GUIDE TO HYDRAULIC CHARACTERISTICS OF SOUTH AFRICAN RIVERS

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A research report submitted to the Faculty of Engineering and the Built Environment, University of the Witwatersrand, Johannesburg, in partial fulfilment of the requirements for the degree of Master of Science in Engineering

Johannesburg, 2008

i. Declaration

I declare that this research report is my own, unaided work. It is being submitted for the Degree of Master of Science in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University.

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Ahmed Yacoob Desai

_____ day of ________________________ 2008

ii. Abstract

The National Water Act (No. 36 of 1998) requires Ecological Reserves to be determined in order to protect the aquatic ecosystems of the water resources. Instream Flow Requirements (IFRs) were established to determine these Ecological Reserves. In order to effectively determine IFRs, hydraulic parameters such as water depth, flow velocity, wetted perimeter and water surface width as functions of flowrate are required. The initial step in obtaining these parameters is to estimate a roughness coefficient to represent the resistance for the site when data is being collected. Many methods exist to aid the hydraulic practitioner in estimating roughness coefficients but they are limited in that they do not represent South African conditions, especially the large-scale roughness regime which is the most important regime in IFR studies. A review of the various resistance phenomena and roughness estimation methods was done to identify how estimations of roughness coefficients for South African rivers can improve. It was found that photographic matching was commonly used due to its simplicity and thus an electronic, using MS Access, photographic matching guide was developed using past IFR studies of South African. The guide presents photographs and hydraulic parameters for 79 IFR sites.

iii. Acknowledgements

The database is a product from a project funded by the Water Research Commission (WRC) entitled: "Ecohydraulic Modelling in River Systems" – Project K5/1508.

The WRC support, comments and suggestions are greatly appreciated.

The studies used to develop the database were commissioned by the following organisations:

- Department of Water Affairs and Forestry -
  Kat, Kromme, Olifants/Doring, Frikkie se Loop, Murara, Mutshindudi, Lower & Middle Olifants, Thukela, Kei, Mkomazi, Oudtshoorn and Letaba

- Komati Basin Water Authority and Department of Water Affairs and Forestry – Komati

- SMEC International Pty Ltd –
  Metolong

Dr Andrew Birkhead provided the hydraulic data for all the studies.

Ms Angelina Jordanova provided data and photographs for the Letaba study.

Ms Delana Louw provided the photographs and ecological information for all the studies not mentioned elsewhere.

Dr Cate Brown provided data and photographs for the Metolong and Olifants/Doring studies.

The School of Civil and Environmental Engineering, University of the Witwatersrand provided a variety of facilities and equipment.

Professor Christopher James and Mr Peter Hirschowitz provided assistance throughout the project.

Mrs Wendy Midgley was helpful in the administration and financial control of the project.

All of their contributions are greatly appreciated.

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vii. List of Symbols

a – weighting factor, varying from 1 to 0

a,b,c – regression coefficients

A – cross-sectional area (m^2)

A - frontal area of an individual plant blocking flow (ft^2) – equation 2.6

A_* - net submerged frontal area of a partially submerged plant (ft^2) – equation 2.7

A_s - total cross sectional area of the stem of an individual plant (ft^2) – equation 2.6

$\sum A_i$ - projected vegetation area in the streamwise direction

B – channel width at water surface (m)

BBM – Building Block Methodology

C – Chezy C roughness coefficient

C_d - effective drag coefficient for the vegetation in the direction of flow

d_s – representative largest size

- d_{84}, d_{50}, d_{16} – 84%, 50%, 16% sediment mass consist of particles small than (m)
- also sometimes represented as D_{84} etc

D - averaged rod diameter

DRIFT - Downstream Response to Imposed Flow Transformation

E_s - modulus of plant stiffness (lb/ft^2)

EIS – Ecological Importance and Sensitivity

EWR – Ecological Water Requirement

f or f_2 or $f_{\text{high flow}}$ – Darcy-Weisbach friction factor

f – effective friction factor [equation 2.5]

F_j – large-scale roughness coefficient

Fr – Froude Number

FS-R - Flow-Stress Response Method

g – gravitational constant [9.81 m/s^2]

γ - specific weight of the fluid

h – elevation of the water surface (m)

h_v – velocity head (m)

H - average undeflected plant height (ft)

H - flow depth – equation 2.9

IFR – Instream Flow Requirement

k_s - representative sediment size

k_n - unit conversion for Manning's equation (1 for SI, and 1.49 for imperial units)

K - conveyance (m^3/s)

L – length (m)

M - relative plant density (number of plants per ft^2)

MAR – Mean Annual Runoff (mm^3)

n – Manning's roughness coefficient

n - vegetation density (rods per unit area) – equation 2.9

n_b – basic Manning roughness coefficient

n_b - Manning's boundary roughness coefficient, excluding the vegetation–equation 2.8

$n_1 – n_4$ – adjustment Manning n factors [equation 3.1]

n_1 – total unit roughness [equation 3.3]

n_{irr} – unit roughness due to irregularities

n_{sur} – unit roughness due to surface

n_{veg} – unit roughness due to vegetations

N - nondimensional vegetation density

m – adjustment for Meandering channels [equation 3.1]

m – number of cross sections [equation 3.2]

NWA – National Water Act (No. 36 of 1998)

PES – Present Ecological State

ρ - fluid density

Q – discharge (m^3/s)

R – hydraulic radius (*m*) or (*ft*) - ratio of the cross sectional area (*A*) to the wetted perimeter (*P*)

Re- the Reynolds Number

Re_{ds} – Reynolds Number, based on a representative largest sediment size

Re^* - the Shear Reynolds number

R_{vol} – volumetric hydraulic radius

RANS – Reynolds Average Navier Stokes

The Navier-Stokes equations are derived from the governing equations of fluid flow. These equations are termed "Reynolds Averaged" as the instantaneous turbulent fluctuations of the velocity and pressure components have been averaged over small-time scales i.e. small compared with variations in the bulk flow that are of any practical importance, but large compared with inter-particle collisions. The "Reynolds Averaged" Navier-Stokes equations are 100% based on modelling of the physical properties. *(HR Wallingford, 2004)*

REC – Recommended Ecological Category

S – energy/water slope

S_f - energy slope, for uniform flow – the slope may be represented by the bed gradient (S_o)

SCI – Socio Cultural Importance

τ_o - boundary shear stress

u_* - the shear velocity

V – velocity (m/s) or (ft/s)

y – average flow depth (m)

y_{eff1} – height of the tops of the roughness elements above the lowest bed level (m)

y_{eff2} – effective flow depth, accounting for the volume of the roughness elements (m)

Δh_v – change in velocity head (m)

σ – standard deviation of the sediment size distribution

ν – kinematic eddy viscosity (m^2/s) or (ft^2/s)

$Z = AR^{2/3}$

1. Introduction

Water resources in South Africa are limited and their management and protection is critically important for the sustainable economic and social development of the country. The National Water Act (No. 36 of 1998) (NWA) has fundamentally reformed the law relating to water resources. Implementation of the NWA requires that 'Basic Human Needs Reserves' and 'Ecological Reserves' be specified for all or part of any significant water resource.

The Basic Human Needs Reserve provides for the essential needs of individuals served by the water resources and includes water for drinking, food preparation and personal hygiene. The Ecological Reserve relates to the water required to protect the aquatic ecosystems of the water resource. Reserve refers to both the quantity and quality of the water in the resource.

Instream flow requirements (IFRs) were established to identify the Reserves by determining the extent to which the natural flow regime may be altered from the natural condition whilst still maintaining the integrity and functioning of the riverine ecosystem at some acceptable level (Jordanova et al, 2002).

Depending on the specialist used for IFR studies, one of the following methodologies is used in selecting sites, surveying sites and collecting hydraulic data:

1. **Building Block Methodology (BBM)** – The conceptual basis of BBM is that some flows within the total flow regime are more important than others for maintenance of that river ecosystem (Tharme & King, 1998; King & Louw 1998; King et al, 2000)

2. **Downstream Response to Imposed Flow Transformation (DRIFT)** – This is a scenario-based process for addressing the ecological and socio-economic consequences of progressive reduction in flows (Brown and King, 2000).

3. **Flow-Stress Response Method (FS-R)** – This method guides the evaluation of the ecological consequences of modified flow regimes using an index to score flow-related stress (O' Keeffe et al, 2002; O'Keeffe and Hughes, 2004).

There are three primary differences between BBM and DRIFT (Jordanova et al, 2002):

- DRIFT is a scenario-based interactive approach, in which a database is created that can be queried to describe the biophysical consequences of any number of potential future flow regimes. The BBM is a prescriptive approach that requires identification of a single predetermined condition, after which a single flow regime is described to facilitate maintenance of that condition.
- The BBM "builds up" a recommended flow regime from scratch, whereas DRIFT takes the present-day flow regime as a starting point, and describes the consequences for all aspects of the river of further reducing the flow regime in different ways.
- DRIFT is designed to describe and quantify the links between changing river condition and the social and economic impacts for the riparian people who rely on the river for subsistence.

The general outcome of the methods is that biotic considerations will dominate the selection of a site. The sites generally illustrate a high degree of habitat and therefore biotic diversity.

