 \\
 f_l &= 26.667 \left[1.0 - \frac{H_2}{H_1} \right] & \frac{H_2}{H_1} > 0.985
 \end{aligned}$$

upper limit:

$$\begin{aligned}
 f_u &= 1.0626 \left[0.7075 - \left(\frac{H_2}{H_1} \right)^4 \right]^{0.0956} & \frac{H_2}{H_1} < 0.9 \\
 f_u &= 0.6 + 3.704 \left[0.954 - \frac{H_2}{H_1} \right] & 0.9 < \frac{H_2}{H_1} < 0.954 \quad (15) \\
 f_u &= 0.4 + 6.452 \left[0.985 - \frac{H_2}{H_1} \right] & 0.954 < \frac{H_2}{H_1} < 0.985 \\
 f_u &= 26.667 \left[1.0 - \frac{H_2}{H_1} \right] & \frac{H_2}{H_1} > 0.985
 \end{aligned}$$

These limits are displayed graphically in Figure 5. Note that these limits merely reflect the limited range of H_1/P_v values used in the experiments. However, they are treated here as absolute limits, with f being interpolated linearly between them according to the value of H_1/P_v :

$$\begin{aligned}
 f &= f_l & \frac{P_v}{H_1} < 0.5 \\
 f &= f_l + \left[\frac{P_v}{H_1} - 0.5 \right] (f_u - f_l) & 0.5 < \frac{P_v}{H_1} < 1.5 \quad (16) \\
 f &= f_u & \frac{P_v}{H_1} > 1.5
 \end{aligned}$$

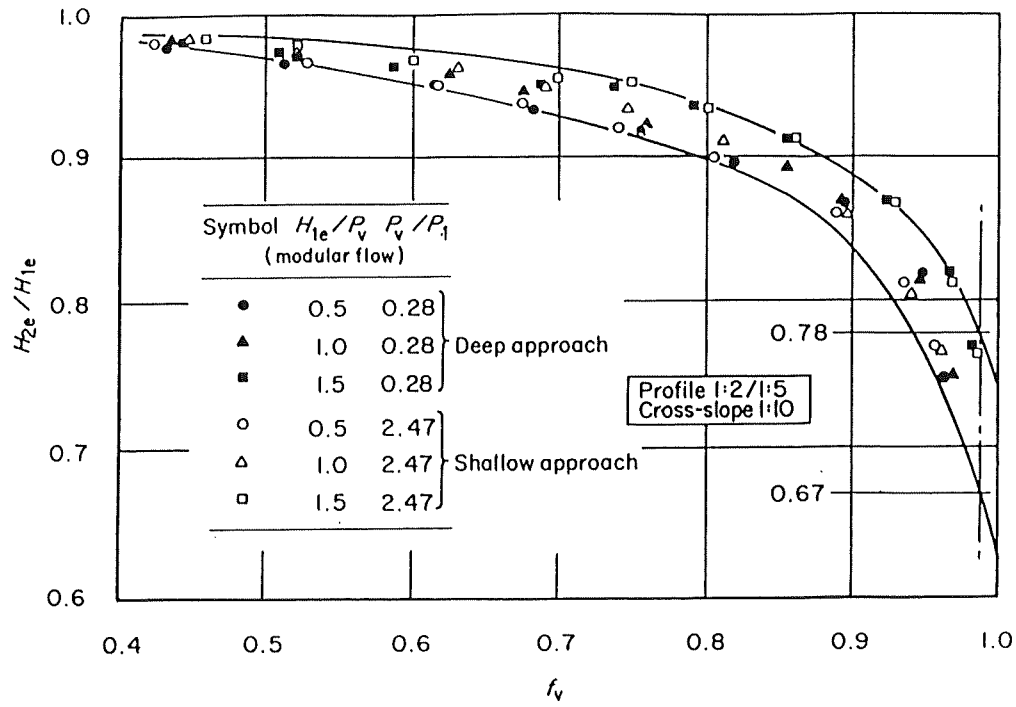


Figure 4 Limits on modular flow for a 1:2/1:5 flat-V weir

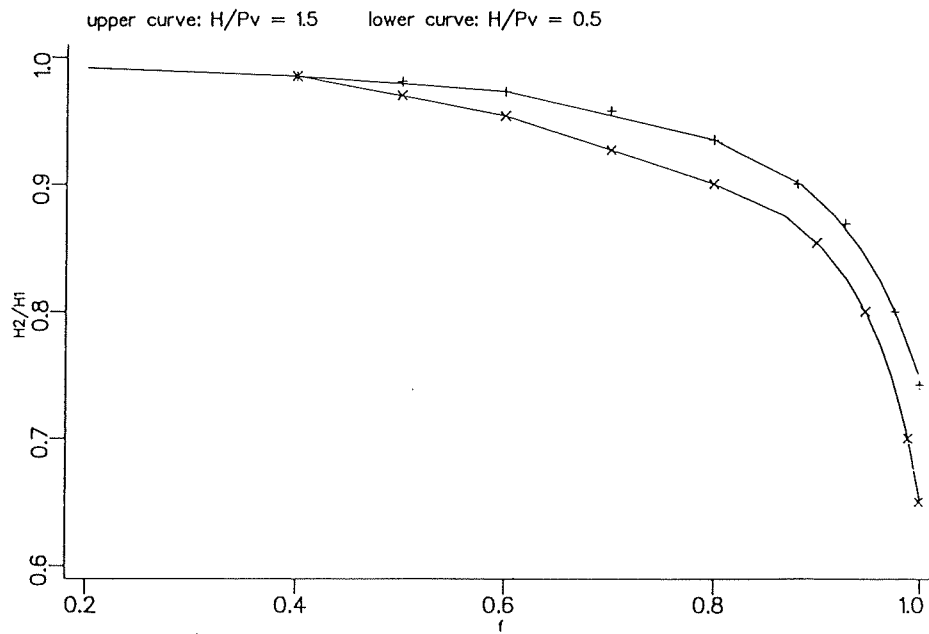


Figure 5 Parameterised envelope curves for the limits on modular flow derived from Figure 5.

