THE EFFECT OF THE RESOLUTION OF TOPOGRAPHY DESCRIPTION ON 2-D MODELLING OF RIVER HABITAT

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DECLARATION

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

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ABSTRACT

The main objective of this report is to assess the effect of different topographic (elevation) data sources on river habitat modelling in low flow conditions. In the study, digital terrain models which consists of various datasets were assessed using 2-D hydraulic software models. The representation of the terrain was sourced from the following: airborne laser scanning, total station survey, a smartphone device and a handheld GPS device. From the results, which consisted of 4 simulations (discharges of 1.5 m^3/s, 1 m^3/s, 0.5 m^3/s, and a field measurement of 0.3 m^3/s) for each topographic dataset, the water level and velocity were derived and a comparison was made against the most accurate data set (total station survey). The comparisons included how each model was able to describe a habitat in terms of defined biotopes. This research proves that a total station survey is still the most accurate, however with the advancement in GPS technology a handheld GPS device has proven to be adequate for a desktop or intermediate study. In addition, a smartphone's GPS tends to be more adequate for large surveys and inefficient for habitat modelling.

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LIST OF ABBREVIATIONS AND ACRONYMS

1-D:	One-Dimensional
2-D:	Two-Dimensional
3-D:	Three-Dimensional
ASTER:	Advanced spaceborne thermal emission and reflection radiometer
CAS:	Cascade (Flow type)
CH:	Chute (Flow type)
CP:	Completeness
CR:	Correctness
DEM:	Digital elevation model
DTM:	Digital Terrain Model
EIA:	Environmental Impact Assessment
FD:	Fast Deep
FEM:	Finite Element Method
FRF:	Fast Riffle Flow (Flow type)
FS:	Fast Shallow
FWI:	Freshwater Institute
GPS:	Global Postioning System
HB:	Habitat Biotope
HSC:	Habitat Suitability Criteria
LIDAR:	Light Detection and Ranging
MAD:	Median absolute deviation
MESC:	Midcontinent Ecological Science centre of teh U.S Geological Survey
QI:	Quality Index
Q_{inflow}:	Inflow Discharge
RS:	Rippled Surface (flow type)
SD:	Slow Deep
SS:	Slow Shallow
STD:	Standard Deviation
WRC:	Water Research Commission (South Africa)
FN:	False Negative
FP:	False Postive
Q:	Quality Coefficient
TN:	True Negitive
TP:	True Postive

GLOSSARY

Biotope	Unit which is used in classification of geomorphological features in rivers. Based on a fine scale and used in small areas and relates to specific water-flow characteristic and substratum behaviour
Clast	Rock fragments from the breakdown of larger rocks
Community	Where different species within a habitat or a geographical area interact and live mutually dependent
Discharge	The volume of flow rate in a channel
Diversity	Various species within a community, area or sample which is based on numbers or richness of a species
Ecology	The study of how organisms interact with each other and their environment
Flow Regime	The behaviour of different magnitudes of flow in terms of timing, frequency and duration
Flow Regime	The changes in occurrence of discharge
Habitat	The grouping of the environmental conditions and the species that allow for species to survive
Hydrology	The study of the interaction between water and the environment
Invertebrate	Species without backbones
Rheophilic	Associated with flowing water
Riparian	On the banks of or alongside a river

Roughness	The size of features (physical size) in a river and related to Manning's n
Stage	The height of the water related to a certain datum of the lowest level in the river bed
Substrate	The material that makes up the river bed
Uniform Flow	The hydraulic conditions are the same at all locations within the river

1 INTRODUCTION

The study of river habitat is fundamental to managing rivers. The benefits provided by natural ecosystems include flood control, carriageways, leisure, purification of waste, habitats for plants and animals, and the growing of food and marketable goods (Baron et al., 2003). These multiple benefits sustain and fulfil human life, so thorough habitat studies are essential requisites. The purpose of ecological river hydraulics is to describe and assess the hydraulic conditions affecting the physical, chemical, and biological behaviour of rivers. This serves to deepen our understanding of conditions and functions, which assists in the provision of adequate management advice.

Habitats can function as a temporally and spatially variable physical, chemical, and biological template (Thirion, 2016), with the key challenge to understand why species live where they do. Duel et al. (2003) describe habitats as ecotopes, which are ecological units where development is determined by factors relating to hydrodynamics and ecological succession. In layman's terms, it is stream flow, water depth, substrates, physio-chemical characteristics, biological features, and the flooding frequency of specific areas which determine the sustainability of living conditions for fish, amphibians, reptiles, wetland birds, and mammals (Duel et al., 2003).

The correlation between physical features and habitat parameters cannot be classified as simply between velocity and shear stress but preferably between various elements: discharge, sediment size, load, and river slope (James and King, 2010). (Dallas and Day, 2004) refers to the variation of discharge and its effect on river measurements such as wetted perimeter, hydraulic conditions and the biotope (or the portion of a habitat associated with a specific assemblage) (Thirion, 2016).

However, one of the most fundamental elements of habitat modelling is the geometric description, which is usually in the form of digital elevation models (DEMs). DEMs are used to define the river channel in detail to enable hydraulic simulation at a certain resolution. Over the years, there have been vast changes in data collection from conventional ground surveys to remote sensing techniques (Ali et al, 2015). The resolution of DEMs can range from high-resolution/accurate in *Light Detection and Ranging* (LIDAR) to low/coarse resolution from *Advanced Spaceborne Thermal Emission and Reflection Radiometer* (ASTER). The simplest form of DEMs are generated from *traditional ground surveying techniques* (topographic contour maps) (Ali et al., 2015).

The method and equipment used contributed to the differences in resolutions. When used in habitat modelling, the results and quality of models are directly affected by the detail of the DEMs.

A further important consideration: DEMs utilised for modelling habitats come at a cost in terms of money and computational demand. The large data volumes increase the number of computational cells and time steps, with the average desktop computer not equipped to handle the required memory demand (Wu and Mao, 2007). It is accepted that DEMs resolutions affect the results produced from the models (Kim et al., 2014; Sanders and Brett, 2007; Cases et al., 2006). However it's unclear to what extent a reduction in the topographical survey affects the quantified aquatic parameters in ecological assessments.

This report presents an interpretation of the effect of the resolution of the DEMs in describing the habitat in rivers under low flow conditions. Different DEMs with different resolution are used as inputs to a 2-D hydraulic model to simulate hydraulic characteristics and hence the different distribution of biotopes in a river reach. The distributions are compared with a visual assessment of the reach, showing the relative reliability of each DEM resolution.

1.1 Specific Research Objectives

The aim of this research is to assess the effect of the degree of variations in topographic resolutions when describing the hydraulic characteristics/habitats of rivers under low discharge conditions. The objectives used to achieve this aim to produce methods to predict:

- flow velocity and depth distribution; and
- topographic models or DEMs.

The objectives have been determined by conducting a literature study, data analyses, theoretical development, and computer modelling.

1.2 Layout of the Report

The report is in seven chapters:

1. **Introduction:** A brief statement of the problem, with methods for the solution presented.

2. **Background:** This chapter provides information about how hydraulic habitats are described in terms of ecological flows, habitat suitability criteria, flow classes and biotopes, modelling of river habitats in terms of 1-D and 2-D software and, finally previous studies looking at topographic resolution on 2-D modelling.

3. **Study Areas and Available Data:** A description of locations and the various types of topographic resolution used in the experiments. This chapter also includes the source of each topographic data set.

4. **Methodology:** Details the research methodology adopted and the software used to model habitats and the approach carried out for verifying the results obtained from each simulation. The experimental investigation performed is discussed**.**

5. **Results:** Results of the simulations, verification, and comparisons are presented followed by a discussion of these results.

6. **Discussion:** An examination of the simulation results in terms of quality/accuracy of the DEMs compared to the base DEM and how each DEM model can be incorporated into different types of habitat studies.

7. **Conclusion and Recommendation:** Conclusions of the research and recommendations for the future.

2 BACKGROUND

The primary purpose of this report is to analyse the influence of various elevation data sources on hydraulic/habitat modelling in rivers under conditions of low discharge. Scientists and engineers studying river flows describe an ecological reserve in terms of hydraulic parameters, which are used to quantify biotic elements. Some of these hydraulic parameters are water depth, velocity and wetted perimeter (Rowlston et al., 2000). The combination of hydraulic analysis and well-defined geometric descriptions is essential for both water modellers who predict water flow and ecologists/habitat modellers who express certain ecological reserves in terms of flow depths and velocity (Jordanova, 2008).

The aim of this chapter is to identify:

- general approaches and measures for describing rivers in terms of DEMs;
- how fish and macroinvertebrate physical habitats are described and their translation to hydraulic parameters;
- the different types of models used to predict habitat behaviour; and
- studies which have examined the effects of topographic description on models.

2.1 Describing Hydraulic Habitat

Published studies reinforce the need to understand the roles of habitat quantity and habitat quality in complex systems inasmuch as they influence aquatic life (Modde et al., 1991). The first step in river modelling is to understand the hydraulic conditions best-suited to different species or communities (James and King, 2010). The main focus is on the habitats used by vegetation, fish, and invertebrates and which flow regime is best-suited to each biotic component. A habitat can be defined as a system which has a number of elements, along with an understanding of the relationship between channel flow and hydraulic features in terms of velocity, depth, substrate, physio-chemical characteristics and biological characteristics (Bovee, 1982; James and King, 2010).

In addition, the determination of river habitats is undertaken in different situations and at different levels. Thus, a study of habitats in a certain reach will fall under one of these four classes based on James and King (2010): Desktop, Rapid, Intermediate, and Comprehensive. Each study has its bases related to the amount of resources allocated and the degree of uncertainty to it, however, other factors also play an important role in a habitat study such as (James and King, 2010):

(1) how the catchment is utilised,

(2) ecological importance,

(3) sensitivity of the river,

(4) human impact on proposed water use, and

(5) the amount of available information.

Figure 2-1 shows how the relationship between the levels of each habitat studies and the degree of analysis needed to carry out the habitat determination.

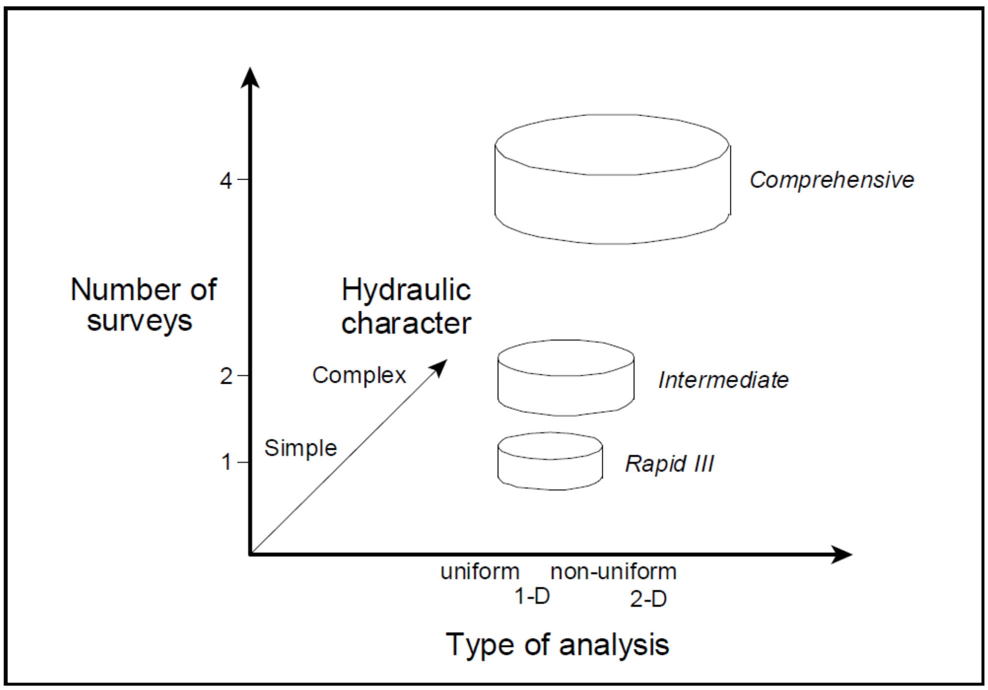

Figure 2-1: The relationship between the levels of habitat studies (James and King, 2010)

2.2 Ecological flows

The link between river flows and biotic components within the river can vary with location. The water flow, combined with sediments, are constantly affecting the river channel/bed by forming, eroding, and maintaining channel features such as banks, bars, pools, riffles, and islands (Paxton et al., 2010).

This complex and ever-changing world defines the conditions required for riverine species and plants to exist, and an understanding of the relationship between channel features and flow is essential. The basic idea that a channel feature is directly related to velocity and shear stress is incorrect.

Other hydraulic parameters and how they interact with each other over time need to be taken into account. These include: (Brandt, 2000):

- discharge,
- sediment size,
- sediment load, and
- river slope.

A further method to describe flows in rivers is the natural flow regime concept developed by (Poff et al., 19997). River flow regimes display regional patterns described by river size, climate, geology, topography and vegetative cover. Poff et al. (1997) suggests five critical components are related to flow regimes:

1. **The magnitude**: The amount of discharge through a fixed location at any given time. The magnitude can be relative or absolute.
2. **The frequency**: Related to magnitude and describes how often a discharge recurs. Example, a 100-year flood.
3. **The duration**: The time/period related to a specific flow condition.
4. **The time**: The regularity with which specific flow condition occurs which is related to seasons, etc.
5. **Rate of change**: How quick or slow a specific flow condition changes to different flow conditions.

These critical components define a river's physical structure, its environment and its habitat. More specifically, habitat features are created/destroyed/maintained by changing ranges of flows as they transport/move a river's bed, banks and sediment. In these terms, stream flow in rivers is the "master variable" governing ecological behaviour. However, the natural flow regime concept does not explain the link between biota and river habitat requirements in terms of hydraulic variables.

2.3 Defining Hydraulic Habitats

Several habitat evaluation techniques that can be utilised in river and lake management to assess the direct effects caused by hydraulic changes on aquatic life: Habitat Suitability Criteria (HSC), Flow Classes, and Hydraulic Biotopes.

2.3.1 Habitat Suitability Criteria (HSC)

Habitat Suitability Criteria (HSC) were first used in North America. The basis of this approach is to collect data in terms of depth, velocity and substratum-particle-size associated with a certain species of interest, and create a habitat suitability curve/model that best suits that species (Brandt, 2000). The main challenge with the HSC method is the ability to transfer one HSC developed from hydraulic data to predict an HSC for another river system. To overcome this challenge HSC models need to take into account a range of locations which describe the conditions for the species, i.e. tributary to mainstream channels (Paxton et al., 2010). Table 1 shows the different condition that are used in the formation of a HSC for different fish species in South Africa which was developed by Paxton et al. (2010).

Developing an HSC for multiple species is time-consuming and therefore most HSC models group species together (suits) then select a species within that suit to represent the guild, as first suggested by Leonard and Orth (1988).

The HSC approach can translate hydraulic and geomorphological data into quantitative indices. These indices are grouped into three categories with specific criteria relative to a particular species (Paxton et al., 2010):

- Category 1: field data are non-existent or limited for a specific species. Data are then collected from HSC libraries, literature, or professional expertise.
- Category 2: Data collected in the field which can be expressed in a frequency distribution for each hydraulic variable used to describe the species preference.
- Category 3: Description of habitats in ratios/proportions of the amount of habitat that is available.

Table 1: Fish guilds for South Africa (Paxton et al., 2010).

Main Species		Sub-Species	Description
Rheophilics			Requiring flowing water
		Fast- Rheophilics	Requiring fast flow (>0.3 m/s) during most phases of the life cycle.
		Slow- Rheophilics	Requiring slow flow (<0.3 m/s) during most phases of the life-cycle.
		Semi- Rheophilics	Requiring flowing water during certain phases of the life-cycle.
		Fast-Semi-Rheophilics	Requiring fast flowing water (>0.3 m/s) during certain Phases of the life-cycle.
		Slow-Semi-Rheophilics	Requiring slow flowing water (<0.3 m s-1) during certain phases of the life-cycle
Limnophilics			No particular flow requirements during any phase of the life

Figure 2-2 shows the HSC curves used for juvenile yellow fish located in the Driehoeks River, Western Cape, South Africa. This figure suggested that juvenile yellow fish tend to prefer greater depths and much higher velocities than other common fish found in South Africa. They also tend to send their time where small cobbles are present even when sand was the most common substratum in the river (Paxton et al., 2010).