Researchers into IFRs for rivers tend to quantify the water needs of the various biotic components in terms of parameters such as water depth, flow velocity, wetted perimeter and water surface width. Hydrologists, water engineers and water resource managers, on the other hand, are more comfortable expressing the water needs in terms of volume and time (King et al, 2000). The methodologies used to determine IFRs therefore require an interface between the two approaches. This interface is found through hydraulic analyses of flow in the rivers. The results of hydraulic analyses and modelling therefore form the essential link between the way in which hydrologists, engineers and water managers express the flow of water in the river, and the way in which river ecologists express the water requirements of the river ecosystem itself (Birkhead, 2001). The product of the hydraulic component comprises relationships between discharge and, among other parameters, water depth, flow velocity, wetted perimeter and water surface width (King et al, 2000).

However, rivers are continuously evolving; they adjust in response to human activities and changing climatic, geologic and hydrologic regimes and are thus highly complex systems. The changes in the river result in changes to local hydraulic conditions and it is difficult (finance and time) to obtain all local hydraulic conditions that are required for effectively determining Ecological Reserves. Hydraulic models are therefore used in conjunction with measured data to develop the required hydraulic relationships for the river or river reach.

Richards (1982) states that flow resistance of a channel controls local hydraulic conditions. It therefore seems appropriate that if the resistance of a river can be quantified, then the hydraulic conditions can be modelled and the required hydraulic relationships thereafter developed for the river or river reach.

Quantifying resistance of a river reach is a complex task because of the interaction between the various sources of resistance. Various guides have been developed to assist hydraulic practitioners in quantifying resistance (section 3), however many South African river types are not well represented in the guides as the conditions under which they were developed are different to South African river conditions and application of them to South Africa Rivers may lead to errors.

This project therefore aims to assist hydraulic practitioners in quantifying the resistance of a river reach for South African rivers through the use of an electronic photographic matching guide. The guide will provide better roughness quantification of roughness coefficients for South African conditions and therefore improve the accuracy of hydraulic modelling.

The guide is developed by collating hydraulic data from previous IFR studies in South Africa and capturing it on to a MS Access database. Section 2 reviews resistance phenomena and various guides in estimating resistance coefficients are thereafter discussed in section 3. Explanations and information on the development of the South African guide is given in sections 4 and 5 and conclusions and recommendations are discussed in section 6.

2. Resistance Phenomena

The relationships between flow depth, average velocity and discharge in a river are governed by the resistance of the channel to flow. Resistance in rivers may originate from a variety of sources such as frictional, bed irregularities, vegetation, macro channel form, channel alignment or local acceleration influences.

Successful quantification of resistance in rivers depends on an understanding of all these sources of resistance as well as application of an appropriate approach (Jordanova et al, 2004).

The basis upon which IFR sites are selected results in sites where channel roughness and vegetational resistance are the main sources of resistance in most situations (Jordanova et al, 2004) and so only these two resistance sources were reviewed and are discussed in the following sections.

"Theoretical aspects" of open channel flow resistance are documented in publications such as Leopold et al (1960), Rouse (1965), Bathurst (1982) and Yen (2002), however these are not useful or appropriate in common applications due to their complexity.

2.1. Channel Roughness

The fundamental source of channel roughness in a river is frictional resistance. Frictional resistance is associated with the occurrence of shear stress along the boundary (i.e. bed). The shear stress originates in the interaction between the flow and the bed and is described by the following equation:

$$\tau_o = \gamma RS_f \qquad (2.1)$$

Where τ_o - the boundary shear stress

R - the hydraulic radius which is the ratio of the cross sectional area (A) to the wetted perimeter (P)

S_f - the energy slope, for uniform flow – the slope may be represented by the bed gradient (S_o)

γ - the specific weight of the fluid

The conventional approach to describe frictional resistance is based on the assumed proportionality between boundary shear and the square of the average velocity, with the resistance accounted for by a single coefficient of resistance (Bathurst, 1982).

The most commonly used equations for frictional resistance are:

- Manning n : $n = \frac{1}{V} R^{2/3} S^{1/2}$ (2.2)
- Darcy-Weisbach : $f = \frac{8g}{V^2} RS$ (2.3)
- Chezy C : $C = \frac{V}{\sqrt{RS}}$ (2.4)

Where V - the cross-sectional average velocity

R - the hydraulic radius

S - the energy or bed slope and

g - the gravitational acceleration

The Manning's equation has come to be the most widely used resistance equation in practical river hydraulics but the resistance equations may be interchanged conveniently as the coefficients are related as follows:

$$\frac{1}{\sqrt{g}} \frac{R^{1/6}}{n} = \frac{C}{\sqrt{g}} = \sqrt{\frac{8}{f}} \qquad (2.5)$$

Relative submergence is defined as the ratio of flow depth (y) to a representative sediment size (k_s). The d_{84} size[1] is commonly used to represent k_s. According to their ratios, the roughness is divided into the following categories by Bathurst et al (1981):

- Large-scale roughness - Roughness elements affect the free surface

  $y/d_{84} < 1.2$

- Intermediate-scale

  $1.2 < y/d_{84} < 4$

- Small-scale – Roughness elements do not affect the free surface

  $y/d_{84} > 4$

Frictional resistance is the dominant resistance source in a river when the relative submergence is greater than 4 i.e. small-scale roughness category.

As the surface water level decreases, the relative submergence decreases and the influence of the roughness elements on flow resistance is manifest as a combination of both element drag and effective boundary shear, or friction (Jordanova & James, 2006). In this intermediate-scale category, Bayazit (1976) found that the resistance is higher than predicted using the small-scale roughness resistance equations and concluded that the small-scale roughness equations are not appropriate for intermediate-scale flows.

Flow resistance due to large-scale roughness is related to the form drag of the roughness elements and their disposition in a riverbed (Jordanova and James, 2006). The form drag of an object varies according to whether the boundary layer on the object is laminar, turbulent, or transitional between these states, which are represented by the Reynolds number. The form drag is also influenced by deformation of the water surface by the object, which depends on the Froude number. The Froude number and Reynolds number are

[1] The size of the median axis of the bed material which is larger than 84% of the material.

therefore variables that can be related to the drag of the roughness elements (Bathurst et al, 1981).

A number of resistance equations for intermediate- and large- scale roughness regimes have been developed, however most are based on modifications of well known resistance equations that were developed for small-scale roughness and their applicability to intermediate- and large- scale roughness is uncertain (Jordanova et al, 2004 & Jordanova and James, 2006). The following references are suggested should the reader wish to obtain further information:-

- Bathurst (1978) proposed a resistance equation for relative submergence $y/d_{84} < 1.5$ based on field data.
- Hey (1979) fully modified the Colebrook-White equation making explicit allowances for the effect of cross-sectional shape, differences in bed and bank roughness and non-uniform sediment on the resistance to flow.
- Bathurst (1985) calibrated Hey's (1979) equation to develop a large-scale roughness equation.
- Bathurst (2002) developed two power equations for the variation of $\left(\frac{8}{f}\right)^{1/2}$ with relative submergence.
- Other references include: Bray (1979); Dittrich and Koll (1997); Lawrence (1997); Lawrence (2000); Nikora et al (2001); Smart et al (2002)

  Jordanova and James (2006) undertook laboratory experiments using concrete hemispheres to develop an approach for estimating intermediate- and large- scale roughness coefficients directly. The research thus enables practitioners to establish resistance coefficients for intermediate- and large- scale roughness during IFR studies which can then be applied to other applications. The Jordanova and James (2006) roughness coefficients for intermediate- and large- scale roughness will therefore improve hydraulic calculations and models and were therefore included in the guide. The research is described in Appendix A, pages 44 – 47.

2.2. *Vegetational Resistance*

Vegetation is an important component of river ecosystems that create habitat diversity for aquatic animals, stabilises channel and banks by reducing scour and is a good indicator of water quality by assessing the presence of certain species. On the other hand, vegetation in rivers influences the overall flow resistance and understanding of the effects of vegetation on channel hydraulics is essential to successfully predict flow resistance (Jordanova et al, 2004).

Resistance due to vegetation depends on the size of the plants, their structural properties, location in the channel and the local flow conditions (Green, 2005), but plant structures are challenging to describe numerically because of their numerous shapes and structures and the mosaic of their distribution along rivers (Anderson et al, 2006). Vegetation further complicates resistance quantification as plants change characteristics with season. The nature of flow resistance due to vegetation is determined by the growth habit of the vegetation, which may be one of four types:

- *Submerged* – entire plant is below the water surface
- *Free-floating* – the plant floats and is unattached to the substratum
- *Floating-leaved* – the plants are rooted in the substratum but most of the foliage is at the water surface
- *Emergent* – the plants are rooted in the substratum and the stems and leaves protrude above the water surface

Various approaches have been developed to predict flow resistance in vegetated channels. The approaches are generally based upon the conventional open channel resistance equations, with the effective roughness coefficients determined experimentally or through estimations of the drag coefficient for vegetated elements (Jordanova et al, 2004). A selection of these approaches is discussed below.