3. Performance of Weirs in the Yorkshire Region

3.1 Assessment of the severity of backwater

The importance of backwater effects at Crump and shallow-V weirs in the Yorkshire Region was tested for the event of 26 to 29 August 1986 (Appendix D provides a summary of the characteristics of the 19 weirs involved). Upstream and downstream level data were available during this period for all but one of the weirs (Oulton Beck at Farrer Lane, for which the period 16 to 31 December 1986 was used), and in most cases this event included the highest recorded levels for the station.

Flows calculated using drowned weir theory were compared with the flows given by the modular rating, and the differences used to classify the influence of backwater effects at each station as either negligible, minor, major or extreme. Example hydrographs for the last three of these categories are given in Figure 6. The sites identified within each category of severity are presented below.

Negligible backwater effects:

No significant flow reduction over the entire event.

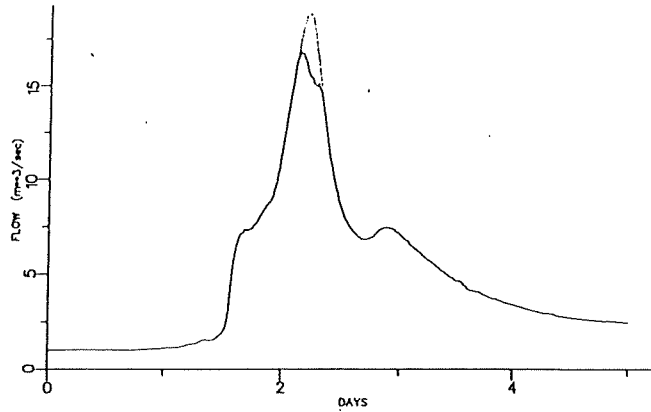
26806 Mires Beck at North Cave
27058 River Riccal at Crook House Farm
27064 River Went at Walden Stubbs
27066 Blackburn Brook at Ashlows Works
27078 River Skell at Alma Reir
27081 Oulton Beck at Farrer Lane
27082 Cundall Beck at Bat Bridge

Minor backwater effects:

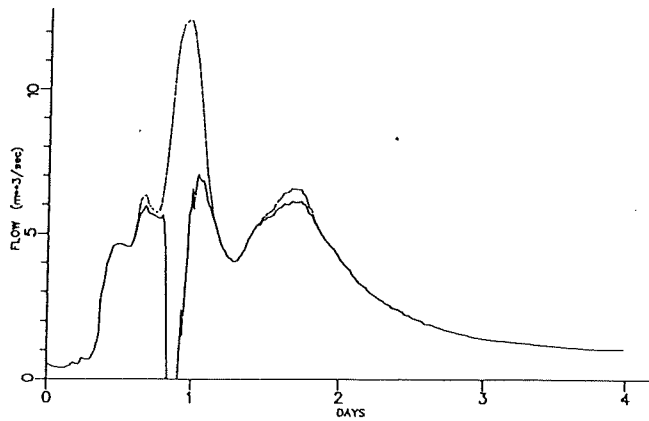
Flow reduction around the peak of the event, typically no more than 25%.

27044 Blackhill Foss at Sandhills Bridge
27049 River Rye at Ness
27074 Spen Beck at Northorpe

(a) River Rye at Ness: minor backwater effect



(b) River Dove at Kirkby Mills: major backwater effect



(c) River Nidd at Skipbridge: extreme backwater effect

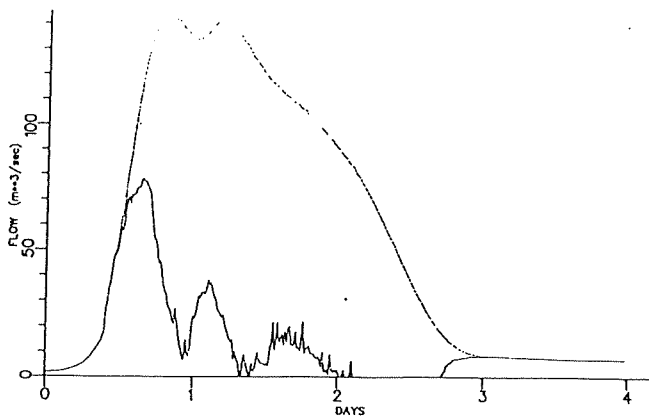


Figure 6 Severity of backwater at three sites for the event of 26-29 August 1986: hydrographs are shown with and without correction for backwater using downstream level data

Major backwater effects.

Flow reduction over much of the event, typically 50% or more around the peak.