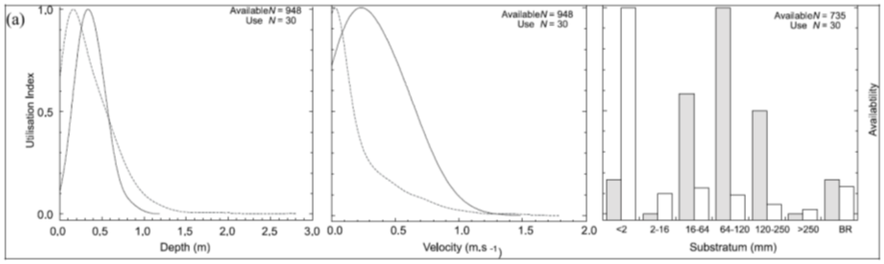

Figure 2-2: HSC curves used for fish species in South Africa (Paxton et al., 2010)

2.3.2 Flow Classes

Flow Classes, originally developed by Oswood and Barder (1982) have the same concept as HSC in relation to hydraulic parameters i.e. depth, velocity, and substratum particles (James and King, 2010). Flow classes are “broad, pre-defined, discrete categories of velocity and depth” (James and King), 2010) and are suitable for numerous species. A common usage for flow classes is for fish where four classes have been developed based on 134 fish species located within South Africa (Kleynhans, 2008). The flow classes which have been developed for South African fish can be seen in Table 2, where SS=Slow Shallow, SD=Slow Deep, FD=Fast Deep, and FS=Fast Shallow.

Table 2: Flow classes for fish in South Africa (Kleynhans, 2008)

Class	Velocity	Depth	Description	Sampling Method
SS	Slow (<0.3 m/s)	Shallow (<0.5m)	Shallow pools and backwaters	Small seine or electroshocking
SD	Slow (<0.3 m/s)	Shallow (<0.5m)	Deep Pools and Backwaters	Large seine or cast net
FS	Slow (<0.3 m/s)	Shallow (<0.5m)	Shallow runs, rapids and riffles	Electroshocking
FD	Slow (<0.3 m/s)	Shallow (<0.5m)	Deep runs, rapids and riffles	Electroshocking

Four flow classes have been developed for invertebrates and were demonstrated by Jordanova et al. (2004). The classes are based on depth-average velocity, subtratum and vegetation (Paxton et al., 2010). Table 3 shows the various cover types for invertebrates.

The advantage of using flow classes is that they are semi-quantitative and the data collection for species is easier than for HSC. Flow classes are well suited to hydraulic modelling. However, the classes do not take into account all species and tend to under or overestimate the critical habitat requirements.

Table 3: Cover type for invertebrates (Kleynhans, 2008; Jordanova et al., 2004)

Cover	Description
Overhanging Vegetation	Marginal vegetation overhanging water by ~0.3 m-< 0.1 m above the water surface
Undercut banks and root wads	Banks overhanging water by ~0.3 m-< 0.1 m above the water surface
Substratum	Substratum particles: rocks, boulders, cobbles, gravel, sand, fine sediment, woody debris
Aquatic Macrophytes	Submerged and emergent water plants

2.3.3 Biotopes

Biotopes, first described by Dahl (1908) are groups made up of both physical and biological conditions. A biotope is defined as a "spatially distinct in-stream environment characterised by specific hydraulic attributes" (King et al., 1995). HSC and Flow Classes define a habitat as the living conditions for a species, whereas biotopes define habitats and species as a group "community" (Olenim and Ducrotoy, 2006). The scale of the biotopes allows for geomorphologists and ecologists to work together, as the smallest scale of a biotope is adequate for a geomorphologist but also coarse enough for ecologists (King et al, 1995). This approach is cost-effective but a challenge still remains: relating the results from hydraulic models (depth and velocity) to hydraulic biotopes present at the specific site (James and King, 2010).

The formation of biotopes is expressed through maps which describe the mosaic of flows and substratum types in a selected river location. The identification can be based on a visual assessment of the surface flow character of a site. The main types of features used in biotopes are backwaters, pools, glides, runs, riffles, and cascades which are descriptive and subjective, however, Rowntree and Wadeson (1998) suggest that they can be quantified through hydraulic indices. These indices are Froude number, velocity, water depth, Reynolds number, shear velocity, and roughness. The dimensionless indices do not give values for depth and velocity which most aquatic animals respond to (Jordanova A, 2008). King and Schael (2001) improved the indices of Rowntree and Wadeson (1998) by recognising hydraulic biotopes in smaller sets, which contain hydraulic indices for mapping aquatic life. Biotopes generally used in South Africa are presented in Table 4. In addition, Table 5 describes the different substratum that can be found in South African rivers which is used to in conjunction with table 4 as each substratum "tends" to effect hydraulic conditions of low flow rivers.

Table 4: Hydraulic biotopes for South Africa (King et al., 1995)

HD	Depth (m)	Flow Description	Substrata	Mean Velocity (m/s)	Froude Number	Comments
Rapid	shallow to deep: up to 0.70	Turbulent, broken water:	Boulders and large cobbles	0.38-0.64	0.371-0.900	CAS is the dominant flow type
Riffle	shallow: <0.30	fast, flickering flow:	cobbles and sometimes small boulders	0.27-0.39	0.332-0.425	FRF is the dominant flow type.
Run	shallow to moderately deep: up to 0.50	fast to moderately fast rippled flow:	a range of substrata	0.05-0.19	0.070-0.200	RS is the dominant flow type.
Pool	shallow or deep: 0.03->1.00	slow, smooth flow:	a range of substrata	0.00-0.10	<0.070	Bedrock and alluvial pools

A case study was conducted by King and Schael (2001) on the Berg River in South Africa's Western Cape employing the above biotopes. Maps were drawn based on the observed distribution of flow types and the substratum class. The study was based on Table 4, however, the study further broke down each biotope classes mentioned in Table 4 as this provided a more detail description of the biotopes. Figure 2-3 shows the biotope maps from the Berg River study.

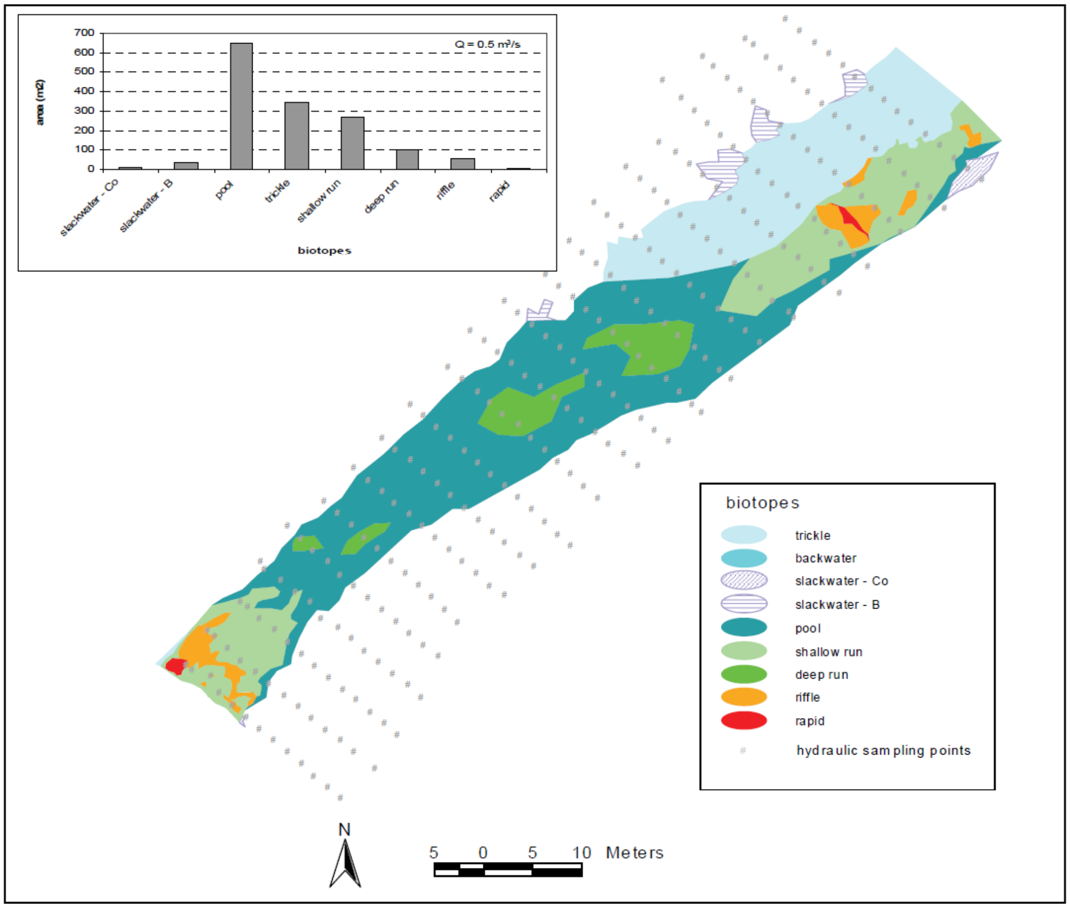

Figure 2-3: Biotopes mapped in the Upper Berg River (King and Schael, 2001)

The advantage of using biotopes is the addition of visual information that provides a wide range of descriptions for various disciplines. A major flaw is the prediction or assumption of the different biotopes and how they consequently respond to flow changes.

Table 5: Definitions of substrates used in biotopes (King et al., 1995)

Substrate	Particle Diameter (mm)
Silt	<0.0625
Sand	0.0625-2
Gravel	2-64
Cobble	64-256
Boulder	>256
Fractured bedrock	Bedrock with significant cracks and crevices which afford some cover
Smooth bedrock	Bedrock lacking cracks or crevices
Cliff	A vertical bedrock face

2.4 Habitat Modelling of Rivers

The study of river ecology is an important element of river planning and management in today's ever-changing environment. Simulations to quantify river habitats are now as important as the simulations of hydrodynamics in rivers.

According to Duel et al. (2003) there are four important steps to habitat modelling:

(1) The first is to mimic the spread (distribution) of ecotopes. Ecological units are made into parameter factors (depth, velocity etc.,) which can relate to the hydrodynamics, morphodynamics and ecological conditions.

(2) The second is to analyse the area for a particular type of flora and fauna species under the conditions of the ecotopes.

(3) The third is to look at habitat suitability taking into consideration the needs of each species (food, shelter, nutrients). This step involves the production of habitat suitability curves/models which consist of numerical ratings indicating the carrying capacity for certain aquatic species.

(4) The fourth is to ascertain if a positive link can be established between suitable habitats and ecological networks. Habitat suitability models may not be 100% accurate in terms of the selected species which will settle or survive (Duel et al, 1995).

The application of habitat modelling is done through either 1-D or 2-D modelling. Water, in 1-D hydraulic modelling, flows longitudinally with models describing the terrain as a series of cross-sections and producing average flow velocities and water depth (Cook, 2008). In 2-D hydraulic modelling flow is allowed to move longitudinally and laterally but the terrain is modelled as a finite surface which is continuous (Cook, 2008). A brief explanation of the 1-D and 2-D models used in this work is given in the following sections.

2.4.1 1-D Model: HEC-RAS

HEC-RAS, developed by the United States Army Corps of Engineers has software that enables users to conduct 1-D steady and unsteady flow calculations. For steady state, the water surface profiles are calculated from one cross-section to another by using a standard step-iterative procedure to solve the energy equation (HEC-RAS, 2002).

There are a number of equations implemented within HEC-RAS for steady state such as energy head loss, total conveyance and velocity coefficient for a cross-section. HEC-RAS models assume for steady state that the flow is steady, the flow is gradually varied, flow is 1-D, and the river channels have small slopes (HEC-RAS, 2002).

For unsteady state modelling, the momentum equation is used to solve the water surface profiles. Unsteady state could arise from water flowing around piers, river confluences, mix flow regimes such as hydraulic jumps and the change in discharge with time.

The input for HEC-RAS includes topographical data for each cross-section, as well as Manning resistance coefficients, flow rates, and boundary conditions. 1-D models such as HEC-RAS have advantages and disadvantage which is listed below (Flood Modeller, 2015):

Advantages:

- fast to run,
- good at describing in-channel water levels and flows, and
- good at representing bridge/weirs/sluices,

Disadvantages:

- need to identify all flow routes,
- complex systems are time consuming,
- can be poor at detailed river analysis, and

- no velocity distribution.

2.4.2 2-D model: River 2-D habitat model

There are a number of commercial and public 2-D modelling tools available, among them River2D. River2D was developed by the Canada Freshwater institute (FWI), Civil and Environmental Department of the University of Alberta, Midcontinent Ecological Science Centre of the U.S. Geological Survey (MESC), and Fisheries Division of the Alberta government. The software models produced by River2D uses depth-averaged, hydrodynamic equations and has the ability to model fish habitats.

It has a finite element algorithm based on a conservative Petrov-Galerkin unwinding formula (Steffler and Blackburn, 2002).

The software consists of four major components which run separately:

- R2D_Bed - Topography module,
- R2D_Mesh - Finite element mesh module,
- R2D_Ice - Ice cover module, and
- River2D - flow and habitat analysis module.

R2D_Bed is characterised by the user inputting the topographical data, and utilising a grid or triangulated irregular network (TIN).

R2D_Ice is used to simulate water flow under an ice cover which have known geometric properties, however this component is not used in this study.

In **R2D_Mesh** the software transforms the topographical data (used on R2D_Bed) into an effective mesh to generate the conditions of the physical habitat.

River2D is the main component where simulations occur adhering to the Petrov-Galerkin formula, conservation of mass and conservation of momentum (Wu, 2007). The model can predict the results of hydraulic parameters – among them depth and velocity - in an explicit way. The software can run simulations for both steady and unsteady flow analyses, and the results are obtained through finite element methods.

The main features of River2D are the depiction of subcritical, supercritical, wet, and dry conditions. River2D has undergone several verification processes, based on theoretical, experimental and field results (Ghanem et al., 1995; Waddle et al., 1996).

The following South African case studies highlight the various elements achieved by River2D:

1. By utilising River2D, (Hirshowitz et al.,2007) used flow classes as an input function in River2D. With the classes defined and used as input, the habitat condition of each reach was expressed as the proportion for the channel width occupied by to a particular flow class.

2. Due to the different components which constitute River2D, a number of simulations can be performed, such as a hypothetical, rapidly-varied flow condition which relates to local control (Jordanova and James, 2007). The results from the simulation were compared to measured data indicating that the velocity-frequency distributions were reliable under large-scale roughness conditions (Jordanova and James, 2007).

2-D models such as River2D have advantages and disadvantage which are listed below (Flood Modeller, 2015):

<u>Advantages:</u>

- no analysis for predefined flow routes,
- easy to set–up,
- more accurate,
- velocity variation, and
- river flow, velocity and depth are direct outputs.

<u>Disadvantages:</u>

- can be slow to run (depends on the computer's specifications), and
- need to refine grid or mesh for river channels.

2.4.3 Comparison of 1-D and 2-D models in habitat prediction

Hydraulic models are important tools for habitat description as they need to integrate hydraulic and biological aspects. Models can vary in different techniques used for simulations purposes:

1. **Diffuse: Saint-Venant equations or the diffusion wave equation.** This technique is based on equations of conservation of mass and conservation of linear momentum. The technique is based on the different classes of water waves such as: dynamic (based on the momentum equation), gravitational (bed slope and friction between the river walls and water is not considered), and cinematic (considers the effect of bed slope and friction between the river walls and water) (Patricia and Raimundo, 2005).

2. **Multivariate**: This is a statistical method which is used to examine data that is produced by more than one variable.

3. **Fuzzy logic approach**: Based on the degree of truth rather than usual true or false logic.

4. **FEM: Finite element method:** This is the most popular method in hydraulic analysis of rivers as it allows one to see the interaction of real world effects such as fluid flow, heat, friction and other physical effects. Software that are based on FEM methods, tend to incorporate the pervious techniques listed above.

1-D models are widely used for ecohydrological studies as they tend to be more simplified and easier to work with, 2-D models are more complex and widely used for aquatic habitat models (Oliveira et al., 2016).

According to Jowett and Duncan (2012) the mathematics used in 2-D models are more appropriate for river habitat simulations as the theory is able to interact with complex riverbeds including obstructions, islands, bends, pools, rifles, and cascades.

Furthermore, Oliveira et al. (2016) compared two software packages PHABSIM (1-D model) and River2D (2-D model) in terms of ecohydrological simulations and showed that 2-D models are more suited for ecohydrological feature simulation, yet 1-D models tend to produce a better fit for the hydraulic variables. The research indicated 1-D models are not able to accurately simulate the characteristics of the habitat due to the inability of 1-D models to not produce a composite mesh cell, had large cell sizes smaller calculation for each cell. According to Waddle et al. (2000) 1-D models are better suited for habitat simulation as 2-D models are more complex and cannot accurately predict depth and velocity values accurately.

Benjankar et al. (2014) did a further study which compared flow properties, such as depth, velocity, and aquatic habitat prediction with 1-D and 2-D models. The study used high-resolution and bathymetric data and comparisons were done on hydraulic parameters at certain cross-sections. The study highlighted the fact that that river features which were smaller than the data spacing affected the outcome between the two models. The study also indicated that hydraulic variables are affected more with 1-D models due to the interpolation of separating the variables into components (Benjankar et al., 2014).

Deciding which model to use should be based on a number of aspects such as cost, precision required, physical habitat, and the morphological characteristics (Oliveira et al., 2016).