Freeman et al (1998) developed a method for estimating Manning's n for shrubs and woody vegetation. They suggested the following equations:

- for the estimation of Manning's n value under submerged flow conditions $(y > 0.8H)$

$$n_{veg} = 0.039k_n\left(\frac{E_s A_s}{\rho V^2 A}\right)^{0.141}\left(\frac{H}{y}\right)^{0.175}(MA)^{0.191}\left(\frac{\upsilon}{VR}\right)^{0.0155} \qquad (2.6)$$

- for the estimation of Manning's n value for emergent conditions $(y < 0.8H)$

$$n_{veg} = 2.2x10^{-6}k_n\left(\frac{E_s A_s}{\rho V^2 A_*}\right)^{0.242}(MA_*)^{0.0623}\left(\frac{\upsilon}{VR}\right)^{0.662} \qquad (2.7)$$

Where

A - the frontal area of an individual plant blocking flow (*ft*^{2})

A_* - the net submerged frontal area of a partially submerged plant (*ft*^{2})

A_s - the total cross sectional area of the stem of an individual plant (*ft*^{2})

E_s - the modulus of plant stiffness (*lb/ft*^{2})

H - the average undeflected plant height (*ft*)

k_n - the unit conversion for Manning's equation (1 for SI, and 1.49 for imperical units)

M - the relative plant density (number of plants per *ft*^{2})

R - the hydraulic radius (*ft*)

V - the velocity (*ft/s*)

υ - the fluid dynamic viscosity (*ft*^{2}*/s*)

Freeman et al (2002) further developed similar equations for bushes and trees.

Petryk and Bosmajian (1975) developed a flow resistance prediction method for densely vegetated flood plains:

$$n = n_b \sqrt{1 + \left(\frac{C_d \sum A_i}{2gAL} \right) \left(\frac{1.49}{n_b} \right)^2 R^{3/4}} \qquad (2.8)$$

Where

n_b - the Manning's boundary roughness coefficient, excluding the vegetation

C_d - the effective drag coefficient for the vegetation in the direction of flow

A - the cross-sectional area of flow

L - the channel length

$\sum A_i$ - the projected vegetation area in the streamwise direction

1.49 – the correction factor for imperial units (1 for SI units)

The analytical results produce Manning *n* values that increase with increasing depth for non-submerged vegetation. The limitations of this model require that the velocity is small enough to prevent a large degree of plant bending, the vegetation is distributed relatively uniformly in the lateral direction, large variations in average velocity do not occur across the channel, the maximum flow depth is less than or equal to the maximum height of vegetation, and large variations in flow velocity do not occur over the flow depth.

The hydraulics of shallow, non submerged flow in a densely vegetated channel cannot be treated using Manning's roughness relationship, mainly due to the fact that, with the water flowing among the randomly patterned vegetation blades, drag resistance, instead of shear resistance, becomes the dominant component in the analysis of the mechanics of the flow system (Jordanova et al, 2004).

Li and Shen (1973) developed a mathematical model to describe the mean flow properties in an open channel with a multi-cylinder distribution. They based their model on the following assumptions:

i. The flows are steady and uniform
ii. Linear superposition of the velocity defect is valid
iii. The boundary shear stress is uniformly distributed over the bed
iv. The form resistance is assumed to be entirely due to vegetation
v. The bed form resistance is negligible

Desai and Chicktay (2005) proved assumption (ii) to be valid. Their experiments consisted of obtaining cross sectional velocity profiles for various cylinder configurations and then testing whether the same profiles could be obtained by linear superposition.

James et al (2001) developed a resistance model for flow through emergent reeds for uniform flow conditions within homogenous arrangements of rigid, vertical stems. They also proposed an alternative form of equation for conditions where resistance arises predominantly from stem drag. The model developed is REEDFLO v2. Sensitivity analysis showed that the bed roughness size, k_s, to be insignificant for vegetated streams where stem drag dominates.

Naot et al (1996) carried out an investigation on the hydrodynamics of turbulent flow in partly vegetated open channels. Three channel configurations were studied, consisting of a rectangular open channel with a vegetated bank, a vegetated corner and a vegetated floodplain. A model predicting complex hydrodynamic behaviour was proposed and two sets of experiments of three-dimensional turbulent flow in partly vegetated rectangular channels were conducted for comparison, with a nondimensional vegetation density (N) used to specify the cases, i.e.

$$N = 100nHD \tag{2.9}$$

Where

n - the vegetation density (rods per unit area)

H - the flow depth

D - the averaged rod diameter

It was concluded that an increase in vegetation density affects the streamwise velocity and the energy of turbulence until the nondimensional vegetation density (*N*) equals 32, after which the vegetated domain becomes practically impenetrable.

The quantification of resistance in a river is complex due to the multiplicity of sources and their high variability. Useful results are largely empirical and case specific with very limited generality. A number of methods have been developed that assist the hydraulic practitioner in estimating roughness coefficients. A discussion of these methods is provided in the section 3.

3. Methodologies to Determine Roughness Coefficients

The procedure for determining roughness coefficients in rivers is partly subjective and requires judgement and skill which must be developed through experience.

Various methods have been developed to aid in achieving this experience, these are:

i. Tables of Manning's n

Chow (1959) produced tables of Manning's *n* for various surface materials covering a wide range of channels, which provide a good initial source of roughness values.

ii. Photographic Matching Guide – Visual Comparison

Estimating resistance coefficients by photographic matching involves using river sites for which roughness coefficients have been calculated as reference sites for estimating roughness coefficients for similar unstudied sites. The objective of photographic matching is to gain experience by examining and becoming acquainted with the appearance of some typical rivers whose roughness coefficients are known. Familiarity with the appearance, geometry and bed, bank and vegetation characteristics of these river sites will improve the hydraulic practitioner's ability to estimate resistance coefficients for other sites.

Photographic matching may be used to (i) obtain a resistance coefficient for use in hydraulic modelling, (ii) as verification to other roughness estimation methods or (iii) as an initial estimate in other roughness estimation methods.

Two commonly used photographic matching books are entitled:

1. Roughness Characteristics of Natural Channels (Barnes, 1967)
2. Roughness Characteristics of New Zealand Rivers (Hicks & Mason, 1998)

Barnes (1967) rarely presents more than a single flow resistance value per section and so changes in flow resistance with changes in discharge are absent, resulting in uncertainties.

Ladson et al (2003)[2] and Marsh et al (2001)[3] have developed web-based guides for 25 Australian and 64 United States rivers respectively. The guides present Manning *n* values, hydraulic data and photographs. The United States data presented are predominantly Barnes (1967) data. The web-based guides require access to the internet, which may be inconvenient (cost and technologically) for South African field conditions. The cost inconvenience is due to internet access being expensive, and the inconvenience of technologically is that low connection speeds or no internet access are achieved during site studies.

iii. United States Soil Conservation Service Method (SCS) (1963)

A method presented by Cowan (1956) for estimating the overall resistance of a channel. The method involves the selection of a basic value of Manning's *n* for a uniform, straight and regular natural channel. The basic value is then adjusted for the effects of surface irregularities, shape and size of channel cross section, obstructions, vegetation and flow conditions and the meandering of the channel. It requires subjective estimates of the effect of various factors on the resistance coefficient. Tables suggesting values for each of the individual adjustments factors are given. These are then combined according to the following equation to get the overall roughness coefficient in terms of Manning's *n*:

$$n = (n_b + n_1 + n_2 + n_3 + n_4)m \qquad (3.1)$$

[2] URL: http://www.rivers.gov.au
[3] URL : http://il.water.usgs.gov/proj/nvalues/nvalues.html

Where n_b – the basic value for the channel surface

n_1 – accounts for the effect of surface irregularities

n_2 – accounts for the variations in shape and size of the cross section

n_3 – accounts for obstructions

n_4 – accounts for vegetation and flow conditions

m – adjustment for meandering channels

Arcement and Schneider (1989) have developed a similar procedure for selecting Manning roughness coefficients for flood plains. The roughness value for the flood plain is determined by selecting a base value of n_b for the natural bare soil surface of the flood plain and adding adjustment factors due to surface irregularity, obstructions, and vegetation. Tables suggesting values for each of the individual adjustments factors are given.

Photographs representing densely vegetated flood plains are presented in Arcement and Schneider (1989) for which roughness coefficient have been verified for use as photographic matching methods.

iv. ASCE Task Force on Friction Factors in Open Channels (1963)

The ASCE Task Force on Friction Factors in Open Channels (1963) reviewed the information available at the time and recommended using f rather than n because it correlates better with experimental data over a wide range of conditions. The following equations are recommended for estimating f :

- For hydraulically rough flow (Re^*> 70):

$$\frac{1}{\sqrt{f}} = c\log\left(\frac{aR}{k_s}\right) \tag{3.2}$$

- For transitional flow ($5 < Re^* < 70$):

$$\frac{1}{\sqrt{f}} = -c\log\left(\frac{k_s}{aR} + \frac{b}{\mathrm{Re}\sqrt{f}}\right) \tag{3.3}$$

- For hydraulically smooth flow ($Re^* < 5$):

$$\frac{1}{\sqrt{f}} = c\log\left(\mathrm{Re}\frac{\sqrt{f}}{b}\right) \tag{3.4}$$

Where f - the Darcy-Weisbach friction factor

R - the hydraulic radius

k_s - the size of roughness elements

Re - the Reynolds Number

a, b, c - are empirical coefficients

The Task Force derived the following values for the constants from various data sets:

$a = 12$
$b = 2.51$
$c = 2$

Re^* - the Shear Reynolds number

$$\mathrm{Re}^* = \frac{u_* k_s}{\upsilon} \tag{3.5}$$

Where υ - the fluid dynamic viscosity

u_* - the shear velocity

$$u_* = \sqrt{\frac{\tau_o}{\rho}} \tag{3.6}$$

Where τ_o - the boundary shear stress (see equation 2.1)

ρ - fluid density

Equations (3.2) to (3.4) were established for lined channels, however they can be used for unlined alluvial channels were bed forms are not present and resistance to flow arises from friction. The appropriate values of k_s is determined by the grain size of the sediment, but as a range of sizes is usually present, specification of a representative value is not straightforward. Values recommended by various researchers in terms of grain size measures (d_s) are listed in Table 3.1.