- 27042 River Dove at Kirkby Mills
- 27069 River Wiske at Kirby Wiske
- 27075 Bedale Beck at Leeming
- 27077 Bradford Beck at Shipley

Extreme backwater effects:

Flow reduction of 50% or more over the entire event.

- 27055 River Rye at Broadway Foot
- 27056 Pickering Beck at Ings Bridge
- 27057 River Seven at Normanby
- 27060 River Kyle at Newton-on-Ouse
- 27062 River Nidd at Skip Bridge

It is worth remarking that the above classification applies to the storm of 26-29 August 1986 and may not be used as a general indicator of proneness of a station to backwater effects. The severity of flows will vary from site to site for this storm and consequently this factor has a bearing on the degree of backwater experienced.

3.2 Derivation of single level rating

The weir theory presented in Section 2 shows how flow can be derived from measurements of level upstream and downstream of a Crump or shallow-vee weir. It might be expected that the nature of backwater at a given site is relatively consistent from event to event and, whilst the theory demands levels at both upstream and downstream sites, there may be some prospect for establishing a single relationship between flow and the upstream level alone. This prospect can be investigated by deriving the flow using the non-modular theory and plotting this against the corresponding upstream level. An empirical stage-discharge relation can then be derived, which will be useful provided the plotted points lie along a single curve. The procedure has been implemented using the weir software and an example result displayed as Figure 7. It can be seen that there is significant variability in the flow for a given upstream level, although the relationship could be used as an envelope approximation in the absence of downstream level measurements.

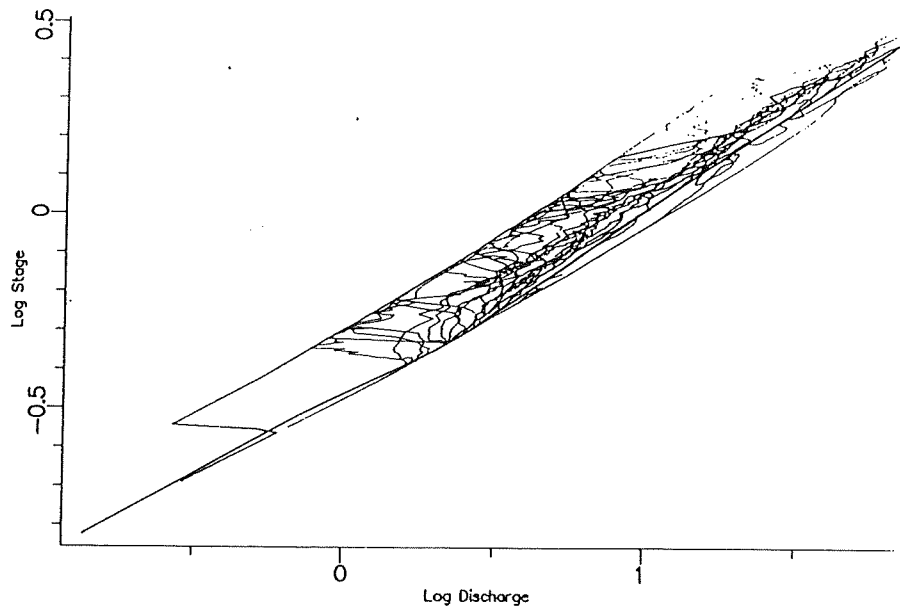


Figure 7 Rating curve for Kirby Wiske gauging station on the River Wiske derived using non-modular flow theory for a flat-vee weir and data from five flood events.

4. Conclusion

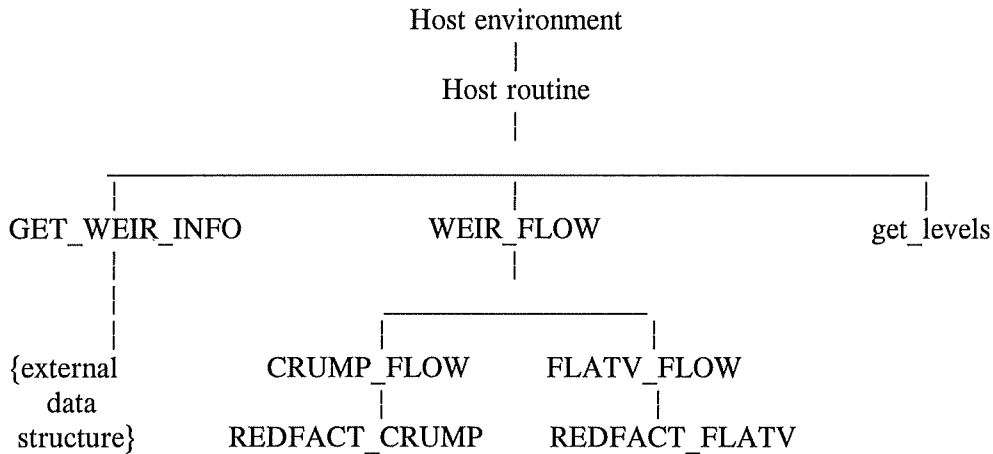
This report has reviewed the theory of flow measurement in the non-modular range using compound Crump and shallow-vee weirs. Software based on this theory has been developed and applied to 19 sites in the Yorkshire Region to estimate flows during backwater conditions and to assess the severity of non-modular flows at each site for one flood event. The software has also been used to demonstrate how an empirical single level rating under non-modular conditions can be established and how its utility, relative to the full non-modular theory, can be judged. It has not been the purpose of this report to assess the validity of the non-modular weir theory through a current meter field programme, an objective which clearly has much to commend it. Details of the weir software and configuration data are given in the Appendices which follow.