2.5 Effects of topography on hydraulic models

In river management, there are many applications which rely on hydraulic models and are able to access river characteristics, habitat conditions, and aquatic life suitability. The predictions of these models are only as good as the topographic data used to describe the channel bed (Legleiter et al., 2011). The mesh resolution is an important topic in 2-D modelling and a number of studies have been conducted to measure the effect of mesh resolution. A study conducted in the UK on the Thames River indicated 2-D models have a stronger sensitivity to mesh resolution than topographic mapping. The main conclusion of this study was that sensitivity was the result of larger objects that were unable to be mapped appropriately (Horritt et al., 2006).

Legleiter et al. (2011) conducted a study using spatial stochastic simulation which was able to study the effects of topographic uncertainty in river flows. The models produced in the research were based on simple meandering rivers and were utilised to predict the distributions of water elevations, depth, velocity, and boundary shear. The uncertainty was described by statistics in terms of channel morphology which resulted in the following: the habitat conditions predicted by the models increased in uncertainty as the topographic data increased in node spacing. The greatest uncertainty was seen at low flows compared to flooding conditions and the uncertainty increased in bends though “topographic steering effects” where the water is steered into another direction compared to the river flow (Legleiter et al., 2011).

A further study looked at the effects of breaking down the mesh to suit the vegetation of the selected river (Mason et al., 2003). The study used LIDAR by segmenting it into ground hits and surface hits for vegetation and rocks. The surface data were then used as a friction parameter and applied to each node in the 2-D models. The conclusion of this study indicated that there were good correlations or relationships between the models and the actual results.

In a further study conducted on the Feather River in California, mesh resolutions in small scales were examined (Crowder and Diplas, 2000). The main objective of the study was to determine the type of topographical features, i.e. rocks, reed beds, and embankments which should be included in 2-D models, and to observe their effect on the outcome of the flow conditions. The major result from the study concluded that obstructions (rocks, boulders, reed bed) affect downstream flow patterns up to a distance of 6-8 times obstruction diameter.

2.6 Conclusion

As stated previously the primary purpose of this report is to analyse the influence of various elevation data sources on hydraulic/habitat modelling in rivers under conditions of low discharge. The combination of hydraulic analysis and well-defined geometric descriptions is essential for both water modellers who predict water flow and ecologists/habitat modellers who express certain ecological reserves in terms of flow depths and velocity (Jordanova, 2008). Therefore, the bases of this report will be on the following elements described in this section:

1. The process of defining hydraulic habitats will be based on biotopes described in section 2.3.3.

2. Habitat modelling will be done using 2-D software program described in section 2.4.2.

These two elements were chosen because they provide a simply but comprehensive method for the evaluation of different elevation on habitat modelling.

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3 STUDY AREA AND AVAILABLE DATA

Johannesburg's Braamfontein Spruit was selected for this study, with a particular reach of the river examined. This specific reach was selected as it had easy accessibility, good physical habitat diversity and different ranges of flows within this reach. These factors were critical for the ecosystem to function.

3.1 Braamfontein Spruit

The Braamfontein Spruit is one of three streams which form part of the Limpopo basin catchment area in the Johannesburg area (the other two are Sandspruit and Jukskei) (Carruthers, 1977), refer to Figure 3-1 for schematic of the rivers within Johannesburg. The river is the longest stream in Johannesburg, its source in Braamfontein. There are two major tributaries - Westdene and Albertville.

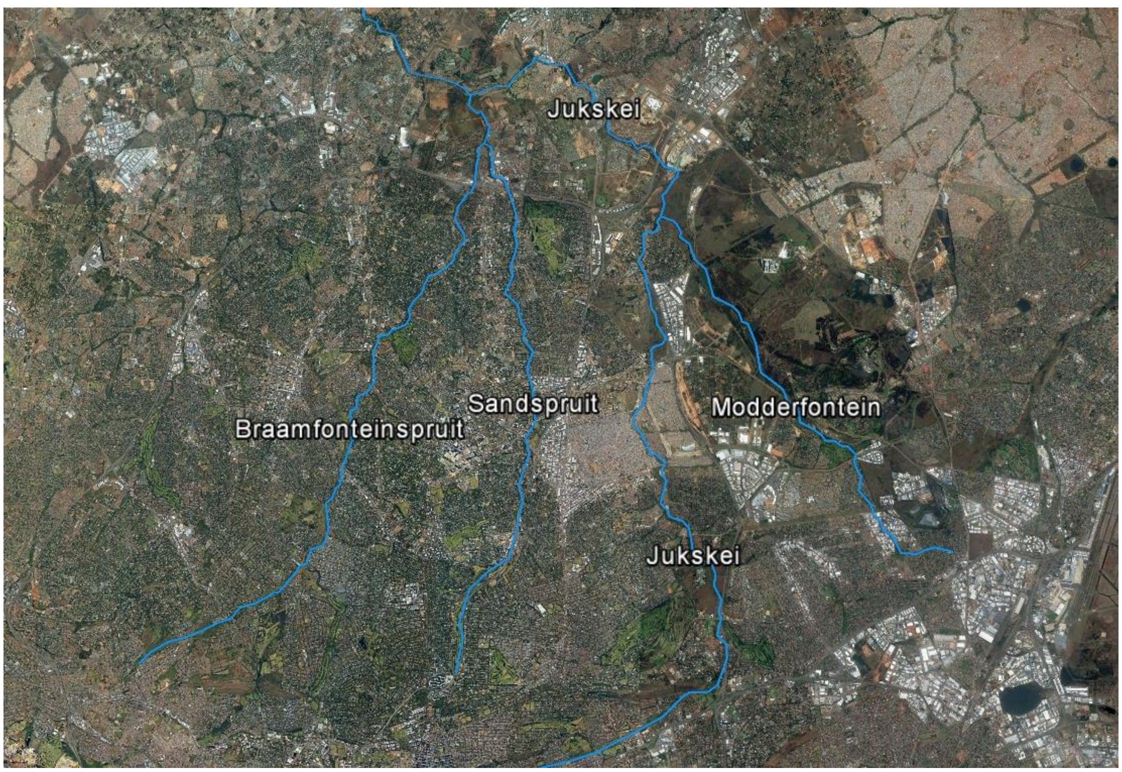

Figure 3-1: Image of the 4 major rivers in Johannesburg (Google Earth, 2017)

The river flows in a northerly direction before joining the Jukskei River approximately 22 km from the source. The segment being investigated on the Braamfontein Spruit is close to Victory Park, Johannesburg (26°08'21.08''S: 28°00'39.21''E), refer to Figure 3-2 for the location of the study reach. The segment length is approximately 110 m long and provides adequate essential features such as boulders, reed beds, cobble- and gravel-bed which has bedrock outcrops. The rocks are an intrusion of igneous rock (Gabbro or Dolerite) which are related to the Bushveld Igneous Complex (Wen, 2008).

A general overview of the site can be seen in Figure 3-3 which was taken downstream of the site, while Figure 3-4 shows the main rock features within the reach. More site photos can be seen in appendix A which show all the major features of the reach.

Figure 3-2: Site Location on the Braamfontein Spruit

Figure 3-3: Looking upstream at the Braamfontein Spruit site

Figure 3-4: Rock features at the Braamfontein Spruit site

3.2 Digital Elevations Models

The digital elevation model is a numerical representation of the terrain and is used as a boundary condition for 2-D models. Depending on the river and what hydraulic analysis is required, topographical survey should include the following (James and King, 2010):

- Single cross-sectional survey,
- multiple cross-sectional survey, and/or
- 3-D survey.

In general, for low level assessments (desktop or a rapid study, refer to section 2.2 for more detail), the topographical survey can include a single cross-sectional survey which enables the evaluation of changes in low flow condition. For intermediate or comprehensive level assessments (refer to section 2.2 for more detail), the survey has to be a multiple cross-sectional survey, as this method gives details in terms of geomorphological, ecological, and hydraulic components (James and King., 2010). However, some assessments may include both sets of surveys as this provides comprehensive information on the hydraulics and other components of the river system.

3.2.1 Methodology for each survey

Each survey used in this research extended from bank to bank of the “macro-channel” (James and King, 2010) and the data had to integrate all changes in slope of the banks. All roughness elements frequently (i.e. inundated annually) (James and King, 2010) conveyed are considered in the overall bed resistance and thus were not surveyed in detail. Larger elements such as boulders and reed beds which are infrequently transported and reduce the flow area were surveyed.

3.2.2 Surveys used

The 3-D Cartesian coordinate data (X, Y, and Z) which are used in a DTM for habitat modelling is the primary component for every simulation. Model adequacy depends on a number of factors, including the vertical accuracy, degree of resolution, modelling objectives, and economic constraints.

The required topographic data for this research required a description of the geometry needed to describe the geometry of the river channel and banks, where data were obtained from various sources. Each source provided data that differed in spatial accuracy and resolution. The sources and data used are described in the following sections.

3.2.2.1 Airborne Data

The most accurate data available on the market is Light Detection and Ranging (LIDAR). The basic principle LIDAR is based on “time of flight measurement” (Bakula et al., 2016), where the measurement is taken from an outgoing laser pulse. The laser provides point clouds in terms of X, Y, and Z coordinates, and each cloud can have more than 1000 points. Due to the high-density point clouds, LIDAR tends to be accurate and can achieve centimetre-level accuracy (Bakula et al., 2016). However, Laser/Radar waves cannot penetrate the water surface: water has little reflectance and consequently little detail is provided on the bed elevations.

The LIDAR for this study was obtained from the City of Johannesburg and the resolution of the data is approximately 1m.

The **Raw LIDAR data** can be seen in the attached CD: Raw Data: LIDAR.

3.2.2.2 Smartphone

The development of mobile phone technology has enabled countries to leap forward in terms of improvements to social, economic, and environmental sectors. One such development includes a variety of smartphones with GPS receiver, accelerometer, digital compass, and camera.

Such phones, with their improved sensors and processing capability, could provide a low-cost surveying tool.

Several free applications with varying capacities and functions are available on the internet. The application used in this study is “Spyglass”, freely available at Apple’s App Store. This application was selected because it had a user-friendly interface, best user reviews, and the GPS accuracy was observed to be the best. The application was developed by “happymagenta”, located in the USA. The application is a powerful toolkit with built in functions such as: viewfinder, milspec compass, gyrocompass, maps, tactical GPS, waypoint tracker, speedometer, and an altimeter (Happymagenta, 2017). The application supports different ranges of coordinate systems useful for this study. Figure 3-5 shows a screenshot of the application in use, where X, Y, and Z coordinates are effortlessly presented with the altimeter.

Even though the presentation of the coordinates on the application was adequate, the manual recording of coordinates associated with different habitats is still required and resulted in a lengthy data collection process.

The **Raw smartphone data** can be seen in the attached CD: Raw Data: Smartphone

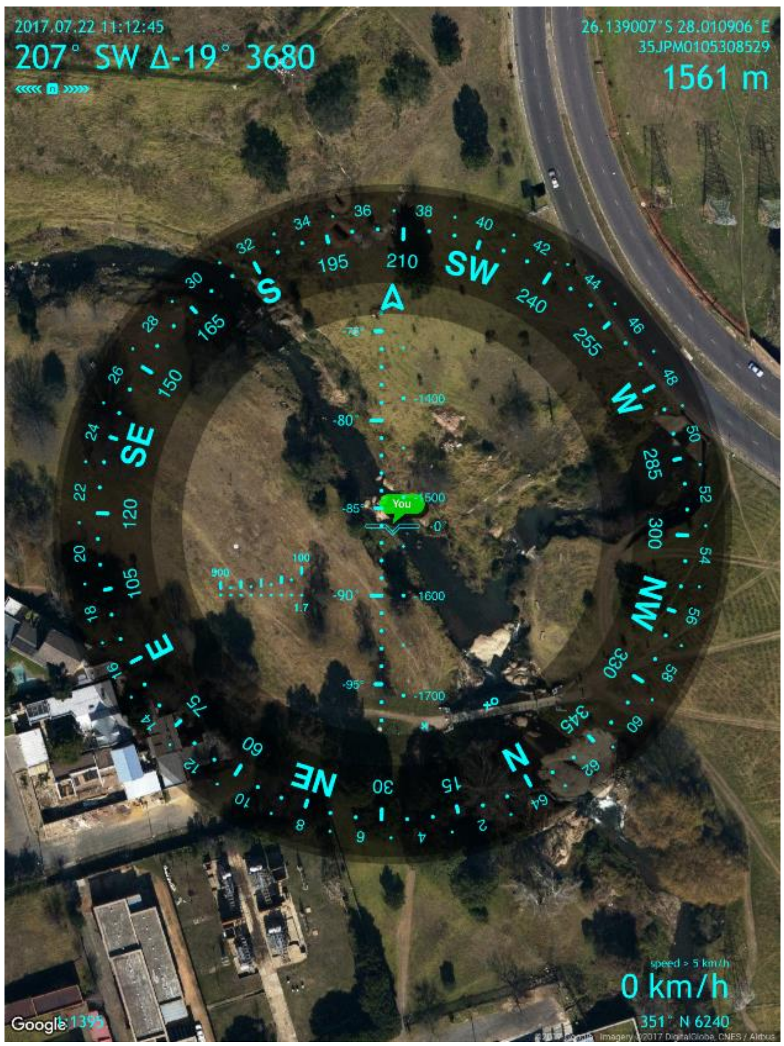

Figure 3-5: Screenshot of Mobile Topographer (Applicality, 2017)

3.2.2.3 Topographic survey (Total Station)

Total stations have been widely used in engineering and industrial surveying systems to measure distance, elevations, and angles. A total station is a combination of Electromagnetic Distance Measuring and Electronic Theodolite comprised of small components such as microprocessors, electronic data collectors, and storage systems (The Constructor, 2017). The total station can calculate georeferenced position, in terms of 3-D Cartesian coordinates. A laser beam is fired to a reflector, which is stationed on the water surface or object, and X, Y, and Z coordinates are produced related to a known reference point. A survey was conducted by *Stuart Dunsmore from Fourth element* on the selected Braamfontein Spruit site, which was made available for this study. Its important to note that the survey was done by an experience hydraulic modeller who knew the important features required for an adequate data set. Figure 3-6 shows a typical total station unit that was used for this study, while Figure 3-7 shows Stuart Dunsmore conducting the survey on the study reach.

The **Raw Total Station data** can be seen in the attached CD: Raw Data: Total Station

Figure 3-6: Typical total station used for river surveying (Opti-cal, 2017)

Figure 3-7: Photograph of Stuart Dunsmore at the Braamfontein Spruit Site

3.2.2.4 Handheld GPS unit

The Global Positioning System comprises more than 24 satellites which orbit the Earth. These satellites are used to transmit signals to GPS units or receivers located on earth. Generally, the GPS units display a location in latitude and longitude coordinates with the elevation in meter or feet.

The GPS unit used in this study was a Garmin GPSmap 60CSx which is capable of tracking up to six satellites. The unit comes with a GPS receiver, barometric altimeter and electronic compass. Figure 3-8 shows the GPS unit used in the study.

The **Raw GPS data** can be seen in the attached CD: Raw Data: Handheld GPS

Figure 3-8: GPS Unit used on the study

4 METHODOLOGY

The research methodology comprises a series of activities associated with the preparation and handling of hydraulic modelling which relates to utilising different elevations data and the evaluation of results. The model River2D was utilised for all simulations of habitats in the Braamfontein Spruit.

4.1 Why 2-D modelling

There is rarely a definitive answer to which models is better, 1-D or 2-D. The advantage and disadvantage have been mentioned in section 2.4, however, for this study a 2-D model was chosen for a number of reasons:

- the research required a more stable and robust model that was easy to manipulate on demand;
- 2-D models generally have a better interface than 1-D thus the models were set-up easier;
- 2-D models such as River2D provide a better visualization of the flow patterns around junctions, flow transfers and ineffective areas;
- 2-D models are sensitive to the mesh generation, thus allow one to compute the effects of changing the topographic description for a river reach; and
- generally, habitat modelling tends to be subjective thus the 2-D modelling allows modellers to represent their view of the reach.

Section 4.2 provides a detail description of how 2-D models work and the process that was undertaken in this research to create the simulation models.

4.2 Hydraulic modelling

The basic concept in hydrodynamic modelling is the prediction of flow depths and velocities across a river channel using computer algorithms in terms of equations describing flow dynamics (RRC, 2017).

Important elements for modelling in 2-D are:

- topographic data for the channel bed and banks;

- an assessment of the bed roughness; and
- water depths and velocity profiles for calibrations or reference.

2-D modelling requires topographic data to be recorded on a grid which runs across the channel or study area.

The hydrodynamic models for the Braamfontein Spruit were performed using River2D software by University of Alberta, Canada, which is a freeware software downloadable from the internet (www.river2d.ualberta.ca). In this study, the latest version (Version 0.95a dated Jan 2010) of River2D was used. The software package has four programs: R2D_Bed, R2D_Ice, R2D_mesh and River2D and each program has graphical user interface. The software programmes are normally used in sequence (R2D_Bed to R2D_mesh to River2D). The basic concepts of modelling in River2D require inputs such as channel bed topography, roughness and eddy viscosity, boundary conditions, and initial flow conditions. Over and above the inputs, the models will require the generation of a discrete mesh or grid to capture flow changes.