Table 3.1 – Recommended k_s Values

Source	k_s
Ackers and White (1973)	1.25 d_{35}
Hey (1979)	3.5 d_{84}
Engelund and Hansen (1967)	2 d_{65}
Kamphuis (1974)	2.5 d_{90}
Mahmood (1971)	5.1 d_{84}
van Rijn (1982)	3 d_{90}

v. *Direct Measurement Method (Barnes, 1967)*

Manning's n is determined directly from discharge, water surface slope and hydraulic geometry of the channel.

This method is applicable to a multi-section reach. Manning's n is obtained from the following equation (3.2):

$$n = \frac{1}{Q}\left(\frac{(h_m - h_1) + (h_{v_m} - h_{v_1}) - (k_{1.2}\Delta h_{v_{1.2}} + k_{2.3}\Delta h_{v_{12.3}} + \cdots k_{(m-1).m}\Delta h_{v_{(m-1).m}})}{\frac{L_{1.2}}{Z_1 Z_2} + \frac{L_{2.3}}{Z_2 Z_3} + \cdots \frac{L_{(m-1).m}}{Z_{(m-1)} Z_m}} \right)^{\frac{1}{2}} \quad (3.7)$$

Where m – is the number of cross sections, mth section being the furthest upstream section

$Z = AR^{2/3}$

L - the reach length (m)

h - the elevation of the water surface (m)

h_v - the velocity head (m)

Q - the discharge (m^3/s)

Δh_v - the change in velocity head (m)

Similar equations for Chézy C and the Darcy-Weisbach friction factor have also been developed.

This method is ideal to accurately determine the roughness coefficient for a reach; however it requires time, money and capacity to obtain the data.

vi. Conveyance Estimation System (CES) (HR Wallingford, 2004)

CES is a software tool that has been developed by HR Wallingford. It is a compilation of bed resistance data and consists of 3 parts:

I. Roughness Advisor

Provides roughness values (unit roughness)[4] based entirely on the local boundary friction. The total unit roughness is determined from: $n_1 = \left[n_{sur}^2 + n_{veg}^2 + n_{irr}^2\right]^{\frac{1}{2}}$ (3.8)

Where $n_{sur}, n_{veg}, n_{irr}$ are unit roughness values due to surface material, vegetation and irregularities.

The unit roughness values are associated with a depth of 1m, which was selected as a representative depth of flow for UK rivers.

[4] A unit roughness represents the roughness due to an identifiable segment boundary friction within the channel section.

II. Conveyance Generator

Determines the channel capacity based on the channel roughness from the roughness advisor and channel morphology. The approach used is based on the depth-integrated Reynolds Average Navier Stokes (RANS) equations for flow in the stream-wise direction. RANS incorporates boundary friction, lateral shearing and momentum exchange energy losses but does not consider form losses. The output is a stage-conveyance relationship i.e.

$$Q = KS^{1/2} \tag{3.9}$$

Where Q - the discharge (m^3/s)

K - the conveyance (m^3/s)

S - the common uniform gradient

III. Uncertainty Estimator

Provides some indication of the uncertainty associated with the conveyance calculations. The output is a set of upper and lower confidence bands for the stage-conveyance relationships.

The methods presented in this section provide professionals with a foundation to develop the expertise in estimating roughness coefficients. However, many South African rivers are not well represented in the methods discussed, as the conditions under which they were developed are different to South African river conditions and application of them to South African Rivers may lead to errors. Furthermore, hydraulic analyses required in the Ecological Reserve determination are focused on the low flow component of the hydrological regime and sites are often characterised by large-scale roughness (Jordanova et al, 2004) but the methods do not effectively analyse the large-scale roughness regime.

Improved methods of roughness estimation therefore have great potential to improve the accuracy of hydraulic calculations, improve the design of engineering structures and rehabilitation works and contribute to better targeted flood management and reserve determination efforts (Anderson et al, 2006).

There is therefore a need to develop a guideline that would represent South African conditions and thus improve river hydraulic studies in South Africa. The development of this guide is discussed in the following section.

4. Development of Guide

Over the past decade, numerous IFR studies have been undertaken in South Africa. In these studies, data representing South African river conditions were collected. However, the data are not easily accessible. The need to develop a guide representing South African conditions was thus matched by the need to make existing data more accessible.

Developments of large-scale roughness resistance predictions methods (Jordanova and James, 2006) and South African IFR hydraulic data provide the foundation for the development of a South African resistance guideline that will result in less uncertainty, not only in Reserve determination but other river related studies.

Photographic matching methods are often preferred due to their simplicity, as only a few calculations are required compared to the analyses of other resistance estimation methods. It was thus decided to develop a photographic matching guide containing hydraulic characteristics from South African IFR studies and a discussion of the development of this guide follows.

In today's high tech world, it is assumed that many hydraulic practitioners would have access to a computer and that it would be a great advantage for them to have the guide in electronic format. Electronic formats will also give the opportunity to provide much more data than a hard copy could. It was therefore decided to develop an electronic guide, but the guide should not use or require expensive software or hardware to operate, thus providing access to the guide for a larger group of practitioners.

Microsoft Access was the choice of database software as this software is not very expensive and comes included in Microsoft Office Suite Professional Edition which most practitioners are assumed to have or can afford.

A discussion of the structure of the database is given in Appendix B, pages 48 – 53. The following sections provide further information on the development of the guideline.

4.1. Site Selection, Site Survey and Data Collection

This section is summarised from Appendix R18 of the Ecological Reserve documentation produced in 1999 (Louw et al. 1999) which highlights the key points of the site selection process.

IFR sites, or EWR (Ecological Water Requirement) sites as they are now called, are selected through a multi-disciplinary process, often consisting of a process of evaluating an aerial video of the river, and ground truthing various options. The IFR site consists of a length of river which could consist of various cross-sections for both hydraulic and ecological purposes.

Environmental Flow requirements are set for each of the IFR sites, and it is therefore vital that;

- the sites are selected to provide as much information as possible about the variety of conditions in a river reach,
- the specialists who need to use these sites to set flow requirements for their discipline can relate to the habitat the sites represent, and
- the persons involved in selecting the sites understand and are experienced with the use of sites in environmental flow requirement studies.

The selection of IFR sites is guided by a number of considerations, including the following:

- The locality of gauging weirs with good quality hydrological data.
- The locality of the proposed and existing developments.

- The locality and characteristics of tributaries.
- The habitat integrity or Present Ecological State (PES) of the different river reaches.
- The boundaries of Level II EcoRegions within the study area
- The reaches where social communities depend on a healthy river ecosystem.
- The suitability of the sites for follow-up monitoring.
- **The habitat diversity for aquatic organisms, marginal and riparian vegetation.**
- **The suitability of the sites for accurate hydraulic modelling throughout the range of possible flows, especially low flows.**
- **Accessibility of the sites.**
- **An area or site that could be critical for ecosystem functioning.** [5]
- The locality of geomorphologically representative sites.

(The criteria in boldface are the most important and therefore the overriding criteria)

Sites with riffles have been commonly selected. These sites are hydraulically complex, especially during low flows, which receive much attention in IFR determination. At such sites, discharge measurements or calculations are difficult and so for these sites where manual gauging was required, discharge was measured at a nearby site where the cross section was acceptable for manual gauging.

Surveys were done to define the cross sectional profile of the river channel in sufficient detail to identify features of interest to river

[5] **These are often represented by riffle units, where low flow conditions or the cessation of flow constitutes a break in the functioning of the river, and consequently, the biota dependent on this habitat and/or perennial flow are adversely affected. Pools are not considered critical habitats in perennial systems since they are still able to function or at least maintain life during periods of no flow (Louw et al, 1999).**

scientists and to enable hydraulic measurements and analysis to be undertaken at sufficient levels of resolution. Surveys were preferably undertaken during low flow conditions to incorporate all significant changes in slope along the profile. The profiles were surveyed from bank to bank of the macro channel and included the location and type of instream, marginal and riparian vegetation.

Longitudinal river bed and water surface profiles are surveyed at the lowest bed level, extending approximately ten channel widths beyond the downstream and upstream cross section.

Discharges were recorded using various methods viz. the use of existing rated sites (natural river sections, surrogate discharge sites and structural gauges) and manual techniques (velocity-area and dilution methods).

Photographs of each site were taken from subsequent identifiable and repeatable position. The photograph positions are:

- across the channel along the surveyed cross section,
- facing upstream and downstream with the surveyed cross section in the foreground and,
- a site view – a photograph showing cross section, upstream and downstream.

However, only photographs that were available were used in the database and so not every site has a complete set of photographs.

4.2. Presentation of Information

Site information, hydrological information, hydraulic properties, photographs, cross sectional and stage discharge plots, ecological information and geomorphological information are presented in the guide. The information presented is a combination of modelled and measured data, the measured data are indicated in the discussion below.

The site information includes:

- the site name - which consists of the river name and IFR No.,
- the river name
- IFR No. of the IFR study
- a locality name, which may provide further site identification.
- Longitude, latitude and altitude [measured]
- the channel slope [measured]
- geomorphological unit type and zone (see Biophysical Information, in the guideline documents on the CD – Appendix C, page 54)
- grading data - % Finer Than (d_{16}, d_{50} and d_{84}) [measured]
- relative roughness scale – small, intermediate and large

Mean Annual Runoff (MAR), virgin and present, are presented as the hydrological information. The virgin represents the natural runoff and present is the current runoff [measured].