Appendices

Appendix A: Data Structure and Interfaces

A.1 Data Flow

Weir configuration data are held in a data structure (text file or database) external to the host routine. In order to perform weir flow calculations, the host routine first extracts the data for a particular configuration from this external structure through the interface `GET_WEIR_INFO` (the required configuration is defined by its station number and either an index number or, more useful in practice, a date on which it is valid). Each pair of upstream and downstream levels, together with the configuration data are then passed to the flow calculation routines through the interface `WEIR_FLOW`, which returns a value of flow. The overall structure of the program is depicted below.



A.2 Host Skeleton

The following listing is a FORTRAN skeleton for a host routine which uses the weir flow routines. Local storage is allocated for the weir data, and need not employ the names given in this example. The meanings of the variables are explained in sections A.3 and A.4, which describe the interfaces.

```

SUBROUTINE HOST(argument_list)
.
.
C Configuration geometry and constants
C
INTEGER      WTYPE,TAPTYP,NCREST
REAL         LRANGE,HRANGE,USDAT,DSDAT,A(6),B(6),CD,CORIOL,KS
C
C Station, index and dates defining configuration
C
CHARACTER*7 GSTN
INTEGER INDEX,SDAY,SMONTH,SYEAR,EDAY,EMONTH,EYEAR
C
C Other station data
C
CHARACTER*7 YW_STN
CHARACTER*20 NAME,LOCATION
C
C Status variables
C
INTEGER ERROR,RDB_STATUS
.
.
C Set station name and index or date of required configuration
.
.
C Retrieve data
C
CALL GET_WEIR_INFO(GSTN,YW_STN,NAME,LOCATION,INDEX,
*                 SDAY,SMONTH,SYEAR,EDAY,EMONTH,EYEAR,
*                 WTYPE,LRANGE,HRANGE,USDAT,DSDAT,
*                 TAPTYP,NCREST,A,B,CD,CORIOL,KS,ERROR,RDB_STATUS)
C
C Handle error conditions
.
.
C Get level data
.
.
C For each pair of upstream and downstream levels, compute flow
C
C Loop...
.
* CALL WEIR_FLOW(WTYPE,Q,H1,H2,USDAT,DSDAT,TAPTYP,
*               NCREST,A,B,CD,CORIOL,KS,ERROR)
C
C Handle error conditions
.
.
C End loop
.
.
RETURN
END

```

A.3 External Weir Data Interface

The argument list and function of the interface routine GET_WEIR_INFO are independent of the structure of the external data, although the operations that the routine employs to retrieve the data will obviously depend on that structure. The version listed below is used in the test environment whilst the version used in the RFFS calibration environment is called GET_YW_WEIR_INFO; otherwise they are identical.

```

SUBROUTINE GET_WEIR_INFO (GSTN, YW_STN, NAME, LOCATION, INDEX,
* SDAY, SMONTH, SYEAR, EDAY, EMONTH, EYEAR,
* WTYPE, LRANGE, HRANGE, USDAT, DSDAT,
* TAPTYP, NCREST, A, B, CD, CORIOL, KS, ERROR, RDB_STATUS)
IMPLICIT NONE
C
C GET WEIR DATA GIVEN HYDROMETRIC STATION NUMBER AND WEIR INDEX
C
C Given the Hydrometric station number and weir configuration index (or date
C for which configuration is required), this subroutine extracts
C the Yorkshire NRA station number, name, and location of a weir from
C the external data structure. Also returned are the details of
C the weir configuration, and the range of dates for which it applies.
C
C -----
C Arguments
C -----
C
CHARACTER*7 GSTN, YW_STN
CHARACTER*(*) NAME, LOCATION
INTEGER WTYPE, INDEX, SDAY, SMONTH, SYEAR, EDAY, EMONTH, EYEAR
INTEGER TAPTYP, NCREST, ERROR, RDB_STATUS
REAL LRANGE, HRANGE, USDAT, DSDAT, A(*), B(*), CD, CORIOL, KS
C
C GSTN      o CHARACTER*7 The Hydrometric station number to be looked up.
C
C YW_STN    o CHARACTER*7 Returns the number used by Yorkshire NRA, if known.
C
C NAME      o CHARACTER*(*) Returns the name of river on which the gauging
C            station is located. Maximum length of any text returned will be
C            20 characters. Strings longer than this will be padded to the
C            right with blank characters.
C
C LOCATION  o CHARACTER*(*) Returns the location where the gauging station is
C            located. Maximum length of any text returned will be 20
C            characters. Strings longer than this will be padded to the
C            right with blank characters.
C
C INDEX     o INTEGER Index to weir configuration. Earliest is 1, subsequent
C            configurations incrementing by 1. If INDEX<1 on entry, then
C            the configuration which is valid on the date given by the input
C            values of SDAY, SMONTH and SYEAR is returned.
C
C SDAY      o INTEGER Day on which the configuration starts to apply.
C
C SMONTH    o INTEGER Month in which the configuration starts to apply.
C
C SYEAR     o INTEGER Year in which the configuration starts to apply.
C
C EDAY      o INTEGER Day on which the configuration ceases to apply (1 if
C            still in use).
C