The intended use of River2D is for natural streams and rivers which takes into account features such as supercritical- and subcritical flow conditions, and wetted area (Golder Associates, 2011). River2D can provide a user with visualizing the simulations - the results of the simulations shown with colour maps, contours, and velocity.

However, the goal of modelling is not to produce the “full reality” (Titeux, 2006) but rather to construct models that make sense. Therefore the approximation of reality is considered a useful tool in modelling (Titeux, 2006). The difficulty of modelling reality is habitats exist as a result of interactions occurring at microscopic to macro levels and models are utilised to describe the behaviour of these interactions. Burnham and Anderson (2002) suggested that “increased sample size allows to chase full reality, but never to catch it”.

4.2.1 Model Setup

The most critical steps involved in 2-D modelling are the description of the stream channel topography which is utilised in the R2D_Bed pre-processor. The raw topographic data mentioned in section 3.2 were converted into a preliminary bed topography file (“.txt” extension) in the form of X-, Y-, and Z coordinates. The X- and Y coordinates were taken as Southings and Eastings respectively, and the Z coordinates were the recorded heights of the habitat features (boulders, reed beds, water surface etc.).

In each text file a default roughness value (k_s) was specified for all nodes of 0.1m, however this was modified within the R2D_bed to channel bed of 0.2m and river banks of 0.6m. Once each node had a default roughness the text file was saved as ".Bed" extension and then opened in R2D-Bed. After opening in R2D_Bed, a Triangulated Irregular Network (TIN) was generated from the nodes. The TIN allows a user to observe "wedges" which are impractical shapes tending to be larger than adjacent elements/shapes. Wedges are frequently located in areas such as tops or toes of banks and water edges (Bright, 2014). Wedges are removed by inserting "breaklines" which allow new nodes to be placed between adjacent nodes and represented features.

As mentioned above, the bed roughness had to be altered from the default. In R2D-Bed the roughness for each node can be changed individually, per certain area, or region. The roughness values are calculated based on Manning's values which relate to dominant substrate classes such as sand, gravel, cobble etc. For the Braamfontein Spruit, observation of the bed material, land formation, and surrounding vegetation provided an estimate of what roughness was required.

APPENDIX A presents site photographs which indicate bed materials and vegetation surrounding the river banks. The river bed materials for this section of the Spruit consist mainly of gravel and cobbles, while the vegetation on the banks consists of thick grass and weeds. Based on these observations, the bed roughness was represented by k_s=0.2m, while the banks were modelled with a higher k_s=0.6m. In this study, bed roughness was not a critical input due to the results being compared to one another. In 2-D modelling the roughness of the bed is taken into account as a resistance factor and directly proportional to bed shear (Bright, 2014).

Following the modified roughness parameters, the final step needed to prepare the DEMs was modifying the upstream and downstream inflows and outflows respectively. The main purpose for this modification was to ensure, as the mesh was generated using R2D-Mesh, that it would locate within the topographic nodes.

Figure 4-1 indicates one of the final DEMs produced by R2B_Bed used on the Braamfontein Spruit.

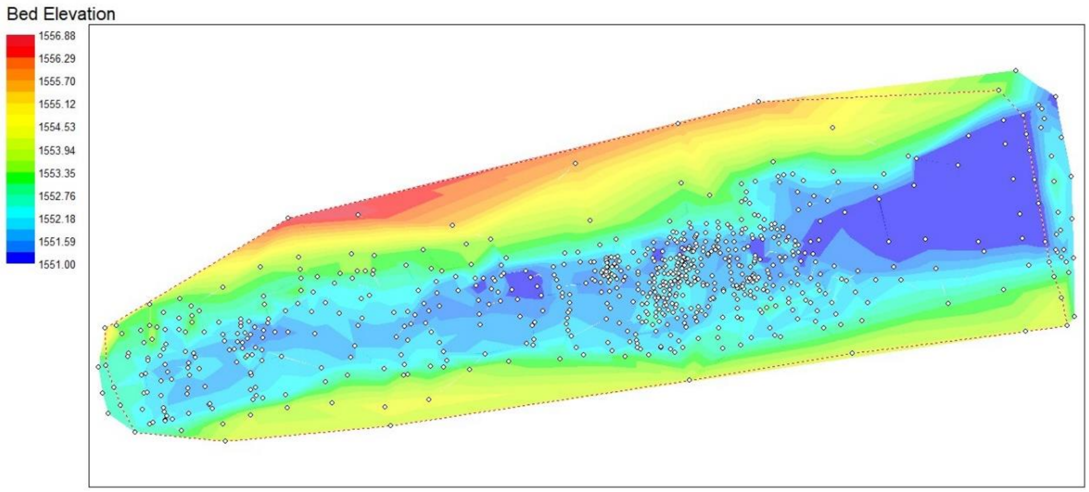

Figure 4-1: One of the Final DEMs for the Braamfontein Spruit

Mesh generation is an important consideration during the model building as it ensures numerical consistency and accuracy during simulation. Each topographic "bed" file is loaded into R2D_Mesh with the boundary nodes generating at 1000m spacing around the exterior boundary (recommended by authors of River2D). Inflow and outflow conditions are set within the exterior boundary. The inflow condition is set by entering inflow discharges (Q_{inflow}) along the boundary of the upstream channel bed. Three randomly picked inflow discharges and a field measurement discharge (refer to section 4.4 for details) were used in this study (refer to Table 6). Outflow boundary conditions are set by a known outflow water elevation instead of a discharge. Figure 4-2 shows inflow and outflow boundary conditions for one of the models on the Braamfontein Spruit ($Q=1.5m^3/s$).

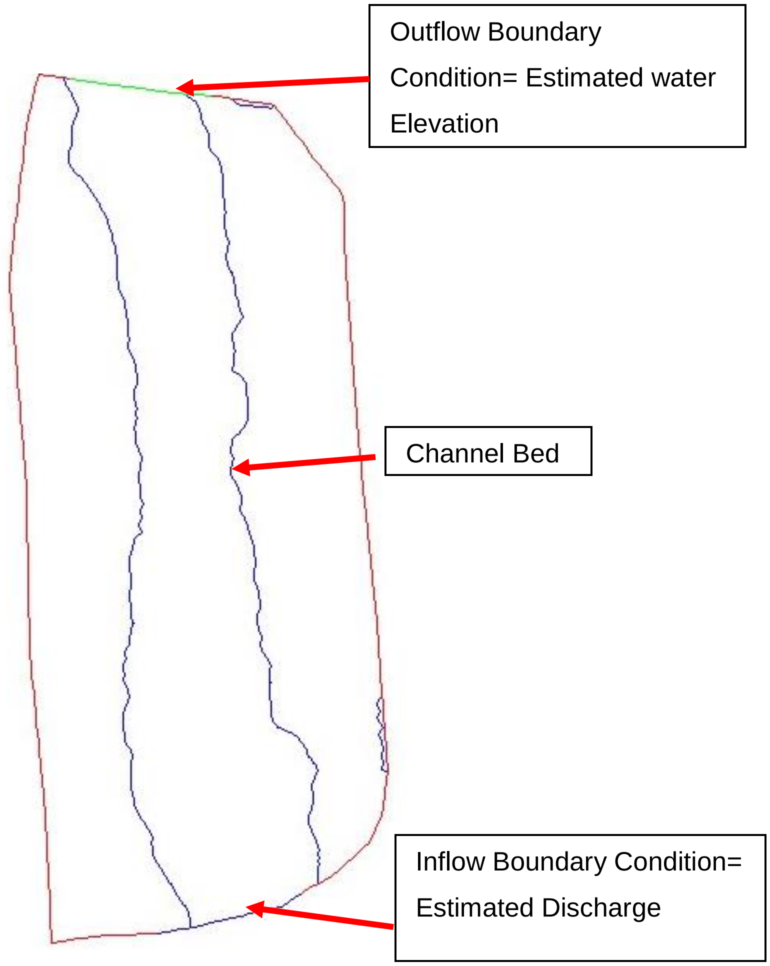

Figure 4-2: Inflow and Outflow boundary condition for Braamfontein Spruit (Q=1.5 m^3/s)

Table 6: Four different discharges used in the study

Discharge Number	Amount
Discharge 1	1.5 m^3/s
Discharge 2	1 m^3/s
Discharge 3	0.5 m^3/s
Field Estimate	0.3 m^3/s

Once boundary conditions are set, a uniform mesh can be generated and triangulate, Figure 4-3 shows one of the meshes that were generated for the total station simulations. The mesh nodes were added to the entire model at 1m spacing. This spacing was recommended by Bright (2014), with finer rather than coarser mesh tending to perform better during flow variation simulation.

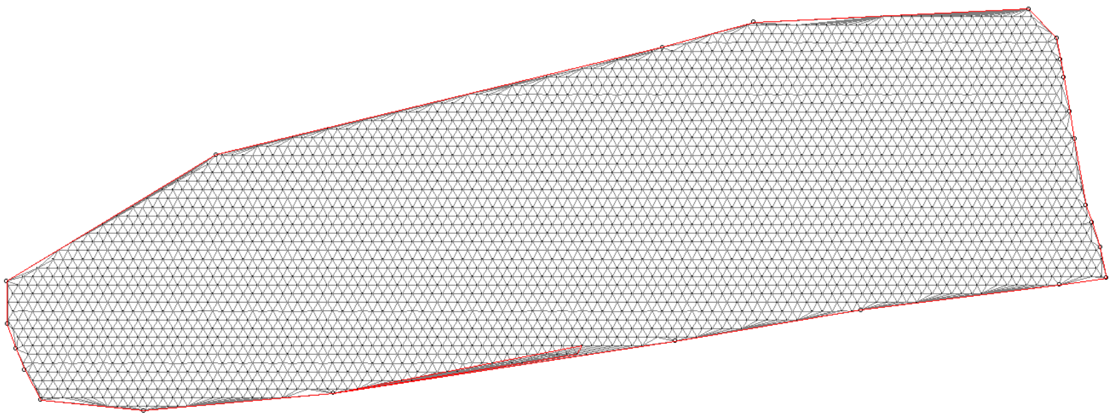

Figure 4-3: Uniform Mesh used for Total Station simulation

Two checks were utilised to assess if the meshes are able to capture the bed elevation:

1. Threshold parameter: This parameter allows a user to specify a maximum allowable elevation between elevation (topographic data) nodes and mesh nodes (River2D generates a uniform mesh based on the topographic data). Considering the size of the reach and the detail that is required to model the habitats, a threshold of 0.1m was used between the two sets of nodes. It's important to note that the threshold can vary from 0.1m to infinity but generally you want the two sets of nodes to be equal. If the threshold parameter was greater than 0.1, more computer memory will be used resulting in less time wasted on computations.

2. Quality Index (QI): This parameter measures the consistency of the mesh. The parameter provides information about the quality of the elements in terms of irregular shapes or equilateral shapes. A QI of 1 would describe a perfectly straight channel bed, however, channel beds are not straight so a QI value greater than 0.15 is considered to be sufficient (Golder Associates, 2011).

All checks for the mesh generation satisfied, model-building moved to the third and last component of the software package - River2D. An estimated inflow water elevation was required before simulations could commence. The estimated water elevation was based on the elevation at the boundary of the model and River2D refines this value during the steady flow simulation.

The final step for in the model set-up and simulations would be steady flow analysis. The steady flow solutions were easily calculated and each flow condition took on average 100-time steps to converge to a steady state.

4.2.2 Simulation

As stated above in section 4.1.1, River2D steady flow modelling was performed with four discharges shown in Table 6 and a corresponding DEM. This results in nine models for the Braamfontein Spruit. Table 7 illustrates the model name, DEM and discharge for each simulation. To date the most accurate river survey is a total station with on board data recording (James and King, 2010). The model results obtained from each simulation were compared to the results obtained from **the observed biotopes** (Refer to section 4.5)**.**

Table 7: Models used for each simulation

Model	DEM	Discharge (m^3/s)
1	Total Station	1.5
2	Total Station	1
3	Total Station	0.5
4	Total Station	0.3 (Field)
5	LIDAR	1.5
6	LIDAR	1
7	LIDAR	0.5
8	LIDAR	0.3 (Field)
9	Smartphone	1.5
10	Smartphone	1
11	Smartphone	0.5
12	Smartphone	0.3 (Field)
13	Handheld GPS	1.5
14	Handheld GPS	1
15	Handheld GPS	0.5
16	Handheld GPS	0.3 (Field)

4.3 Methods used for results evaluation

4.3.1 Velocity and water Depth

The general consensus is that river habitat description and modelling should be based on velocity and depth values (Bright, 2014; Duel et al., 1995; Bovee, 1982; Jordanova, 2008: James and King, 2010). The advantage of using River2D is it permits a user to “dump” specific parameters based on the nodes inputted during the preliminary stages of setting up the model into an Excel Spreadsheet. For each simulation, both velocity and depth values were exported into Excel where segregation of data was performed. The segregation of data (velocity and depth) was done in four stages, which was based on biotope definition (refer to section 2.3.3). Calculations were performed by counting the number of cells specified (Excel spreadsheet) for a set of criteria shown in Table 8. However, Table 8 varies slightly compared to Table 4 due the values in Table 4 tending to overlap from one biotope to another. This “overlap” would have caused difficulty in segregating the simulation results thus a slight modification of the values was done in order to simplify the calculations. The modification of Table 4 was simply to assign each biotope its own “range criteria” but still based on Table 4. For example, Table 4 suggested that pools have a velocity between **0.00-0.1** m/s and runs have a velocity between **0.05-0.19** m/s, and for this research pools have a velocity between **0.00-0.1** m/s and runs have a velocity between **0.1-0.2** m/s.

Table 8: Criteria for Biotopes

		Magnitude Criteria	
Stage	Habitat	Velocity (m/s)	Depth (m)
1	Pools	0-0.1	>0.7
2	Run	0.1-0.2	0.3-0.5
3	Riffle	0.2-0.4	0-0.3
4	Rapid	>0.4	0.5-0.7

After the segregation of the data into biotopes in terms of velocity and depth, an average between the two sets was used to describe the biotope which was based on a certain DEM model described in section 3.2.

4.3.2 Sensitivity and specificity

The sensitivity and specificity of the results produced in section 4.2.1 was further evaluated by adopting the Lee et al. (2003) method to assess satellite images. A coefficient is used to relate the reference models (observed biotope, refer to section 4.5) to the tested models (refer to Table 8).

The following circumstances in the evaluation process were used: True Positive, True Negative, False Positive, and False Negative. These cases can be detailed mathematically as:

$$True\ Positive\ (TP:) = |X \cap R|$$

$$True\ Negative\ (TN:) = |U/(X \cap R)|$$

$$False\ Positive\ (FP:) = \ |X \backslash R|$$

$$False\ Negative\ (FN:) = \ |R \backslash X|$$

Where X is the test model biotope (Pools, Rapid, Riffle, Run), R is the reference model biotope (Pools, Rapid, Riffle, Run), and U is a space. For this study the cases can further be explained as: TP - Biotope class in both sets R and X, TN - Biotope class not in both sets R and X, FP - Biotope class not in R but in X, FN - Biotope class in R and not in X.

The above cases were used in three equations to evaluate the different sets of topographic data:

$$Completeness\ (CP:) = \frac{TP}{TP + FN} \qquad \ldots (2)$$

$$Quality\ Coefficient\ (QC):= \frac{TP}{TP + FP + FN} \quad \ldots (3)$$

Where CP indicates how the biotope class defined by R data set were also defined by X data set, and QC gives an overall assessment of the similarity between the data sets.

The quality coefficient has a range from 0 to 1, where 1 is the most desired relationship between the data sets. A value of 0 indicates a complete different biotope and no relationship between the data set is visible.

4.4 Field Data Collection and Interpretation

Field work concentrated on the hydraulic characterisation of the Braamfontein Spruit in terms of the different biotopes as described in previous sections. The field measurements involved were localized velocity and depth measurements at specific selected points. These measurements were used for the validation of the models. Field results can be seen in Appendix D.

4.4.1 Field Equipment

The velocity was measured using a Global Flow Probe. The Probe is used to measure the average water velocity. There are two reasons why it's based on average (Global Water, 2004):

1. The velocity varies throughout the flow's cross-section. The general understanding is that the velocities are greater in the centre of the flow and are lower nearer the boundaries (both directions).

2. Flow in rivers tend to have surges with time. This pulsating flow has to be averaged to obtain an accurate flow reading.

Each location (biotope) was divided into 3 subsections where a measuring tape was run across the biotope for reference. The velocity for each subsection was calculated by obtaining a vertical flow profile at the centre. The device was set to zero and moved up from the river bed until max velocity was reached. The velocities were recorded as well as the water depth for each subsection. Figure 4-4 shows the Flow Probe used in this research.