The hydraulic properties include: Discharge (m^3/s) [measured], area (m^2), wetted perimeter (m), hydraulic radius (m), water surface width (m), water surface slope – longitudinal [measured], distance (m) over which the slope was measured [measured], maximum and average flow depths (m), average velocity (m/s) and Manning n, Chezy C and Fj[6] roughness coefficients. Note that when no water slope was measured, the roughness coefficients could not be determined. However, the site information has been included in the database for information purposes and so that the data do not get lost and one may use it as reference data if the site is ever studied again.

[6] Research undertaken by Jordanova and James (2006) for Large Scale Roughness – see section 2 and Appendix A

A cross sectional plot of the IFR site is included to indicate the cross sectional profile, and may indicate a water surface level for a specific discharge. Where vegetation surveys were undertaken, the vegetation is also indicated. Further details of each cross section may be found in the caption below the plot.

A stage-discharge plot and the stage-discharge equation coefficients for the rating equation, $y = aQ^b + c$, are included to provide the user with an understanding of how discharge varies with flow depth for the site. Q is the discharge, y is the maximum flow depth and a,b,c are the regression coefficients.

Stage-discharge plots and rating equations are outputs of a one-dimensional hydraulic model. The rating equation is used along with the cross-sectional geometry to compute the relationship between discharge and other hydraulic properties (e.g. average flow depth, wetted perimeter and average flow velocity). This information is necessary for all sites during all eco-hydraulic studies. Stage-discharge information therefore provides the basis for all further hydraulic analysis.

All available photographs for each site are presented.

Ecological information included is: Quaternary catchment – which is a regional reference to the site. Present Ecological State (PES) and Ecological Importance and Sensitivity (EIS) are also included and the reader should refer to the Biophysical Information, authored by Delana Louw, document in the guide for more information.

Depending on the search option used, the sites will be presented in ascending order of the search criteria.

5. How to Use the Guide

In order to use the guide, the following hardware and software requirements are recommended:

- 60MB of HDD space – this is required to copy the database to the hard drive. The user should refer to the README.TXT file for instructions to copy the guide to the hard drive.
- 512 MB of memory (minimum)
- CD Drive (minimum)
- MS Access (2002 or later)
- MS Word (2002 or later), and enough space to install these software

Insert the CD (Appendix C, page 54) into the CD/DVD drive and open the folder, *Guideline to Hydraulic Characteristics of SA Rivers*. Open the Access database file, *Characteristics of SA Rivers.mdb*.

Once the database (*Characteristics of SA Rivers.mdb*) is opened, a menu with three options will be visible: Begin Searching Database, Documents and Exit Access, Figure 1.

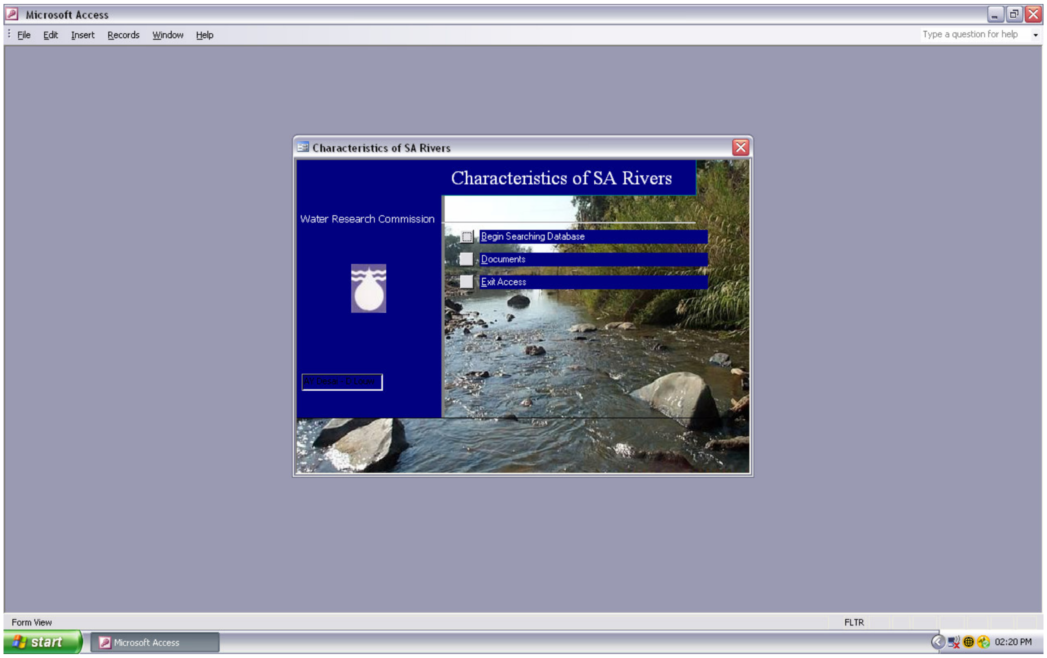


Figure 1 - Main Menu

The underlined letters are hot keys and so the options may be chosen either by clicking the grey squares or pressing ALT + hot key.

'Begin Searching Database' option will open up a second menu, Figure 2, containing 5 search options: Search for Bed Material, Search for a Range of Maximum Flow Depths, Search for a Geomorphological Unit, Search for a Range of Manning Roughness Coefficients, and Search for a River. The sixth option will result in the main menu opening, Figure 1. The options may be accessed by clicking on the grey square or ALT + hot key.

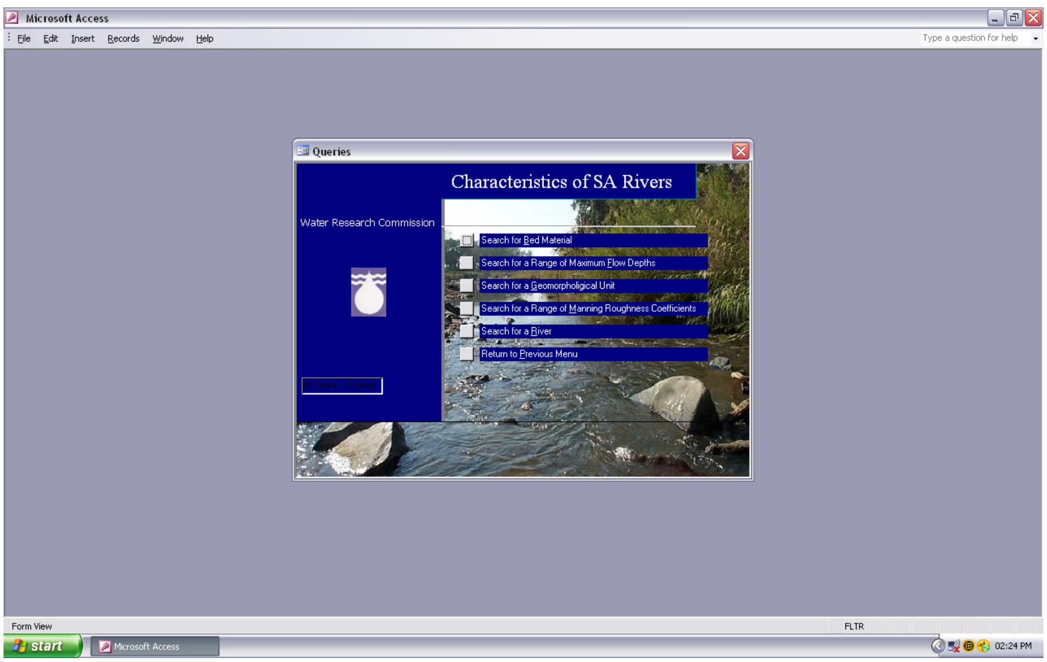


Figure 2 - Search Menu

After selecting a search option, a prompt will be displayed asking for the search criteria. The prompts are:

- Search for Bed Material: "Please Enter in One of the Following Bed Material Types Below" – the user needs to enter in the bed material type listed in the box. Note that the *s before and after the material type need to be included as search criteria. The reason for this is to include sites with multiple bed material types. Once the text has been typed into the space, click OK or press Enter twice to execute the query.

To cancel this search, click the X button which is at the top right of the box.

- Search for a Range of Maximum Flow Depths: "Please Enter in the Maximum Flow Depth Range" – the user needs to enter in the Lower and Upper Limits of the maximum flow range they wish to search for in the respective spaces provided. Once the values have been entered, click OK or press Enter repeatedly until query executes.

  To enter in the values into the spaces, either click on the space or press Tab until the cursor is in the correct space you require.

  To cancel this search, click the X button which is at the top right of the box.

- Search for a Geomorphological Unit: "Select a Geomorphological Unit" – the user is required to click on a geomorphological unit from the list.

  To cancel this search, click the X button which is at the top right of the box.

- Search for a Range of Manning Roughness Coefficients: "Please Enter in the Manning Range" – the user needs to enter in the Lower and Upper Limits of the Manning *n* range they wish to search for in the respective spaces provided. Once the values have been entered, click OK or press Enter repeatedly until query executes.

  To enter in the values into the spaces, either click on the space or press Tab until the cursor is in the correct space you require.

  To cancel this search, click the X button which is at the top right of the box.

- Search for a River: “Select a River/IFR Study” – the user is required to click on a river name/IFR study from the list.

  To cancel this search, click the X button which is at the top right of the box.

Note that if the OK button is highlighted (i.e. a blue square is visible around the word) and enter is pressed, the query will execute despite the user not inputting the correct criteria.