```

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```
C
C EMONTH   o INTEGER Month in which the configuration ceases to apply (1 if
C           still in use).
C
C EYEAR    o INTEGER Year in which the configuration ceases to apply (2100 if
C           still in use).
C
C WTYPE     o INTEGER Type of weir: This is read from the external data
C           structure as a string and interpreted as
C           1='Crump', 2='FlatV' or 0='Null'.
C
C LRRANGE   o REAL Low and high limits of valid
C HRANGE    o           upstream level range
C
C USDAT     o REAL Corrections to be added to upstream and downstream levels
C DSDAT     o           to bring them to the crest datum.
C
C TAPTYP    o INTEGER Type of secondary tapping:
C           0 : none
C           1 : crest tapping
C           2 : downstream tapping
C
C NCREST    o INTEGER Number of weir crests (max 3 for FlatV, 6 for Crump)
C
C A,B       o REAL Weir geometry arrays:
C           'Crump': first crest: A(1) = depth of approach
C                               B(1) = width of crest
C                               n'th crest A(n) = step up from first crest
C                               B(n) = width of crest
C           'FlatV': first crest: A(1) = depth of approach
C                               B(1) = cross-slope of crest
C                               A(2) = width of crest
C                               B(2) = slope of channel sides
C                               n'th crest A(2n-1) = step up from first crest
C                               others as first crest
C
C CD        o REAL Coefficient of discharge
C
C CORIOL    o REAL Coriolis coefficient for dynamic head calculation
C
C KS        o REAL Level correction to account for fluid effects.
C
C ERROR     o INTEGER Error return, returns 0 for success, or :
C           1 - configuration not found
C           2 - station ID not valid (e.g. bad characters)
C           5 - error reading geometry
C           8 - error accessing external data structure
C
C RDB_STATUS o INTEGER Status of access to external data structure
```

A.4 Flow Routine Interface

The argument list and function of the flow routine interface routine, WEIR_FLOW, are presented below:

```
SUBROUTINE WEIR_FLOW(WTYPE, Q, H1, H2, USDAT, DSDAT, TAPTYP,
*                   NCREST, A, B, CD, CORIOL, KS, ERROR)
```

```

C COMPUTE FLOW OVER WEIR GIVEN CONFIGURATION AND UP/DOWNSTREAM LEVELS
C
C -----
C Arguments
C -----
C
      INTEGER WTYPE,TAPTYP,NCREST,ERROR
      REAL Q,H1,H2
      REAL USDAT,DSDAT,A(*),B(*),CD,CORIOL,KS
C
C H1      REAL Gauged upstream level
C
C H2      REAL If TAPTYP=1 : Pressure head at crest tapping
C           If TAPTYP=2 : Gauged downstream level
C
C Q       REAL Computed flow over weir
C
C ERROR   INTEGER Error flag, 0 for success or
C           1 - iteration failed to converge, solution inaccurate
C           2 - iteration diverged
C
C Other variables - see GET_WEIR_INFO

```

Appendix B: The Test Environment

B.1 User Notes

The program WEIR_TEST allows the user to make test calculations of flows for a specified weir configuration held in the WEIR_TABLE text file. It communicates interactively with the user, or can be switched to receive input from a prepared input file if requested. Output can be seen on the terminal or sent to an output file as required. The weir configuration is specified by station number and index. Levels may be entered directly, or retrieved from the database.

For levels entered directly, the output line is

```
(error code), upstream level, downstream level, flow, flow over  
each crest
```

For levels retrieved from the database, the output line for each level is

```
flow, upstream level, (error code)
```

The error code is 1 if the maximum number of iterations is exceeded, and 2 if the iteration diverges.

B.2 Reference

The following FORTRAN I/O channels should be assigned:

- 15 - WEIR_TABLE,
- 20 - (optional) input file,
- 16 - (optional) output file.

WEIR_TEST.OBJ must be linked with