Figure 4-4: Global Flow Probe used for measuring average velocities

4.4.2 Location of each measured biotope

As mentioned previously, the study reach is approximately 100 m long, the average channel width is 8.4 m, ranging from 4.9 m to 9.2 m. The choice of each point/measurement was chosen where each biotope class was "seen" and Figure 4-4 shows the locations where the measurements were taken: an average discharge was calculated from three points

(1) Right hand side rapids (Blue Circle on Figure 4-4,

(2) Left hand side deep run (Yellow Circle on Figure 4-4 for which both velocity and depth were measured.

All other points (shown in Red Cross) were based where particular biotopes (Runs, Rapids, Riffle and Pools) were located within the reach to achieve a comparison of the simulation results and the field measurements of velocities and depths.

4.4.3 Calculation of discharge

The method were used to calculate the discharge:

1. The average velocity (obtained with the Flow Probe) times the area of the related subsection described previously in this section equals the flow for the subsection (Q=VxA). This calculation is applied for each subsection where the total discharge is equal to the addition of all the sub-sections discharge.

Where V is m/s, A is in m^2 and Q is in m^3/s.

Table 9 shows the velocities and depths for each measured biotope.

Table 9: Field measurements for each Biotope

	Left Run	Right Run	Left Rapid	Upstream of Left Run
Average Depth (m)	0.7	0.12	0.2	0.47
Average velocity (m/s)	0.16	0.14	0.85	0.49

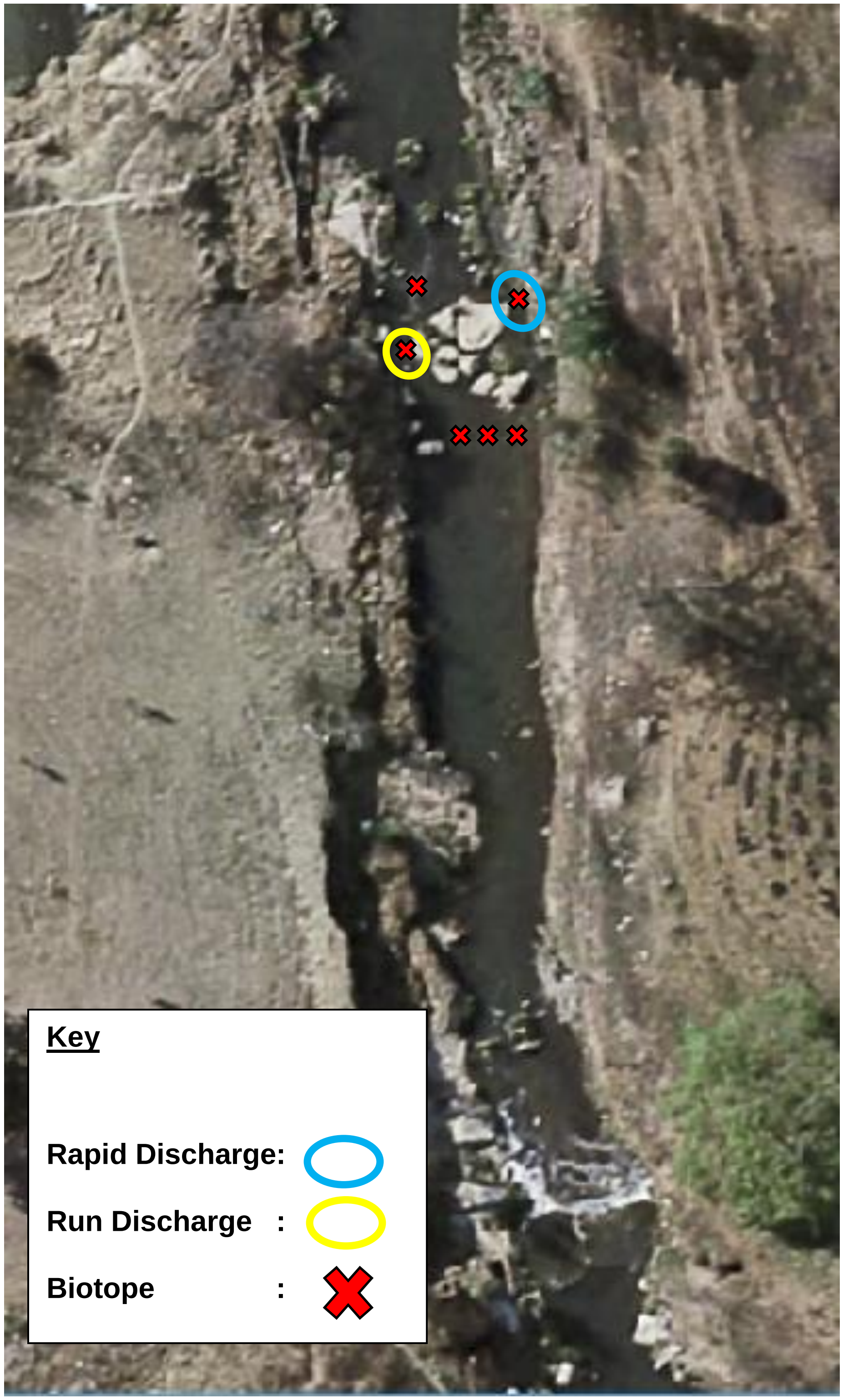

Figure 4-5: Location of the field measurements for the Braamfontein Spruit reach

4.5 Visual Delineation

Visual information from habitat modelling is vital and every opportunity must be taken to photograph the full range of biotopes for a river reach. King et al., (2008), suggest photography of river reaches are “accurate quantitative information”. Each photo can describe the changes in width and depth within the reach by relating water depths to known features such as large boulders or bank vegetation.

Google Earth Pro in conjunction with field photos (see Appendix A) was used for the delineation of the study reach. The reach was broken up into the four biotopes mentioned in section 2.3.3 and was based on field observations and sound engineering judgement. Google Earth Pro allows polygons to be drawn on satellite images, where the perimeter is provided in metre and area is given in metre squared. In addition, each polygon is colour coded and allows for an effective observation of the different classes of biotopes within the reach. Figure 4-6 shows the final delineation of the study reach using both Google Earth and photos taken of the site and Figure 4-7 shows the percentage of biotopes based on Figure 4-6.

In addition to using Google Earth Pro and field photos, a hand drawn picture was made. The purpose of this hand drawn picture was to provide a simple but effective illustration of the river features, flow depths and where each biotope was located within the reach. Appendix B indicates the hand drawn picture showing all the “essential” features of the river and the biotopes.

This process of “segregation” of the reach in terms of biotopes is used for a verification and a reference for the simulation results (results from all four DEMs) and in addition will supply a quantitative results. However, the segregation process tends to be subjective from one person to another.

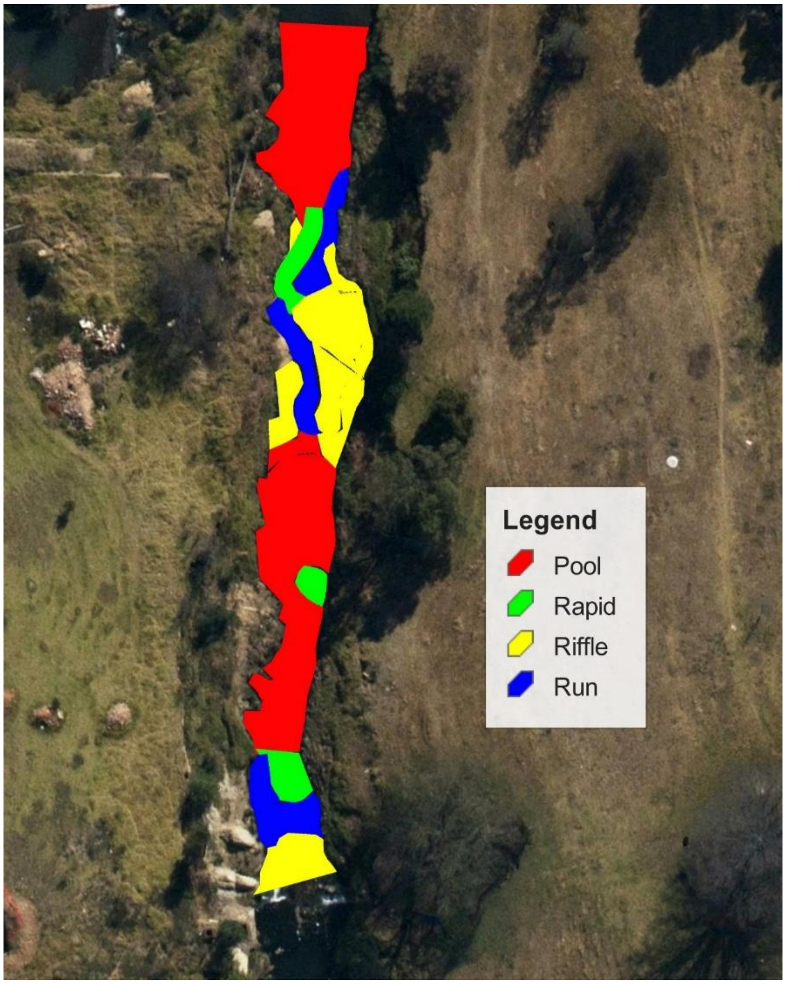

Figure 4-6: The final visual delineation of the study reach using both Google Earth and photos taken of the site.

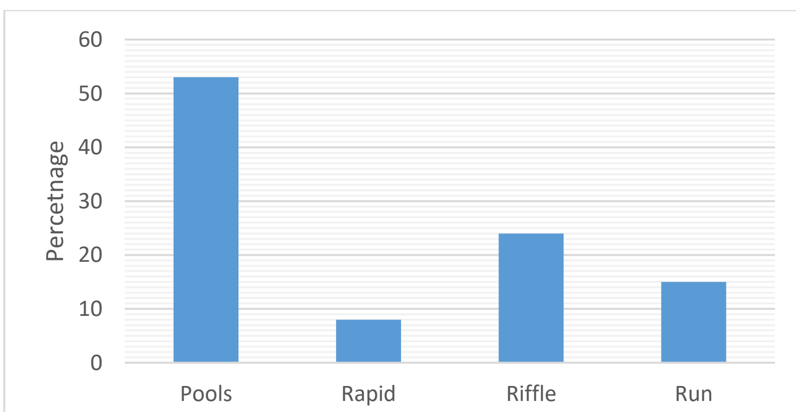

Figure 4-7: Biotope Percentage from Visual Delineation

5 RESULTS

This chapter includes the outcomes from the simulations for each DEM described in section 3.2.2. The main output of the simulation models is displayed in terms of velocity and depth. The calculated percentage of each biotope is shown and explained. Further, statistical analysis is shown for a comprehensive comparison.

5.1 Model simulation results

Due to the number of figures produced from the simulations, only the total station results are shown in Figure 5-1 to Figure 5-6. The LIDAR, handheld GPS and Smartphone results can be seen in Appendix C. The figures indicate both the water depth and velocity from each simulation. The figures allow for a visual inspection and indicate similarities in terms of major habitat features for all ranges of discharges. Each DEM has recognized major features such as large boulders and reed beds along and within the river. As anticipated, prediction of the features worsens as the quality of the DEM decreases. The total station DEM gives additional specific detail of the river's features compared to the other three DEMs. This is due to the low spatial resolution of the other three DEMs and the inaccuracy of the GPS receivers.

The time required to process each simulation also decreases with respect to the quality of the DEM. Time refers to how long the computer is able to generate the results from the simulations of River2D which is based on the performance of the computer. The simulations were conducted on an Intel Core i3-4010U CPU 1.70GHz processor, 6Gb Ram and system type x64-based.

The maximum values for both velocity and depth for all the models can be seen in Table 10.

Table 10: Max Velocity and Water Depth

	Velocity (m/s)				Water Depth (m)			
	Q=1.5	Q=1	Q=0.5	0.3 (Field)	Q=1.5	Q=1	Q=0.5	0.3 (Field)
Total Station	2.23	1.76	1.45	0.89	1.20	1.14	1.05	0.98
LIDAR	0.36	0.24	0.12	0.731	1.34	1.34	1.34	1.34
Smart phone	1.44	1.08	0.73	0.61	3.49	3.49	3.49	3.5
Handheld GPS	1.79	1.58	1.54	1.18	2.01	2.00	2.0	2