Once the criteria are entered, a query result form (Figure 3) will open with the relevant records. Note that if incorrect criteria are entered or no data matches the search, a blank form will be produced.

Note that the previous dialogue boxes (i.e. the ones requiring inputs) will remain open, this is done intentionally and the user must not close them. They will close automatically when the user closes the query result form. If they are closed, some of the options on the query result form will not operate correctly; the user will be requested to re-input the criteria and if the incorrect criteria are inserted then the larger images and hydraulic data will not match up to the query result form records.

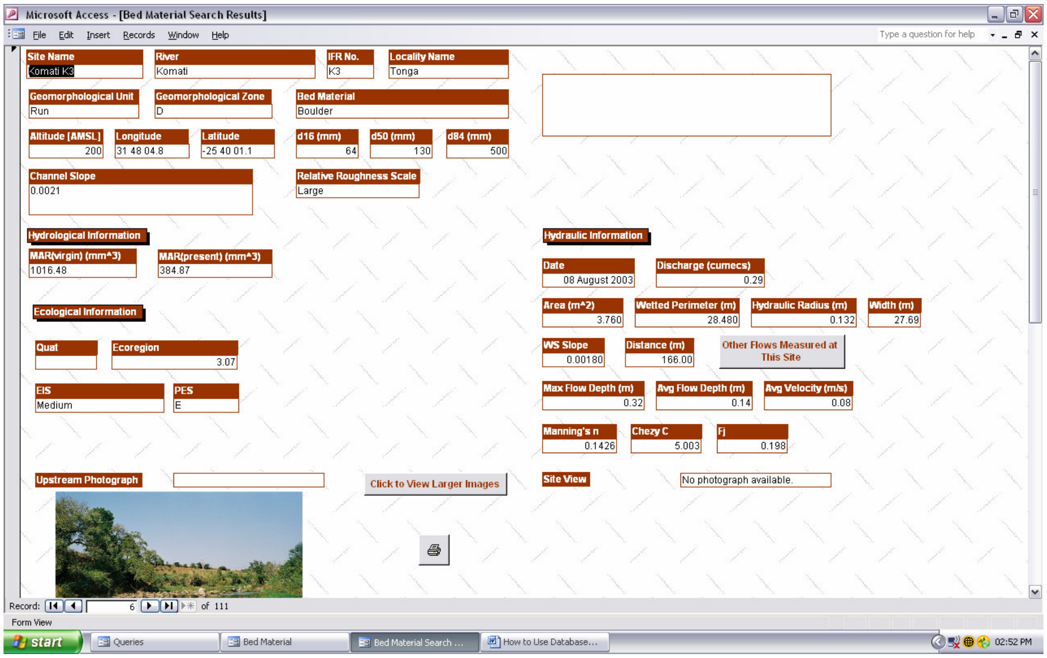
The number of records found can be seen at the bottom left of the form page. To move to another record, either scroll with the mouse scroll button or use the navigation section at the bottom of the form page, Figure 3. To go to a specific record number (if you know the number), type it into the navigation section and press Enter.
The navigation buttons are:

|◀ - 1st Record
◀ - Back one record
▶ - Next Record
▶| - Last Record

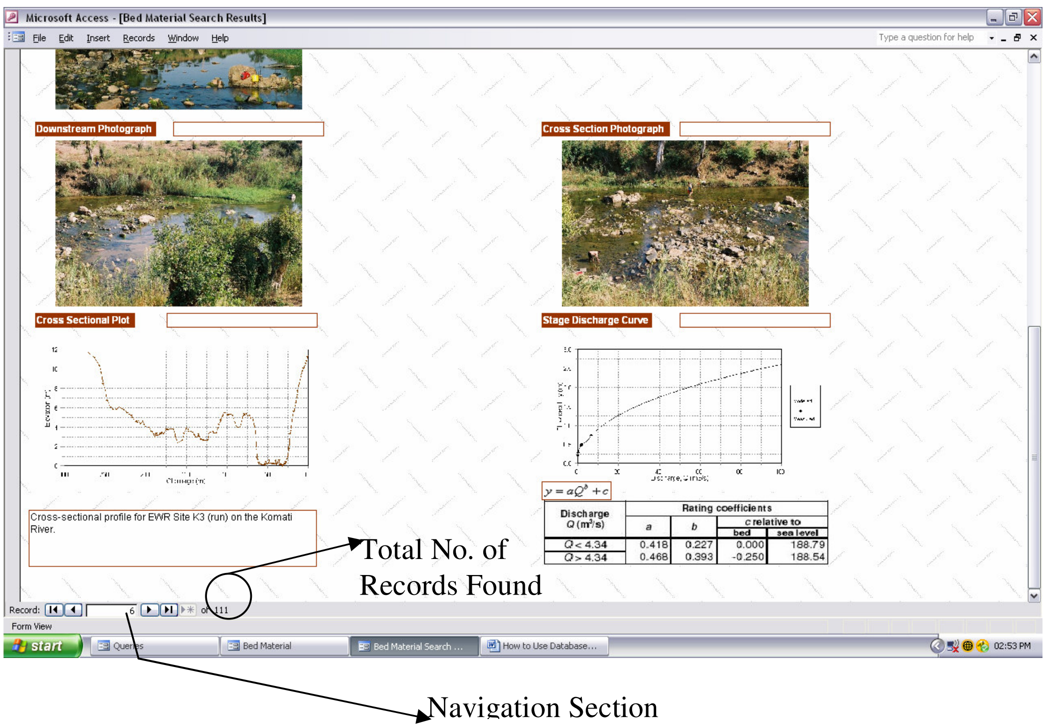
To view the lower portion of the form, use the vertical scroll bar to go down or press PgDn, scrolling with mouse button will not scroll down the page but move to the next/previous record. To go back up to the upper portion, use the vertical scroll bar to go up or press PgUp. Note that time should be given for the images to load on the form before moving onto the next record or else the database will jam with an error being displayed. The user will then have to restart the database by closing it and reopening the database after a minute.

An option to print out the current form is provided, Figure 4. Click once on the button and 4 pages will be printed to the default printer. An example of the printed pages is provided in Appendix D, pages 54 - 58.

Larger images may be viewed by clicking *Click to View Larger Images* button, Figure 4. This will open another form, Figure 5, which will contain all the images of the current site being viewed. The various images (upstream, downstream, cross-section and site view photographs and cross-section and stage-discharge plots) are in their respective tabs.



Upper Portion



Discharge Q (m³/s)	Rating coefficients			
	a	b	c relative to bed	c relative to sea level
Q < 4.34	0.418	0.227	0.000	188.79
Q > 4.34	0.468	0.393	-0.250	188.54