```
GET_WEIR_INFO.OBJ
```

```
WEIR_FLOW.OBJ
```

```
CRUMP_FLOW.OBJ
```

```
FLATV_FLOW.OBJ or WEIR.OLB/LIB
```

```
REDFACT_CRUMP.OBJ
```

```
REDFACT_FLATV.OBJ
```

YWLIB.OLB/LIB and other standard libraries

Appendix C: RFFS Calibration Environment

C.1 User Notes

Weir configuration data are held on the database. If flow stations in the model calibration input file (see Technical Note No. 11) are specified as downstream stations (i.e. in the form 'D nnnnn') then the Calibration System will attempt to use flows calculated from weir theory at that station. If the downstream station or weir configuration does not exist, or downstream levels are missing, the appropriate rating curve for the station will be used instead. It is clearly not possible to use the non-modular weir theory if downstream levels are not available.

C.2 Reference

The calibration software requests flows for a particular station and range of dates through a call to `GET_YW_FLOWS_S`. If the requested station is a downstream station (i.e. of the form 'D nnnnn') then `GET_YW_FLOWS_S` will retrieve weir configuration data through the interface `GET_YW_WEIR_INFO`, and will retrieve downstream levels as well as upstream levels. If the retrievals are successful, the `WEIR_FLOW` interface is used to compute flow for all times at which downstream levels are available. Any missing flow values are filled in using the appropriate rating curve(s).

The operation of `GET_YW_WEIR_INFO` and `GET_YW_FLOWS_S` can be tested using the utility programs `TEST_GET_YW_WEIR_INFO` and `TEST_GET_YW_FLOWS_S`.

The object code for `GET_YW_FLOWS_S` and `GET_YW_WEIR_INFO` is held in `YWLIB.OLB`

The object code for `WEIR_FLOW` and lower-level routines is held in `WEIR.OLB`

`TEST_GET_YW_WEIR_INFO` and `TEST_GET_YW_FLOWS_S` must be linked with `YWLIB` and other standard libraries.

Appendix D: Geometrical details of Weirs

D.1 General

The geometrical details of weirs are held as "weir tables" in the form of a clear text file called WEIR_TABLE, with embedded comments at the end of each data line to clarify the contents. Configuration entries are separated by blank lines. A station may have several configuration entries, each with a different index and range of dates. Line of numeric data are read in FORTRAN list-directed format, but the overall format (number of lines and the items on them) is fixed. Character data should be left-justified on the line.

The following listing shows the correspondance between the organisation of data for a single configuration, and the variables returned by GET_WEIR_INFO (see section A.3). Lines in italics indicate alternative or repeating lines, and are not part of the table.

GSTN YWSTN	:National Ref. No., Yorkshire No.
NAME	:River name
LOCATION	:Station name
INDEX	:Configuration index
SDAY SMONTH SYEAR	:Configuration start date
EDAY EMONTH EYEAR	:Configuration end date
WTYPE	:FlatV or Crump
LRANGE HRANGE	:Valid range (metres)
USDAT DSDAT	:Datum corrections to add to
up/downstream levels	
TAPTYP NCREST	:Weir type, number of crests
<i>Crump weir</i>	
A(1) B(1)	:Gauging crest: u/s weir height, width
<i>FlatV weir</i>	
A(1) B(1)	:Gauging crest: u/s weir
height, cross-slope	
A(2) B(2)	:crest width, slope of channel sides
<i>For each other crest of a Crump weir (k=2...NCREST)</i>	
A(k) B(k)	:Other crest: step from gauging
crest, width	
<i>For each other crest of a FlatV weir (k=2...NCREST)</i>	
A(2*k-1) B(2*k-1)	:Other crest: step from gauging
crest, cross-slope	
A(2*k) B(2*k)	:crest width, slope of channel sides
<i>All weirs</i>	
CD	:coefficient of discharge
CORIOL	:Coriolis coefficient

D.2 Weirs in the Yorkshire Region

A complete list of the geometrical details of the weirs in the Yorkshire Region with

measured downstream levels is presented below in the weir table format described above. All the weirs are single-crested, but an extra, artificial, crest has been introduced for the weirs at Kirby Wiske on the River Wiske, and Leeming on the Bedale Beck, in an attempt to improve the predictions for out-of-structure flow.

26806 3480	:National Ref. No., Yorkshire No.
Mires Beck	:River name
North Cave	:Station name
1	:Configuration index
1 1 1900	:Configuration start date
1 1 2100	:Configuration end date
FlatV	:FlatV or Crump
0.0 1.21	:Valid range (metres)
0.0 -0.45	:Datum corrections to add to up/downstream levels
2 1	:Weir type,number of crests
0.67 10.0	:Gauging crest: u/s weir height,cross-slope
4.99 0.0	:crest width,slope of channel sides
0.620	:coefficient of discharge
1.0	:Coriolis coefficient
27042 2560	:National Ref. No., Yorkshire No.
Dove	:River name
Kirkby Mills	:Station name
1	:Configuration index
1 1 1900	:Configuration start date
1 1 2100	:Configuration end date
FlatV	:FlatV or Crump
0.0 1.2	:Valid range (metres)
0.0 -0.4	:Datum corrections to add to up/downstream levels
2 1	:Weir type,number of crests
0.6 10	:Gauging crest: u/s weir height,cross-slope
8.0 0.0	:crest width,slope of channel sides