5.1.1 Total Station Simulation Model Results

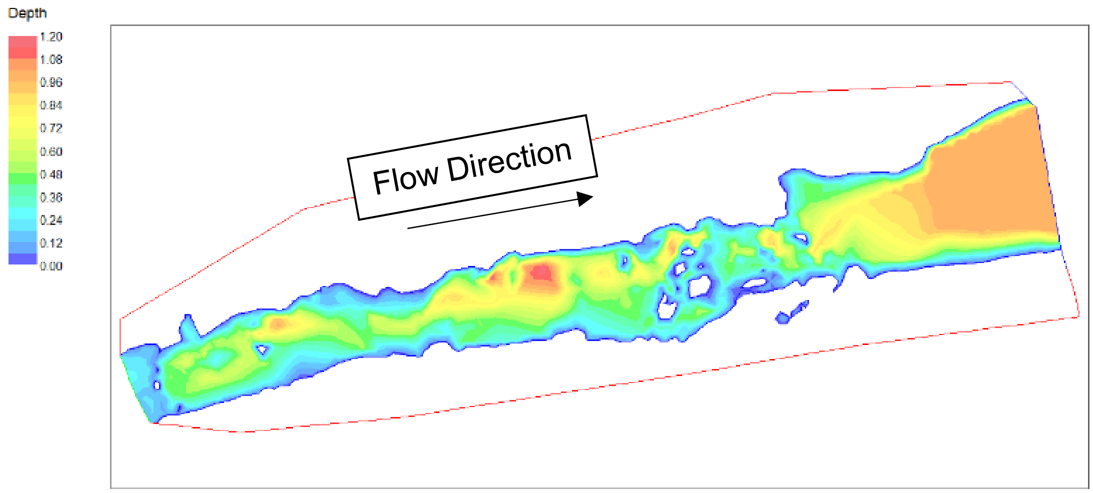

Figure 5-1: Depth from River2D with Q=1.5 m³/s and Total Station DEM

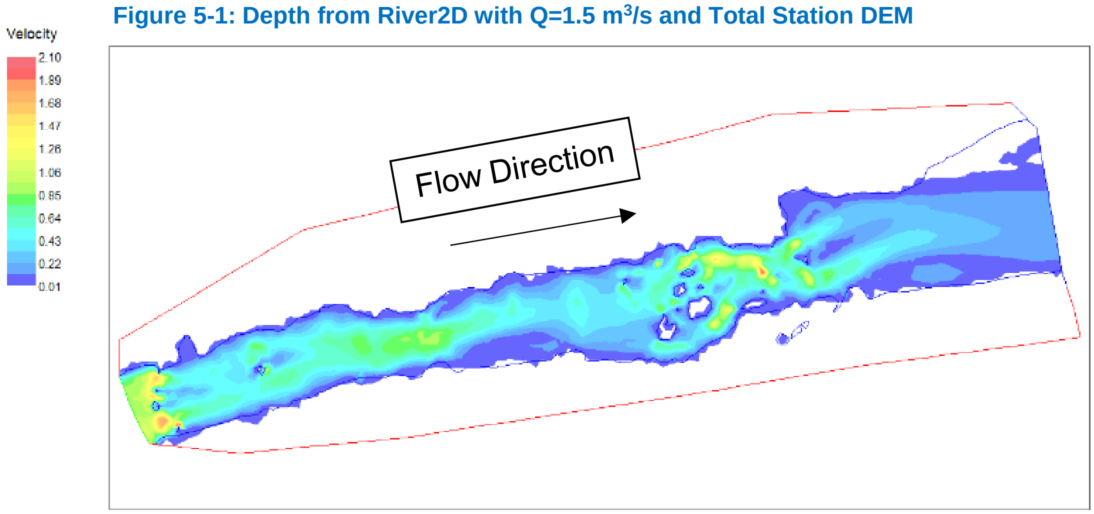

Figure 5-2: Water velocity from River2D with Q=1.5 m³/s and Total Station DEM

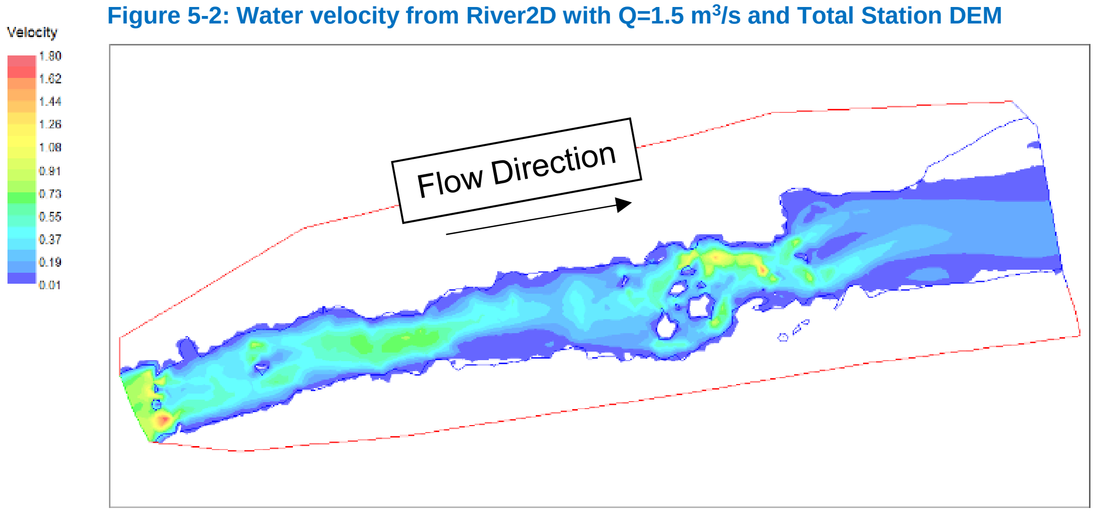

Figure 5-3: Velocity from River2D with Q=1 m³/s and Total Station DEM

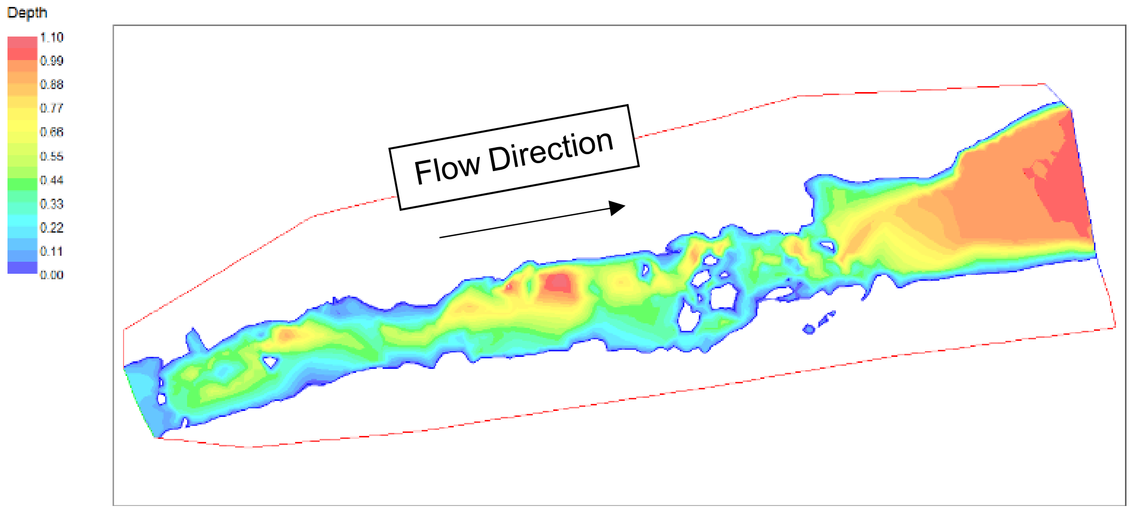

Figure 5-4: Water Depth from River 2D with Q=1 m^3/s and Total station DEM

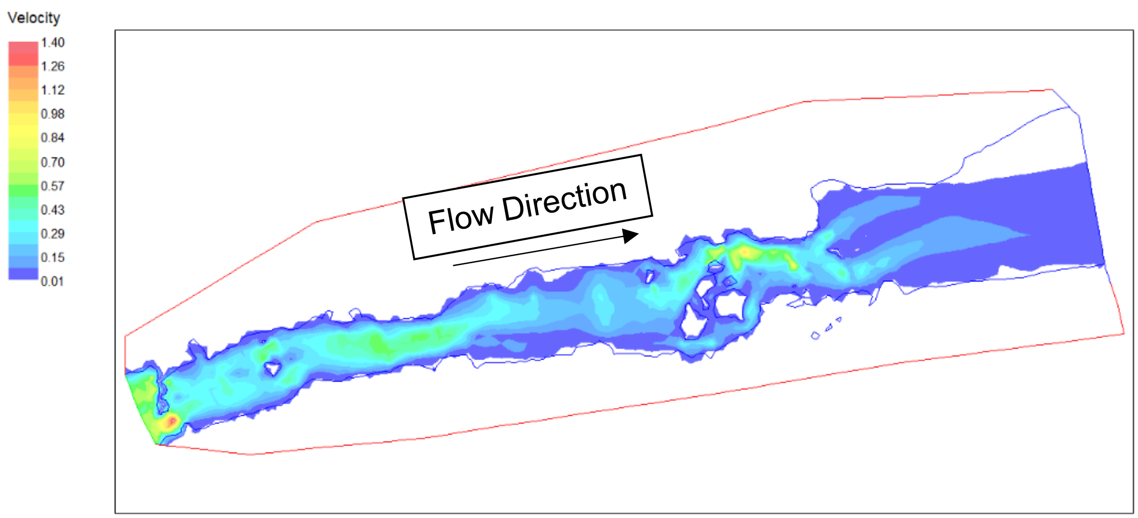

Figure 5-5: Velocity from River2D with Q=0.5 m^3/s and Total Station DEM

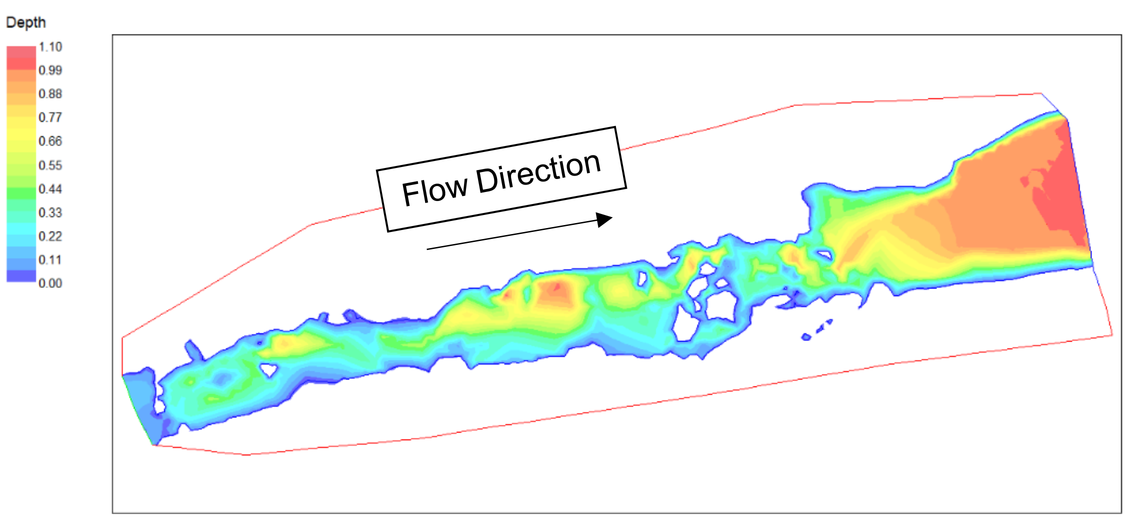

Figure 5-6: Water Depth from River2D with Q=0.5 m^3/s and Total Station DEM

5.2 Biotope Percentage

The biotope "percentages" were calculated on the averages between the velocity and water depth which was explained in detail in section 4.2.2. Histograms are used to show the averages, displayed in percentages of a certain biotope within the river.

The histograms for the total station are directly related to Figure 5-1 to Figure 5-6, while the histograms for the hand held GPS, Smartphone and LIDAR are related to the figures in Appendix C. These figures form the root of the final percentages of biotopes for each simulation. Figure 5-7 to Figure 5-10 show the final histograms for each biotope based on the different simulations. As stated in section 4.2.2, the visual delineation results are used as a reference for all the other simulations.

The histograms show, based on the percentage of biotopes within the river, that pools are the dominant features; all four simulations predicted this dominance. The portion of areas associated with Rapids, Riffles and Runs decreased as the quality worsened with respect to the DEM. By contrast, the proportion associated with Pools is larger for DEMs with a lower quality, with changes up to 40%.

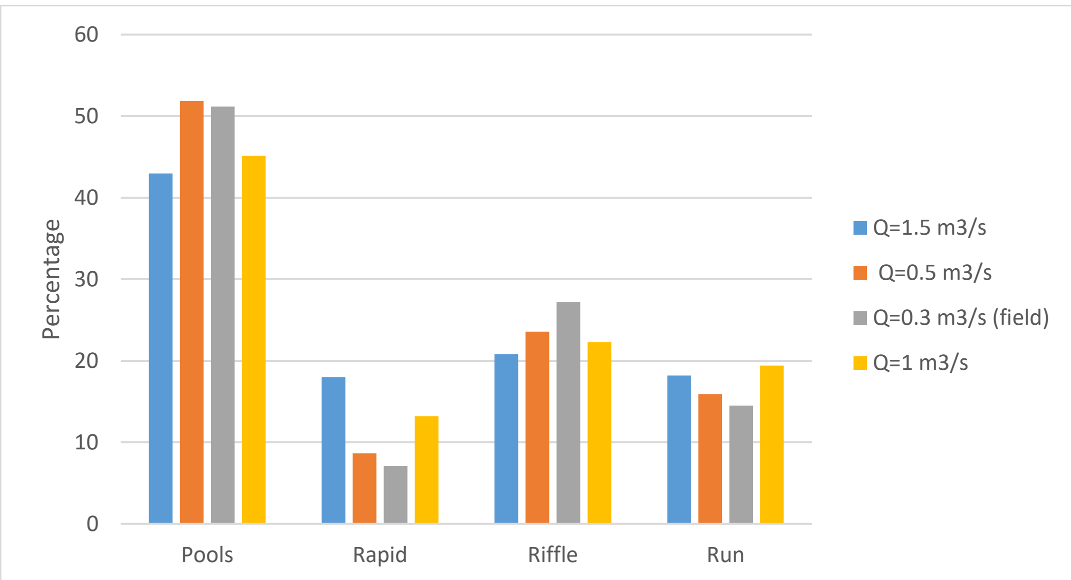

Figure 5-7: Average Percentage of Biotopes for Total Station DEM

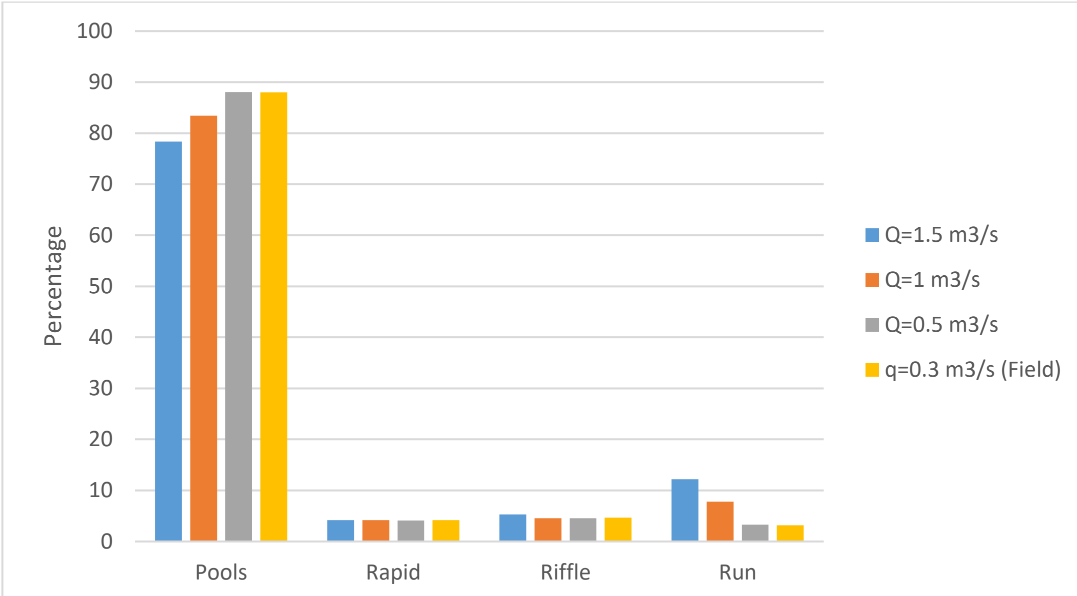

Figure 5-8: Average Percentage of Biotopes for LIDAR DEM

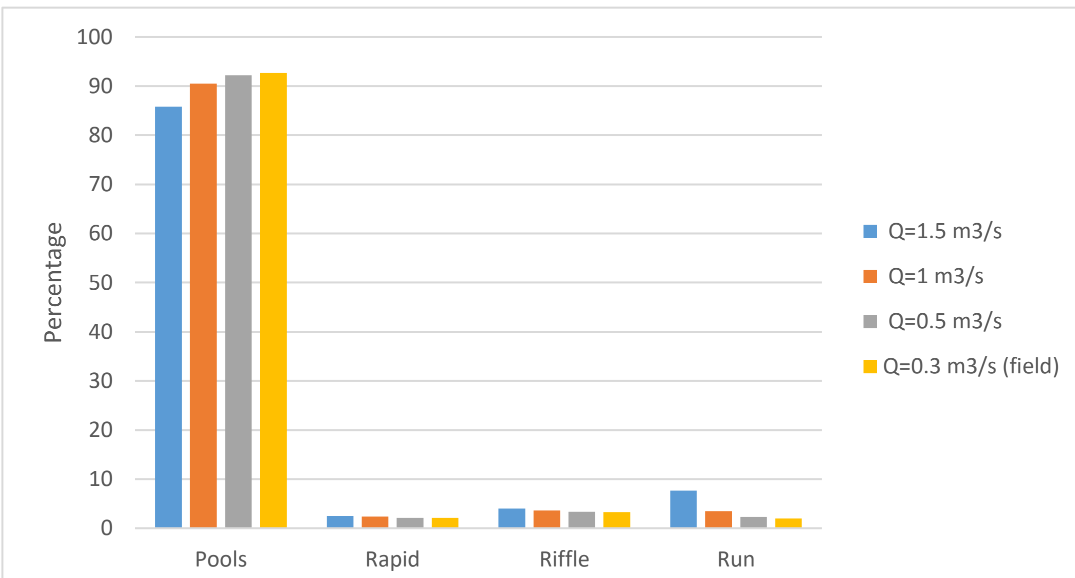

Figure 5-9: Average Percentage of Biotopes for Smartphone DEM

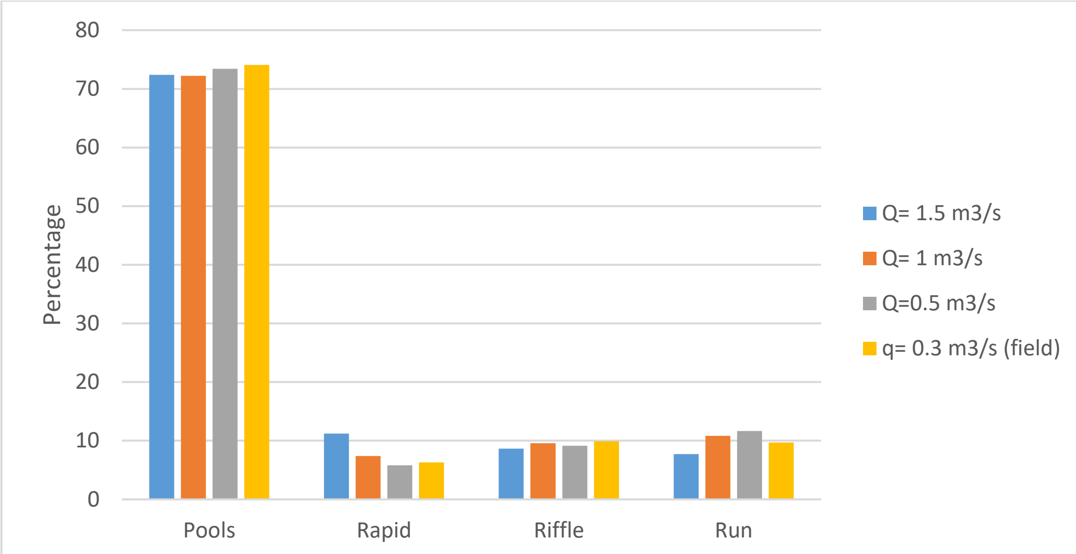

Figure 5-10: Average Percentage of Biotopes for Hand Held GPS DEM

Table 11 shows the results from the visual delineation. As predicted, the results indicate that the reach comprises of 53% of pools followed by 24% riffles, 15% runs and 8% rapids. The results tend to follow the total station prediction which can be seen on Table 11 to Table 15 which details the percentage errors for each DEM compared to the visual delineation results. In additional, delineation shows a histogram of the visual delineation tends to follow the same pattern as the total station histogram shown in Figure 5-7.