Lower Portion

Figure 3 - Example of Query Result Form

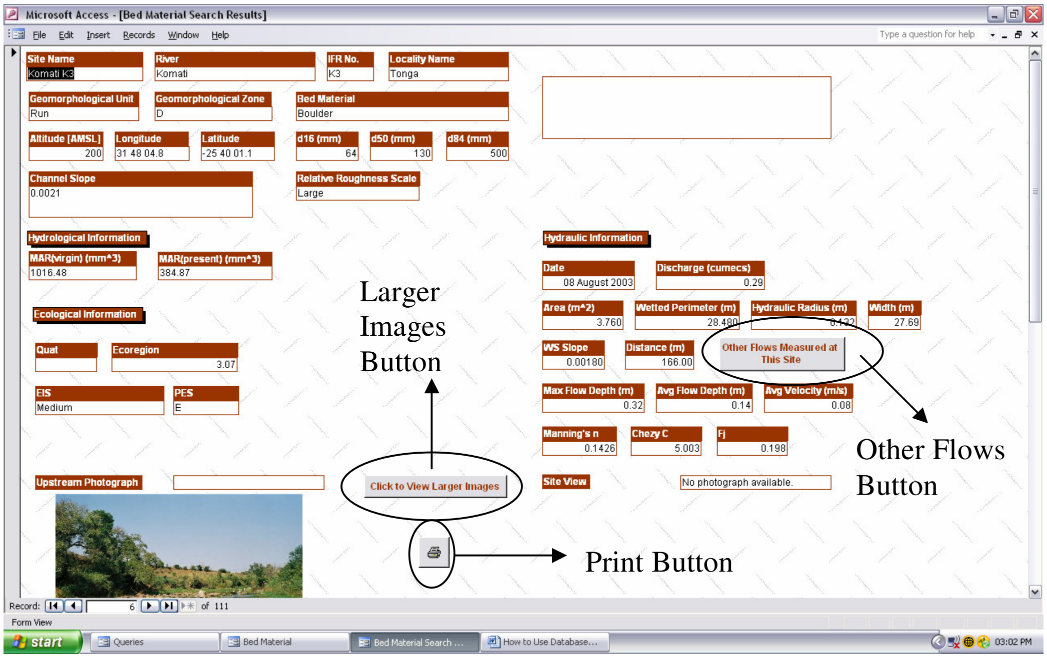


Figure 4 - *Print*, *Larger Images* and *Other Flows* Buttons

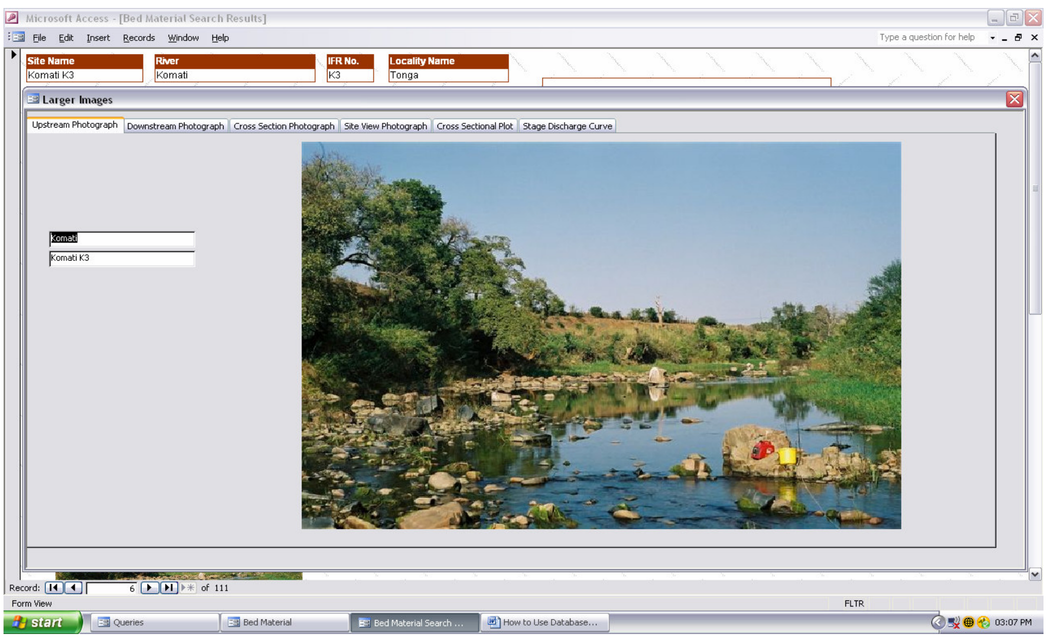


Figure 5 – Larger Images Form

By clicking on *Other Flows Measured at This Site*, you will be able to view all the measured and modelled data that was obtained on the current site being viewed, Figure 6 is a screen shot illustrating the result.

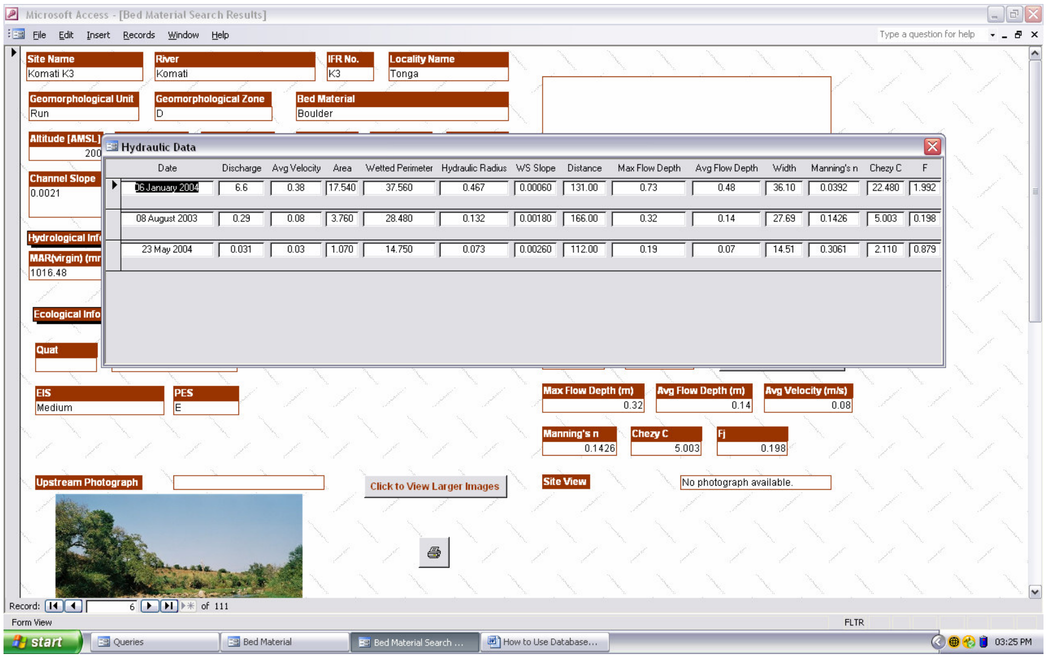


Figure 6 – Hydraulic Data for the Current Site

The larger image and hydraulic data forms are programmed such that when it is open no other object may be selected in Access. This means that in order to go back to the query result form, the user needs to close the form by clicking on the X at the top right corner of the form.

Once you have finished navigating through the records, close the query result form by clicking on the X at the top right corner of the form pages. If this form is not closed, no further queries can be performed.

The query menu will be visible again and a new query may be made. Multiple queries cannot be done as the data is locked once a query is executed and nothing else can then access the data, an error message will be displayed stating that the data is in use should multiple queries be attempted.

To exit, click on the "Return to Previous Menu" option and then select "Exit Access" option. This will close the database.

The "Document" option on the main menu opens a form with links to the following documents:

Introduction: A brief description of what and why the database was developed.

Site Selection, Site Survey and Data Collection: An explanation of how the river sites where selected, surveyed and how the data was collected.

Biophysical Information: An explanation of the ecological information that is included in the database, authored by Delana Louw et al.

Presentation of Information: A discussion of the information that may be found in the database.

How to Use Database: This document, explaining how to run the database.

Acknowledgements: All acknowledgements are made in this document.

Glossary: A list of symbols and abbreviations

References: A list of references

These documents may also be accessed directly on the CD; they are in the *Documents* subfolder of *Guideline to Hydraulic Characteristics of SA Rivers* folder. The documents are in MS Word format.

6. Conclusions and Recommendations

There are a number of methods available to help hydraulic practitioners estimate roughness coefficients for open channels. However, many of them do not have enough data or information to represent South African river conditions. Over the past decade, IFR studies have been undertaken on many rivers in South Africa and so the availability of data matched with the need for a guide representing South African conditions have led to an electronic guide containing South African data being developed.

The guide, *Guide to Hydraulic Characteristics of South African Rivers*, is an MS Access database containing hydraulic parameters and photographs. It is to be used as a photographic matching guide where the hydraulic practitioner attempts to match the unstudied river site's characteristics to the studied river site's characteristics found in the guideline.

A photographic matching guide was chosen as they are simple to use compared to the analyses of other resistance estimation methods. It is foreseen that the guide will improve the hydraulic practitioner's ability to estimate roughness coefficients for South African rivers. This increase in confidence of estimation will result in better rehabilitation programmes and hydraulic designs.

The limitation to the guide is that it does not contain any data or hydraulic characteristics which may be found in other existing guides that represent South African conditions. By including the relevant data from these guides, the South African guideline will provide much better estimations as there will be more characteristics to choose from. Until then, practitioners are advised to consult other guides as well. The guide also does not include resistance due to vegetation and alluvial roughness.

The guide only produces measured and modelled data of the studied sites; it would be a more useful guide if other modelling tools were incorporated with the guide. The guide will then be a complete software: from estimating roughness coefficients to plotting stage-discharge curves to modelling all the hydraulic parameters.

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Appendix A – Jordanova and James (2006) Intermediate- and Large- Scale Roughness Research

A.1 Large-Scale Roughness

The general large-scale roughness equation proposed by Jordanova and James (2006) is:

$$V = \frac{1}{Fj}\sqrt{2 \cdot g \cdot R_{vol} \cdot S} \qquad \text{(A1.1)}$$

Where

V - is the average velocity (m/s)

S - is the energy slope

R_{Vol} – is the volumetric hydraulic radius which is the ratio of water volume to plan area.

Fj - is the large-scale resistance coefficient calculated according to:

$$Fj = 0.05 \cdot Fr^{-0.868} \cdot \mathrm{Re}_{ds}{}^{0.12} \cdot \sigma^{-0.228} \qquad \text{(A1.2)}$$

Where

Fr - is the Froude Number, which can be calculated according to:

$$Fr = \sqrt{\frac{Q^2 \cdot B}{g \cdot A^3}} \qquad \text{(A1.3)}$$

Where

Q - is the discharge (m/s)

B - is the channel width at the water surface (m)

A - is the cross-sectional flow area (m^2)

Re_{ds} is the Reynolds number, based on a representative largest sediment size, which can be calculated according to:

$$\mathrm{Re}_{ds} = V \cdot ds/\nu \qquad \text{(A1.4)}$$

Where

V - is the average velocity

ν - is the kinematic eddy viscosity

d_s - is a representative largest sediment size

σ is the geometric standard deviation of the sediment size distribution. The equation suggested by Jordanova and James (2006) is:

$$\sigma = d_{84}/d_{50} \qquad \text{(A1.5)}$$

Where

84% of the sediment mass consists of particles smaller than d_{84} and

50% of the sediment mass consists of particles smaller than d_{50}.

A.2 Intermediate-Scale Roughness

Under intermediate-scale roughness conditions, the total discharge can be considered to be the sum of the discharges below and above the tops of the large roughness elements. Alternatively, the discharge can be calculated using a velocity obtained as a weighted product of velocities reflecting the influences of roughness element drag and boundary friction, with the weighting factor depending on the relative submergence. An approach for each hypothesis was developed and are presented below.