0.620	:coefficient of discharge
1.0	:Coriolis coefficient
27044 2835	:National Ref. No., Yorkshire No.
Blackhill Foss	:River name
Sandhills Bridge	:Station name
1	:Configuration index
13 6 1984	:Configuration start date
1 1 2100	:Configuration end date
FlatV	:FlatV or Crump
0.0 1.28	:Valid range (metres)
0.0 -0.38	:Datum corrections to add to up/downstream levels
2 1	:Weir type,number of crests
0.73 10	:Gauging crest: u/s weir height,cross-slope
4.02 0.0	:crest width,slope of channel sides
0.620	:coefficient of discharge
1.0	:Coriolis coefficient
27049 2505	:National Ref. No., Yorkshire No.
Rye	:River name

Ness	:Station name
1	:Configuration index
1 1 1900	:Configuration start date
1 1 2100	:Configuration end date
FlatV	:FlatV or Crump
0.0 1.450	:Valid range (metres)
0.0 -0.45	:Datum corrections to add to up/downstream levels
2 1	:Weir type,number of crests
0.55 10	:Gauging crest: u/s weir height,cross-slope
12.0 0.0	:crest width,slope of channel sides
0.620	:coefficient of discharge
1.0	:Coriolis coefficient
27055 2508	:National Ref. No., Yorkshire No.
Rye	:River name
Broadway Foot	:Station name
1	:Configuration index
1 1 1900	:Configuration start date
1 1 2100	:Configuration end date
Crump	:FlatV or Crump
0.0 0.4	:Valid range (metres)
0.0 -0.3	:Datum corrections to add to up/downstream levels
2 1	:Weir type,number of crests
0.52 15.0	:Gauging crest: u/s weir height,crest width
0.633	:coefficient of discharge
1.0	:Coriolis coefficient
27056 2515	:National Ref. No., Yorkshire No.
Pickering Beck	:River name
Ings Bridge	:Station name
1	:Configuration index
1 1 1900	:Configuration start date
1 1 2100	:Configuration end date
Crump	:FlatV or Crump
0.0 0.4	:Valid range (metres)
0.0 -0.2	:Datum corrections to add to up/downstream levels
2 1	:Weir type,number of crests
0.285 7.0	:Gauging crest: u/s weir height,crest width
0.633	:coefficient of discharge
1.0	:Coriolis coefficient
27057 2540	:National Ref. No., Yorkshire No.
River Seven	:River name
Normanby	:Station name
1	:Configuration index
1 1 1900	:Configuration start date
1 1 2100	:Configuration end date
Crump	:FlatV or Crump
0.0 0.6	:Valid range (metres)
0.0 -0.499	:Datum corrections to add to up/downstream levels
2 1	:Weir type,number of crests
0.5 6.0	:Gauging crest: u/s weir height,crest width
0.633	:coefficient of discharge
1.0	:Coriolis coefficient

27058 2580	:National Ref. No., Yorkshire No.
Riccall	:River name
Crook House Farm	:Station name
1	:Configuration index
1 1 1900	:Configuration start date
1 1 2100	:Configuration end date
FlatV	:FlatV or Crump
0.0 0.645	:Valid range (metres)
0.0 -0.2	:Datum corrections to add to up/downstream levels
2 1	:Weir type,number of crests
0.205 10	:Gauging crest: u/s weir height,cross-slope
4.0 0.0	:crest width,slope of channel sides
0.620	:coefficient of discharge
1.0	:Coriolis coefficient
27060 2480	:National Ref. No., Yorkshire No.
Kyle	:River name
Newton on Ouse	:Station name
1	:Configuration index
1 1 1900	:Configuration start date
1 1 2100	:Configuration end date
FlatV	:FlatV or Crump
0.0 0.77	:Valid range (metres)
0.0 -0.3	:Datum corrections to add to up/downstream levels
2 1	:Weir type,number of crests
0.43 10	:Gauging crest: u/s weir height,cross-slope
6.145 0.0	:crest width,slope of channel sides
0.620	:coefficient of discharge
1.0	:Coriolis coefficient
27062 2102	:National Ref. No., Yorkshire No.
Nidd	:River name
Skip Bridge	:Station name
1	:Configuration index
1 1 1900	:Configuration start date
1 1 2100	:Configuration end date
FlatV	:FlatV or Crump
0.0 2.25	:Valid range (metres)
0.0 -0.7	:Datum corrections to add to up/downstream levels
2 1	:Weir type,number of crests
1.02 10	:Gauging crest: u/s weir height,cross-slope
17.01 0.0	:crest width,slope of channel sides
0.620	:coefficient of discharge
1.0	:Coriolis coefficient
27064 0920	:National Ref. No., Yorkshire No.
Went	:River name
Walden Stubbs	:Station name
1	:Configuration index
1 1 1900	:Configuration start date
1 1 2100	:Configuration end date
FlatV	:FlatV or Crump
0.0 0.980	:Valid range (metres)
0.0 -0.35	:Datum corrections to add to

2 1	up/downstream levels
0.34 10	:Weir type,number of crests
	:Gauging crest: u/s weir
	height,cross-slope
6.964 0.0	:crest width,slope of channel
	sides
0.620	:coefficient of discharge
1.0	:Coriolis coefficient
27066 0660	:National Ref. No., Yorkshire No.
Blackburn Brook	:River name
Ashlowes Works Secondary	:Station name
1	:Configuration index
1 1 1900	:Configuration start date
1 1 2100	:Configuration end date
FlatV	:FlatV or Crump
0.0 1.6	:Valid range (metres)
0.0 -0.7	:Datum corrections to add to
	up/downstream levels
2 1	:Weir type,number of crests
0.794 10	:Gauging crest: u/s weir
	height,cross-slope
3.96 0.0	:crest width,slope of channel
	sides
0.620	:coefficient of discharge
1.0	:Coriolis coefficient
27069 2320	:National Ref. No., Yorkshire No.
Wiske	:River name
Kirkby Wiske	:Station name
1	:Configuration index
1 1 1900	:Configuration start date
1 1 2100	:Configuration end date
FlatV	:FlatV or Crump