Table 11: Visual delineation results

	Area (m^2)				
	Pools	**Rapid**	**Run**	**Riffle**	**Total Area**
Amount	356	57	99	160	672
%	53	8	15	24	100

Table 12: Percentage error compared to visual Delineation Results for Q=1.5 m^3/s

	Discharge = 1.5 m^3/s			
	Percentage error compared to Visual Delineation results			
	Total Station %	**LIDAR%**	**Smartphone %**	**Handheld GPS%**
Pools	19	32	38	27
Run	18	19	49	48
Riffle	13	78	83	64
Rapid	56	48	68	29

Table 13: Percentage error compared to visual Delineation Results for Q=1 m^3/s

Discharge = 1 m^3/s				
	Percentage error compared to Visual Delineation results			
	Total Station	**LIDAR**	**Smartphone**	**Handheld GPS**
Pools	15	36	41	27
Run	23	48	77	28
Riffle	7	81	85	60
Rapid	39	48	71	7

Table 14: Percentage error compared to visual Delineation Results for Q=0.5 m^3/s

Discharge = 0.5 m^3/s				
	Percentage error compared to Visual Delineation results			
	Total Station	**LIDAR**	**Smartphone**	**Handheld GPS**
Pools	2	40	43	28
Run	6	78	84	22
Riffle	2	81	86	62
Rapid	8	49	73	27

Table 15: Percentage error compared to visual Delineation Results for Q=0.3 m^3/s (Field)

Discharge = 0.3 m^3/s (Field)				
	Percentage error compared to Visual Delineation results			
	Total Station	**LIDAR**	**Smartphone**	**Handheld GPS**
Pools	3	40	28	43
Run	3	79	36	87
Riffle	12	81	59	86
Rapid	11	48	21	74

5.3 Statistical Results

The performance of each simulations measured through **TP**, **TN**, **FP** and **FN** (see section 4.2.2) can be seen in Table 16 to Table 19 . **TP** indicates a percentage of which a certain biotope is shared between the visual results and the modelled results. The **TP** values were calculated by finding the **minimum** percentage between the Visual and the model results for each biotope. Based on **TP** values, the best model that has similarity to the visual delineation biotopes is the total station with an average (an average between all four discharges) similarity of 95% followed by handheld GPS with 65%, LIDAR with 51%, and smartphone with 51%.

TN indicates the percentage of biotope that is **not** picked up by both the visual results and the DEMs. The **TN** values were calculated by summing up the *(100%-Visual %)+(100%-DEM %)* for each Biotope. Based on **TN** values, the best model that has similarity to the visual delineation biotopes is the total station with an average (an average between all four discharges) similarity of 21% followed by handheld GPS with 26%, LIDAR with 28%, and smartphone with 29%.

FP is the percentage of a biotope not in the visual results but in the DEM results. The **FP** values were calculated by saying that **if** *DEM% is greater than Visual%, then DEM%- Visual else zero* for each biotope, however the total station and handheld GPS had an average of 14%, while LIDAR and the smartphone had an average of 15%.

FN is the percentage of biotopes in the visual results but not in the DEM models. The FN values were calculated by saying that **if** *visual % is greater than DEM %, then Visual % - DEM% else zero* for each biotope. Based on **FN** values, the best model that has similarity to the visual delineation biotopes is the total station with an average (an average between all four discharges) similarity of 5% followed by handheld GPS with 35%, LIDAR with 46%, and smartphone with 49%. The overall averages can be seen in Table 20 which can be read in conjunction with Table 16 to Table 19 which show the **TP, TN, FP and FN** for each discharge. A detailed tables of percentage differences between the each biotope (in terms of Visual results and a DEM) can be seen in Appendix E.

Table 16: Similarity between the visual results and a DEM with respect to a discharge of 1.5 m3/s

Q=1.5 m^3/s																
	True Positive				True Negative				False Positive				False Negative			
	Total Station	LIDAR	Smart Phone	Handheld GPS	Total Station	LIDAR	Smart Phone	Handheld GPS	Total Station	LIDAR	Smart Phone	Handheld GPS	Total Station	LIDAR	Smart Phone	Handheld GPS
Pools (%)	43	53	53	53	104	69	61	75	0	25	33	19	10	0	0	0
Run (%)	15	12	8	8	167	173	177	177	3	0	0	0	0	3	7	7
Riffle (%)	21	5	4	9	155	171	172	167	0	0	0	0	3	19	20	15
Rapid (%)	8	4	3	8	174	188	189	181	10	0	0	3	0	4	5	0

Table 17: Similarity between the visual results and a DEM with respect to a discharge of 1 m3/s

Q=1 m^3/s																
	True Positive				True Negative				False Positive				False Negative			
	Total Station	LIDAR	Smart Phone	Hand held GPS	Total Station	LIDAR	Smart Phone	Hand held GPS	Total Station	LIDAR	Smart Phone	Hand held GPS	Total Station	LIDAR	Smart Phone	Hand held GPS
Pools (%)	45	53	53	53	102	64	56	75	0	30	38	19	8	0	0	0
Run (%)	15	8	4	11	166	177	181	174	4	0	0	0	0	7	11	4
Riffle (%)	22	5	4	10	154	171	172	166	0	0	0	0	2	19	20	14
Rapid (%)	8	4	2	7	179	188	190	185	5	0	0	0	0	4	6	1

Table 18: Similarity between the visual results and a DEM with respect to a discharge of 0.5 m3/s

Q=0.5 m^3/s																
	True Positive				True Negative				False Positive				False Negative			
	Total Station	LIDAR	Smart Phone	Handheld GPS	Total Station	LIDAR	Smart Phone	Handheld GPS	Total Station	LIDAR	Smart Phone	Handheld GPS	Total Station	LIDAR	Smart Phone	Handheld GPS
Pools	52	53	53	53	95	59	55	74	0	35	39	20	1	0	0	0
Run	15	3	2	12	169	182	183	173	1	0	0	0	0	12	13	3
Riffle	24	5	3	9	152	171	173	167	0	0	0	0	0	19	21	15
Rapid	8	4	2	6	183	188	190	186	1	0	0	0	0	4	6	2

Table 19: Similarity between the visual results and a DEM with respect to a discharge of 0.3 m3/s (field)

Q=0.3 m^3/s																
	True Positive				True Negative				False Positive				False Negative			
	Total Station	LIDAR	Smart Phone	Handheld GPS	Total Station	LIDAR	Smart Phone	Handheld GPS	Total Station	LIDAR	Smart Phone	Handheld GPS	Total Station	LIDAR	Smart Phone	Handheld GPS
Pools	51	53	53	53	96	59	73	54	0	35	21	40	2	0	0	0
Run	15	3	10	2	170	182	175	183	0	0	0	0	0	12	5	13
Riffle	24	5	10	3	149	171	166	173	3	0	0	0	0	19	14	21
Rapid	7	4	6	2	185	188	186	190	0	0	0	0	1	4	2	6

Table 20: The average similarity between the visual results and a DEM

True Positive (TP)			
Total Station	LIDAR	Smartphone	Handheld GPS
95%	54%	51%	65%
True Negative (TN)			
Total Station	LIDAR	Smartphone	Handheld GPS
21%	28%	29%	26%
False Positive (FP)			
Total Station	LIDAR	Smartphone	Handheld GPS
14%	15%	15%	14%
False Negative (FN)			
Total Station	LIDAR	Smartphone	Handheld GPS
5%	46%	49%	35%

Table 21 to Table 24 indicate the values of the indices expressed in section 4.2.2: **CP** and **QC** for each resolution. **CP** measures how much a certain biotope is defined by the visual results were also defined by the DEMs. The **CP** value for each biotope was calculated by taking the associated **TP** value for that biotope and dividing it by the sum of *(associated **TP** value and the associated **FN** value)*. CP Values can range between 0 and 1, where 1 is the most desirable value. The results show that the total station DEM provides the best **CP** values for all discharges and biotopes, followed by handheld GPS, LIDAR, and smartphone.

The **QC** values measures the over results/assessment between the visual results and each DEM for each Biotope. The **QC** value for each biotope was calculated by taking the associated **TP** value for that biotope and dividing it by the sum of *(associated **TP** value, associated **FN** value and the associated **FP** value)*. **QC** values also range from 0 to 1, where 1 is the most desirable value. The results show that the total station DEM provides the best **QC** values for all discharges and biotopes, followed by handheld GPS, LIDAR, and smartphone.

Table 21: Similarity indexes in the analysis for discharge 1.5m3/s

	Completeness				Quality Coefficient			
	Total Station	LIDAR	Smart Phone	Handheld GPS	Total Station	LIDAR	Smart Phone	Handheld GPS
Pools	0.81	1.00	1.00	1.00	0.81	0.68	0.62	0.73
Run	1.00	0.81	0.51	0.52	0.82	0.81	0.51	0.52
Riffle	0.87	0.22	0.17	0.36	0.87	0.22	0.17	0.36
Rapid	1.00	0.52	0.32	1.00	0.44	0.52	0.32	0.71

Table 22: Similarity indexes in the analysis for discharge 1m3/s

	Completeness				Quality Coefficient			
	Total Station	LIDAR	Smart Phone	Handheld GPS	Total Station	LIDAR	Smart Phone	Handheld GPS
Pools	0.85	1.00	1.00	1.00	0.85	0.64	0.59	0.73
Run	1.00	0.52	0.23	0.72	0.77	0.52	0.23	0.72
Riffle	0.93	0.19	0.15	0.40	0.93	0.19	0.15	0.40
Rapid	1.00	0.52	0.29	0.93	0.61	0.52	0.29	0.93

Table 23: Similarity indexes in the analysis for discharge 0.5m3/s

	Completeness				Quality Coefficient			
	Total Station	LIDAR	Smart Phone	Handheld GPS	Total Station	LIDAR	Smart Phone	Handheld GPS
Pool	0.98	1.00	1.00	1.00	0.98	0.60	0.57	0.72
Run	1.00	0.22	0.16	0.78	0.94	0.22	0.16	0.78
Riffle	0.98	0.19	0.14	0.38	0.98	0.19	0.14	0.38
Rapid	1.00	0.51	0.27	0.73	0.92	0.51	0.27	0.73

Table 24: Similarity indexes in the analysis for discharge 0.3 m3/s (field)

	Completeness				Quality Coefficient			
	Total Station	LIDAR	Smart Phone	Handheld GPS	Total Station	LIDAR	Smart Phone	Handheld GPS
Pool	0.97	1.00	1.00	1.00	0.97	0.60	0.72	0.57
Run	0.97	0.21	0.64	0.13	0.97	0.21	0.64	0.13
Riffle	1.00	0.19	0.41	0.14	0.88	0.19	0.41	0.14
Rapid	0.89	0.52	0.79	0.26	0.89	0.52	0.79	0.26

6 DISCUSSION

In this chapter, the results of the report are discussed with the following aims:

(1) to discuss the quality of the DEM compared to the reference;

(2) to identify the optimal surveying sources required for a robust habitat study; and

(3) to discuss which DEM is best-suited to which type of habitat study.

6.1 Quality of DEMs Compared to the Reference

The general trend from this study suggests that DEMs unable to describe the terrain adequately for habitat simulations have a lower number of features mapped within the river reach. This is clearly visible with the inspections of the simulation results, as the total station DEM provides adequate description of all the features within the reach. However, as the DEM's quality deteriorates, features such as Runs, Riffles, and Rapids tend to be absent or barely visible. Velocity patterns which are used to describe Riffles and Rapids (fast moving water around features) are not identifiable from DEMs with low quality X, Y, and Z coordinate data and tend to be observed as Runs or Pools. A detailed discussion of each topographic data source is presented below.

6.1.1 Total Station

As anticipated, using a DEM with accurate and more precise elevation data leads to better description of habitats than that of poorer elevation data. Total Station were the most accurate DEM of the four compared to the visual results and produced the best quality.

The similarity indices for the total station models were the closest to 1, where 1 is a perfect match to the reference. The quality of the total station prediction tended to decrease with a decrease in discharge, which was expected. In addition, the total station models produced the lowest percentage error compared the other 3 sources of data. Furthermore, this source of data has some advantage such as: it allows work to be carried out fast, accuracy is high, tends to be eliminated errors during reading and recording and the calculation of coordinates tends to be fast and accurate. However there is still a limitation on using this source and some of the disadvantage include:

- Instruments tend to be costly,

- Working a total station can be difficult and requires a skilled person,

- Often the data needs to be check with the correct software

6.1.2 Handheld GPS

Handheld GPS was the second most accurate DEM of the four compared to the visual results and showed to be the most practical source.

The similarity indices for the handheld GPS tend to range from 0.36 to 1 (for all four discharges), where 1 is a perfect match to the reference. The quality of the total station prediction tended to decrease with a decrease in discharge. In addition, the percentage error for all three discharges ranged between 7% and 87%, where a discharge of 1 m^3/s produced a 7% difference for rapids and a discharge of 0.3 m^3/s produced a difference of 87% for runs. This source of data has potential to compete with a total station data and can provide an effective solution against economic constraints. An added advantage for using the handheld GPS is that it offers easy portability through/along the river and an efficient way to record locations called "waypoints" (even though this was not used during this study). However there is still a limitation on using this source, as it struggled with representing the terrain. This limitation could have been brought on by a number of factors (Lovetoknow, 2015):

1. **Geometric Dilution of Precision**: This is when the GPS records the wrong position if a satellite is angled incorrectly.

2. **Visibility**: Often a satellite will block or disconnect a GPS receiver because the satellite has moved more than 170 000 km away from the receiver. Frequently the main cause of disconnection is buildings, trees, thick bushes, and cloud cover.

3. **The Atmosphere Delay**: The signal produced by the satellite is slowed when travelling through the atmosphere therefore affecting the accuracy.

4. **Clock Errors**: Satellite clocks are some of the most accurate clocks produced, however they are not perfect and, due to the distance satellites to Earth, time errors are produced.

5. **Orbital Errors**: These are errors produced by the wrong location of the satellite.

6.1.3 LIDAR

LIDAR tends to be the most precise in describing the terrain of the river (banks and floodplains). The similarity indices for the LIDAR tends to range from 0.21 to 1 (for all four discharges), where 1 is a perfect match to the reference. As with the Total Station/Handheld GPS predictions, the quality of the LIDAR prediction tended to decrease with a decrease in discharge. In addition, the percentage error for all three discharges ranged between 32% and 81%, where a discharge of 1.5 m^3/s produced a 32% difference for pools and a discharge of 0.3 m^3/s produced a difference of 81% for riffle. Figure 6-1 shows the LIDAR used in this research and shows how it was able to pick up the banks but was insufficient for picking up river features. In addition, there are number of other factors that could have contributed to a low quality value:

1. The surface heights are discrete and not continuous (Ali et al., 2015).

2. LIDAR is not always available and the costs associated with conducting a survey are extremely high.

3. The major disadvantage for using LIDAR in habitat modelling is its inability to penetrate the water surface and dense vegetation.

4. LIDAR generally comes in 1m resolutions and thus the level of detail it can survey (in terms of rocks, boulders etc.) is low. Figure 6-1 shows the LIDAR used for this research and some of the major features in the river were not surveyed

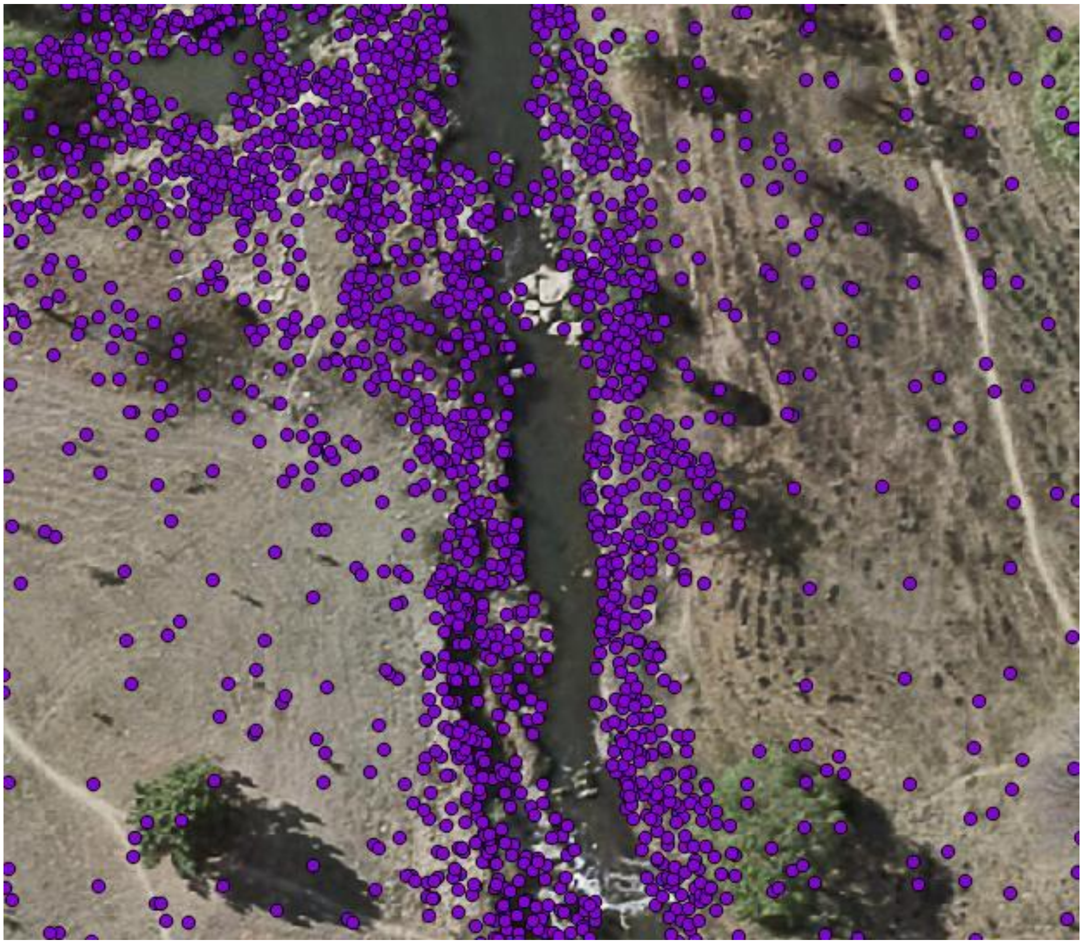

Figure 6-1: LIDAR Data used to produce a DEM

6.1.4 Smartphone

The outcomes from the simulation models based on the smartphone data did not provide adequate results. The data produced from this source has a low level of accuracy and often was not of acceptable standard. The generation of the DEM required small changes in order to produce a working model for the research. Some of the changes were moving nodes, removing nodes, and producing nodes for the water level. The similarity indices for the smartphone tends to range from 0.16 to 1 (for all four discharges), where 1 is a perfect match to the reference. The quality of the Smartphone prediction was opposite to the other three sources and tended to increase with a decrease in discharge.