1. The average flow velocity for this condition is given by

$$V = \sqrt{\frac{4}{f}}\sqrt{2gy_{eff\,2}}\sqrt{S} \qquad \text{(A1.6)}$$

Where

y_{eff2} - is the effective flow depth, accounting for the volume of the roughness elements (m) – Figure A1,

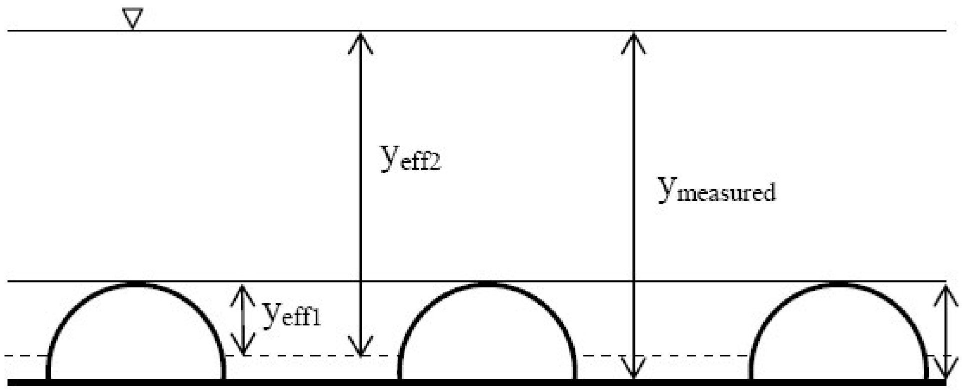

Figure A7 - Intermediate-Scale Roughness Condition

S - is the energy slope,

V - is the average velocity (m/s), and

f - is an effective friction factor that accounts for bed element resistance, given by

$$\sqrt{\frac{4}{f}} = \left(\frac{y_{eff1}}{y_{eff2}}\right)^{3/2}\left(\frac{1}{F_j}\right) + \left(1 - \frac{y_{eff1}}{y_{eff2}}\right)^{3/2}\sqrt{\frac{4}{f_2}} \qquad \text{(A1.7)}$$

Where

f_2 - is the friction factor under small-scale roughness conditions,

F_j - is the large-scale resistance coefficient (see equation A1.2), and y_{eff1} - is the height of the tops of the roughness elements above the lowest bed level.

2. Flow resistance for intermediate-scale roughness may also be described as a combination of roughness element drag and boundary friction equations, the velocity is described as

$$V = \left(\frac{1}{Fj}\right)^{a}\left(\sqrt{\frac{4}{f_2}}\right)^{(1-a)}\sqrt{2 \cdot g \cdot R_{Vol} \cdot S} \qquad \text{(A1.8)}$$

Where

a - is a weighting factor, varying from 1 to 0, that depends on the relative submergence (y_{eff2}/d_s) according to

$$a = -0.67\ln\left(\frac{y_{eff\,2}}{d_s}\right) + 0.992 \qquad \text{(A1.9)}$$

Where

d_s - is a representative largest sediment size.

Note that with $\left(\frac{y_{eff\,2}}{d_s}\right) = 0.988$, this equation gives $a = 1$, and the equation becomes the same as that for large-scale roughness (equation A1.1). With $a = 0$, equation A1.8 will take the form of equation 2.3.

Appendix B – Database Structure

Microsoft Access uses tables to store data/information. The tables created are listed below with data type and description of each field presented.

Table B2 - Cross Sections Table

Fields	**Data Type**	**Description**
SiteName	Text	Primary Key – River Name IFR No.
ChannelSlope	Text	Longitudinal Channel Slope
GeomorphZone	Text	Geomorphological Unit
River	Text	River Name
LocalName	Text	Locality Name
IFRNo	Text	IFR Number e.g. IFR 1 = 1
CrossSection	Text	Cross Section Plot – File Address Required
Notes	Text	Cross Section Plot Caption
yQCurves	Text	Stage-Discharge Plots – File Address Required
yQNotes	Memo	Stage-Discharge Caption
yQEqt	Text	Stage-Discharge Coefficient – File Address Required
BedMaterial	Text	Bed Material Types
d_{16}	Number	Particle Size – 16%
d_{50}	Number	Particle Size – 50%
d_{84}	Number	Particle Size – 84%

Table B3 - Ecological Table

Fields	Data Type	Description
SiteName	Text	Primary Key – River Name IFR No.
Quat	Text	Quaternary
MAR(virgin)	Text	Mean Annual Rainfall – virgin
MAR(present)	Text	Mean Annual Rainfall – present
Altitude	Number	Site Altitude
PES	Text	Present Ecological State
Latitude	Text	Latitude of Site
Longitude	Text	Longitude of Site
Ecoregion	Number	
GeomorphologicalZone	Text	Geomorphological Zone
EIS	Text	Ecological Importance and Sensitivity

Table B4 - Hydraulics Table

Fields	Data Type	Description
Site Name	Text	River Name IFR No.
Date	Date/Time	Date of Study
Discharge	Text	Discharge Measured
Key	Text	Primary Key - Site Name and Discharge
Scale	Number	Roughness Scale
F	Number	Jordanova and James (2006)
Avg Velocity	Number	Average Velocity
Area	Number	Cross Sectional Area
Wetted Perimeter	Number	Wetted Perimeter
Hydraulic Radius	Number	Hydraulic Radius
Slope	Number	Water Surface Slope
Distance	Number	Length over which Water Slope Measured
Max Flow Depth	Number	Maximum Flow Depth at Cross Section
Avg Flow Depth	Number	Average Flow Depth at Cross Section
Width	Number	Width of Cross Section
Manning's *n*	Number	Manning's *n*
Chezy *C*	Number	Chezy *C*

Table B5 - Photographs Table

Fields	Data Type	Description
SiteName	Text	River Name IFR No.
Date	Date/Time	Date of Study
Key	Text	Primary Key - Site Name and Discharge
UpstreamPhotograph	Text	Upstream Photograph – File Address Required
DownstreamPhotograph	Text	Downstream Photograph – File Address Required
CrossSection	Text	Cross Sectional Photograph – File Address Required
Site View	Text	Site View Photograph – File Address Required
Additional Information	Text	Additional Site Info

Table B6 – Hyperlink to Word Files

Fields	Data Type	Description
Wordfiles	Hyperlink	Hyperlink to Word Documents

Table B7 – Switchboard Items

This table is automatically generated when a switchboard menu/sub-menus are created. Switchboards will be discussed later.

Primary Key – is the field that uniquely identifies a record

File Address Required – is the address of the file e.g. \Photographs\Komati\Komati.jpg. Note - the address should include everything after C:\Guide to Hydraulic Characteristics of SA River {The address can be found at the top of the screen when in windows explorer}

In order to link the tables together, the following relationships were setup by indicating in Access which fields in each table are common.

Cross Sections Table: SiteName <--> **Ecological Table:** SiteName <--> **Hydraulics** Table: Site Name

Hydraulics Table: Key <--> **Photographs Table:** Key

Thereafter the following queries were set up:

BedMaterial Query – Query to produce the user specified bed material types

Geo Unit List – Query to obtain geomorphological unit list

Geomorphological Unit Query – Query to produce the user specified geomorphological unit

Manning n Query – Query to produce the user specified range of Manning's *n*

Max Flow Depth Query – Query to produce the user specified range of maximum flow depth

River List Query – Query to obtain a list of rivers in the database

River Query – Query to produce the user specified river data

The queries have been programmed to search a specific field for the user specified criteria which would have been obtained from forms which were created. These forms would then pass on the search criteria to the respective queries which would use a form to display the records found. The following forms were created:

Bed Material Crit Form – Form to request user to input bed material type
Bed Material Form, Geomorphological Unit Form, Hydraulics Form, Manning n Query and River Query – These are the query result forms used by the queries to display the records found (see Appendix D for an example)
Documents Form – Form to list the documents
Geo Unit List Form – Form to request user to select geomorphological unit
Larger Images – Bed Material Query, Geo Query, Manning Query, Max Flow Query and River Query – These are the forms to show the larger images
Manning Range Form – Form to request user for Manning n range
River List Form – Form to request user to select a river
Switchboard – Switchboard form

The following Macros were created:

Close Manning Range Form, Close Max Flow Depth Range Form, Close BedMaterialCrit, CloseGeo and CloseRiver – These macros will close the forms that request the user for inputs. The forms will close when the user closes the query result forms.

The reason for keeping the ‘input’ forms open is because their inputs are used for displaying the correct large images for the record, if the forms are closed, the user needs to re-input the criteria.

The minimise command in these macros will minimise the window – this is also done after the user closes the query result forms. The reason for this is to produce a minimised menu.

Print Current Record Macro – This macro will print one copy of the current record to the default printer. The macro will execute when the print command button is clicked.

Switchboard Macro – This macro has all the commands that are required in the menus.

A switchboard will now be explained.

Switchboard

A switchboard is a utility in Access that assists the programmer to set up the menus in the database. The switchboard requires Macros with commands as to what should be done when a certain action is carried out by the user. Switchboard manager was then used to specify which command to use for each action. The switchboard manager automatically creates a Table and Form which can be edited afterwards to suit the database style.

Appendix C – Guide to Hydraulic Characteristics of SA Rivers CD

The CD containing the Guide to Hydraulic Characteristics of SA Rivers is attached below. To execute the database, open the folder: Guide to Hydraulic Characteristics of SA Rivers, and open *Characteristics of SA Rivers.mdb* file. Note that MS Access 2000 or later is required to open the file. For more information, see sections 4 and 5 of the main report.

Appendix D – Example of Query Result Form

The pages overleaf are a print out of a record from the guideline. Each record will produce 4 pages with site information, hydraulic data, photographs and cross sectional and stage-discharge plots.