0.0 0.51	:Valid range (metres)
0.0 -0.3	:Datum corrections to add to
	up/downstream levels
2 2	:Weir type,number of crests
0.36 10	:Gauging crest: u/s weir
	height,cross-slope
5.997 0.0	:crest width,slope of channel
	sides
0.50 50	:Other crests: step to gauging
	crest,cross-slope
1.3 1.0	:crest width,slope of channel
	sides
0.620	:coefficient of discharge
1.0	:Coriolis coefficient
27071 0	:National Ref. No., Yorkshire No.
Swale	:River name
Crakehill	:Station name
1	:Configuration index
1 1 1900	:Configuration start date
1 1 2100	:Configuration end date
Crump	:FlatV or Crump
0.0 1.7	:Valid range (metres)
0.0 0.0	:Datum corrections to add to
	up/downstream levels
1 1	:Weir type,number of crests
1.4 20.0	:Gauging crest: u/s weir
	height,crest width
0.633	:coefficient of discharge

1.0	:Coriolis coefficient
27074 1385	:National Ref. No., Yorkshire No.
Spen Beck	:River name
Northorpe Secondary	:Station name
1	:Configuration index
1 1 1900	:Configuration start date
1 1 2100	:Configuration end date
Crump	:FlatV or Crump
0.0 1.260	:Valid range (metres)
0.0 -1.5	:Datum corrections to add to up/downstream levels
2 1	:Weir type,number of crests
0.9 6.885	:Gauging crest: u/s weir height,crest width
0.633	:coefficient of discharge
1.0	:Coriolis coefficient
27075 2330	:National Ref. No., Yorkshire No.
Bedale Beck	:River name
Leeming	:Station name
1	:Configuration index
1 1 1900	:Configuration start date
1 1 2100	:Configuration end date
FlatV	:FlatV or Crump
0.0 0.75	:Valid range (metres)
0.0 -0.75	:Datum corrections to add to up/downstream levels
2 2	:Weir type,number of crests
0.55 10	:Gauging crest: u/s weir height,cross-slope
6.0 0.0	:crest width,slope of channel sides
0.75 50	:Other crest: step from gauge crest,cross-slope
0.6 1.5	:crest width,slope of channel sides
0.620	:coefficient of discharge
1.0	:Coriolis coefficient
27077 1650	:National Ref. No., Yorkshire No.
Bradford Beck	:River name
Shipley	:Station name
1	:Configuration index
1 1 1900	:Configuration start date
1 1 2100	:Configuration end date
FlatV	:FlatV or Crump
0.0 2.02	:Valid range (metres)
0.0 -0.4	:Datum corrections to add to up/downstream levels
2 1	:Weir type,number of crests
0.38 10	:Gauging crest: u/s weir height,cross-slope
6.0 0.0	:crest width,slope of channel sides
0.620	:coefficient of discharge
1.0	:Coriolis coefficient
27078 2216	:National Ref. No., Yorkshire No.
River Skell	:River name
Alma Weir	:Station name
1	:Configuration index
1 1 1900	:Configuration start date

1 1 2100	:Configuration end date
FlatV	:FlatV or Crump
0.0 1.4	:Valid range (metres)
0.0 -1.297	:Datum corrections to add to up/downstream levels
2 1	:Weir type,number of crests
0.95 10	:Gauging crest: u/s weir height,cross-slope
25.04 0.0	:crest width,slope of channel sides
0.620	:coefficient of discharge
1.0	:Coriolis coefficient
27081 1715	:National Ref. No., Yorkshire No.
Oulton Brook	:River name
Farrer Lane	:Station name
1	:Configuration index
1 1 1900	:Configuration start date
1 1 2100	:Configuration end date
FlatV	:FlatV or Crump
0.0 1.6	:Valid range (metres)
0.0 -0.36	:Datum corrections to add to up/downstream levels
2 1	:Weir type,number of crests
0.4 10	:Gauging crest: u/s weir height,cross-slope
4.995 0.0	:crest width,slope of channel sides
0.620	:coefficient of discharge
1.0	:Coriolis coefficient
27082 2311	:National Ref. No., Yorkshire No.
Cundall Beck	:River name
Bat Bridge	:Station name
1	:Configuration index
1 1 1900	:Configuration start date
1 1 2100	:Configuration end date
FlatV	:FlatV or Crump
0.0 1.07	:Valid range (metres)
0.0 -0.5	:Datum corrections to add to up/downstream levels
2 1	:Weir type,number of crests
0.5 10	:Gauging crest: u/s weir height,cross-slope
3.987 0.0	:crest width,slope of channel sides
0.620	:coefficient of discharge
1.0	:Coriolis coefficient

Appendix E: The IH Database

E.1 Database Format

The IH event database is an RdB/VMS relational database. The field, relation and index definitions for the weir configuration data are built using BUILD_WEIR_DEFS.RDO, and the configuration entries are built using BUILD_WEIR_ENTRIES.RDO.

E.2 Format Conversion

A utility program, WEIR_REFORM, creates BUILD_WEIR_ENTRIES.RDO from the text file WEIR_TABLE.DAT. Input and output file names are fixed within the program.

Appendix F: List of Files

A summary of the files used in the non-modular weir software is presented below:

(a) Flow Routines

WEIR_FLOW.FOR : interface
CRUMP_FLOW.FOR
FLATV_FLOW.FOR
REDFACT_CRUMP.FOR
REDFACT_FLATV.FOR

Object code held in YWLIB.OLB

(b) Test Environment

WEIR_TEST.FOR : test program
GET_WEIR_INFO.FOR
WEIR_TEST.LNK : link commands
WEIR_TEST.COM : channel assignment and run
WEIR_TABLE.DAT : a weir configuration table
WEIR_TEST.INP : input file
WEIR_TEST.OUT : output file

(c) RFFS Calibration Environment (IH Database)

GET_YW_FLOWS_S.FOR
GET_YW_WEIR_INFO.RFO
TEST_GET_YW_WEIR_INFO.FOR
BUILD_WEIR_DEFS.RDO
BUILD_WEIR_ENTRIES.RDO

(d) Definitive Configurations of Yorkshire Weirs

WEIR_TABLE.DAT