A number of factors influence a smartphones GPS and its ability to record accurate results:

1. Smartphone GPS cannot locate a position on its own and requires assistance from the cell phone network provider. The location is based on cell phone towers in the area (3 towers needed) and their proximity.

2. The GPS chip within the smartphone can vary between makes and models. With a really good signal, a smartphone can achieve an accuracy of 10m.

3. The GPS signal is also affected by the general factors mentioned for the handheld GPS.

6.2 Habitat assessment/studies

As mentioned in section 2.1, assessing the effects of topographic data on habitat modelling is important as these assessments are used to find effective solutions to river management, improve quality of freshwater ecosystems, and understand the communities and habitats which exist within the rivers. The DEMs of each model was elevated and assessed to see which DEM is best suited for one of the four levels of studies mentioned in section 2.1.

6.2.1 Desktop and Rapid One Study

The desktop and Rapid 1 methods focus on hydrological factors and gather information from other studies which relate hydraulic, geomorphological, and ecological conditions. The basis of this method is an empirical approach and doesn't use the hydraulic information directly. The difference between desktop and Rapid 1 study is the accuracy of the assessment, as Rapid 1 requires more information about hydraulic conditions. The topographic data is not required for these two assessments so none of the DEMs used in this research is suitable.

6.2.2 Rapid Two and Three Study

Both Rapid 2 and 3 depend on Rapid 1 for a simple desktop study and can still be considered as a quick and low-cost assessment for small-scale projects. Rapid two requires a more detailed assessment and measurement on the discharge and depth, and a simple indication on the biota which exist within the river reach (used for making ecological predictions). Like Rapid 1, a Rapid 2 assessment does not require topographic data, however, Rapid 3 requires additional collection of limited topographic data.

The DEM produced by the LIDAR (if already available) data is best suited for a Rapid 3 assessment as it only requires empirical calculations and small amounts of field measurements. LIDAR provides sufficient data to detail the banks and even though it does not give an accurate description of the river's habitats, it can still provide some detail of habitats. If LIDAR is not available and the study is constrained by economic factors then a quick field measurement from a smartphone– or handheld GPS is adequate but reasonable judgement must be used.

6.2.3 Intermediate Study

An Intermediate study involves a more detailed study on the hydraulics and habitat. It involves gathering additional information and more rigorous simulation models. The purpose of this study is to provide accurate ratings for discharge, velocity, and water depth.

Based on the above requirements for an Intermediate study, the DEM has to be sourced from a handheld GPS or a total station. Due to the complex hydraulic analysis used to model habitats, the DEM has to describe the terrain in a manner that is suitable for detailed solutions such as velocity, discharge curves, and flow regimes, thus handheld GPS or total station data is required.

6.2.4 Comprehensive Study

A Comprehensive study takes the Intermediate study one-step further by employing more rigorous and complex analysis (3-D simulations are used but rarely for habitat modelling). The main objective of this study is to further the hydraulic analysis over and above any other study already mentioned. Field measurements are taken throughout the year (From Summer to Winter, and then Winter to Summer) as this provides a full description of the flow conditions existing within a river reach. The foundation for this advanced simulation requires fully detailed bank and channel topographic detail which maps all the minor and major features.

Based on the above requirements for a comprehensive study, the DEM has to be sourced from a total station. However, the combination of both total station and LIDAR will probably provide the most accurate and detailed DEM of any survey source available on the market.

6.2.5 What is the Optimal DEM?

The inability for a DEM to identify important features within a river reach will have a huge effect on any habitat study as some of these features would be key areas for aquatic species. As discussed previously, there are a number of studies of habitat assessments – each is important and at times interlinked which can be seen in Figure 2-1.

Other important aspects for habitat are the conditions for species to spawn (Casado et al., 2016). Flow conditions which are not identified such as Riffle and Rapids tend to produce an "underestimated" result, while failure in identifying Runs and Pools directly impacts the assessment on how macroinvertebrates spawn (Casado et al., 2016). In addition, failure to identify features which provide feeding, refuge, and nesting will directly impact any habitat study.

Assessing the optimal DEM based on these four sources is difficult because accuracy and area surveyed are inter-linked. If accurate data are required then the only option is a total station survey with up-to-date technology considered to be adequate for such a comprehensive study. However, this option requires a skilled person to operate the total station and tends to be time consuming. Alternatively, if one wants a wider area, a handheld GPS is an option due to its ease of operation and its ability to access difficult locations.

The results of this research indicate the lack of technology available to provide a cost-effective solution for a robust habitat assessment. Little work has been carried out on the available technology and the uncertainty in topographic data used in river habitat studies especially in policies or in government frameworks used for management of rivers. Failure in further studies could result in the breakdown of ecosystems and loss of aquatic life as technology is becoming more expensive in terms of topographic surveying.

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7 CONCLUSION AND RECOMMENDATION

Ecohydraulics is based on the relationship between discharge and the available habitat which exists within and around the river system. In addition, the modelling of ecohydraulics is used to simulate or predict essential hydraulic conditions such as discharge, velocity, depth, and river features that could change the behaviour of aquatic species or communities. The foundation of habitat modelling is the Digital Elevation Model (DEM) which could be gathered from a number of sources such as LIDAR, GPS, satellite, total station etc. However, the degree of the resolution varies and plays an important role in the outcome of modelling.

This study assessed the influence of different topographic elevation data on the description of habitats in low flow conditions. A reach of the Braamfontein Spruit, Johannesburg was used as a test area. The research was conducted using 2-D model software (River2D) and the sources of the DEMS were: (1) total station survey, (2) 1m resolution LIDAR, (3) a smartphone GPS application, and (4) a handheld GPS unit.

The study did have several limitations and constraints such as:

- The required time for the research was 6-months as this research is a partial fulfilment for an MSc in Engineering. However with more time, one would conduct the total station survey in more detail and not depend on outside sources, the addition of more topographical equipment for evaluations, a full scale field measurements for all seasons of the year and include a bathymetric survey.

- The field measurements were based on one flow conditions (very low flow) and a more suitable study with various flow conditions should be done

- The detail in the topographical survey is based on the amount of resource and time allocated for each survey. Thus a certain resolution can vary within any of the techniques, depending on the user and how adequate he/she thinks the survey is adequate.

The following major conclusion can be drawn:

- Hydraulic modelling and habitat description depend completely on the quality of the description of the terrain i.e. the DEM. Different DEMs as a result of different sources directly affects the results of river simulations.

- Data from **total station** surveys describe the terrain most accurately and this survey technique is very common in comprehensive habitat modelling.

- Data from **LIDAR** scanning has the most precise coordinates in terms of X, Y and Z. Overall the data is the most accurate in terms of describing the banks of the river but falls short when detailing features within the river (resolution is 1m). The DEM provided by LIDAR scanning gives discrete surface elevations, useful for studies requiring coarser DEMs. However, the data does depend on economic constraints, does not penetrate the water surface and is unable to penetrate areas with dense vegetation. If LIDAR is available then the data is more than adequate for a desktop study or preliminary design.

- Data from **smartphone GPS** had the poorest quality and was least accurate in terms of describing habitats. The application in habitat modelling should be limited to the use of large areas as most smartphones have an accuracy of ±10m due to the different infrastructure components that make up using a smartphone GPS. However, the use of smartphone data can be justified for Rapid Studies as they tend to describe in small detail the major features that exist in a river system.

- Data from the **handheld GPS** led to satisfactory results but it did not provide very high accuracy in the habitat models. But due to the ease of use and its reasonable ability to predict habitats, a GPS unit should be more than adequate for a Rapid or Intermediate Study.

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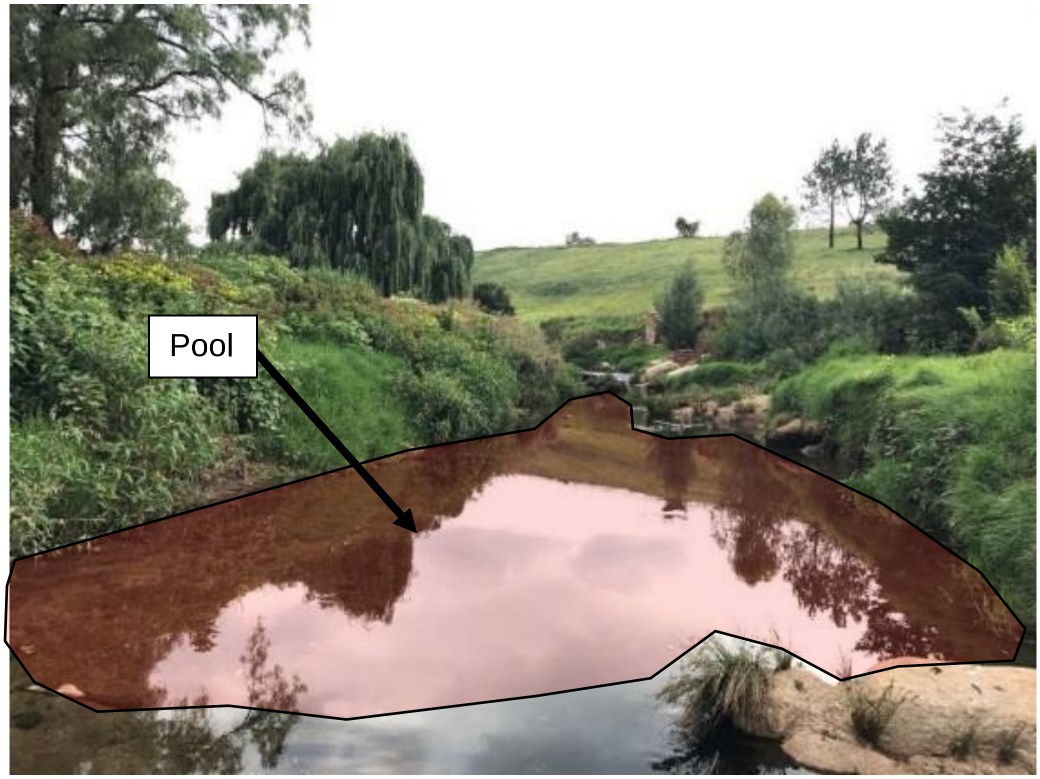
9 APPENDICES

APPENDIX A

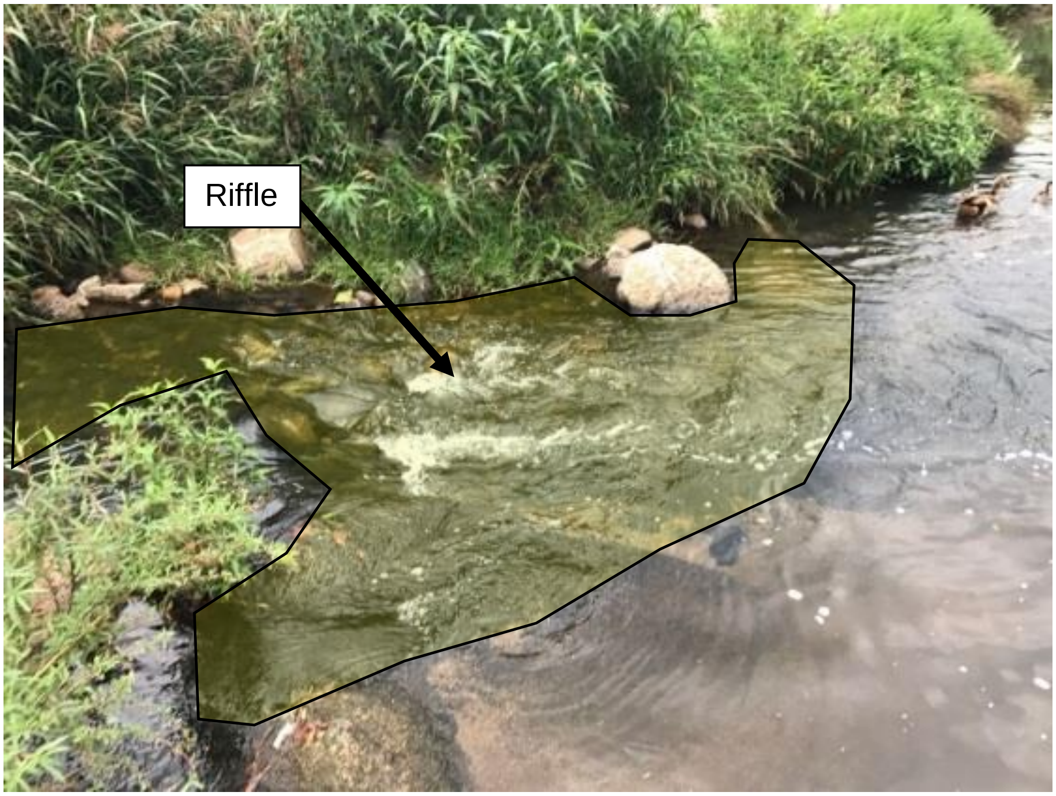
SITE PHOTOS OF THE BRAAMFONTEIN SPRUIT

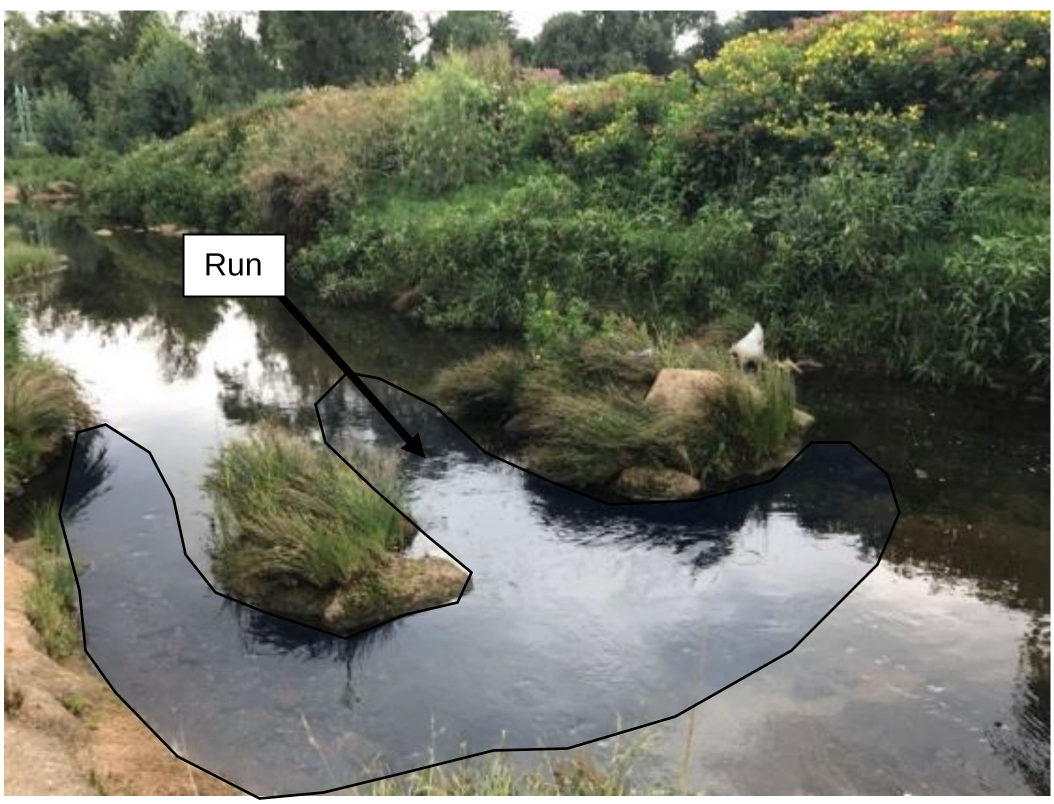

Pool


Rapid


Pool


Pool
Riffle


Riffle


Run

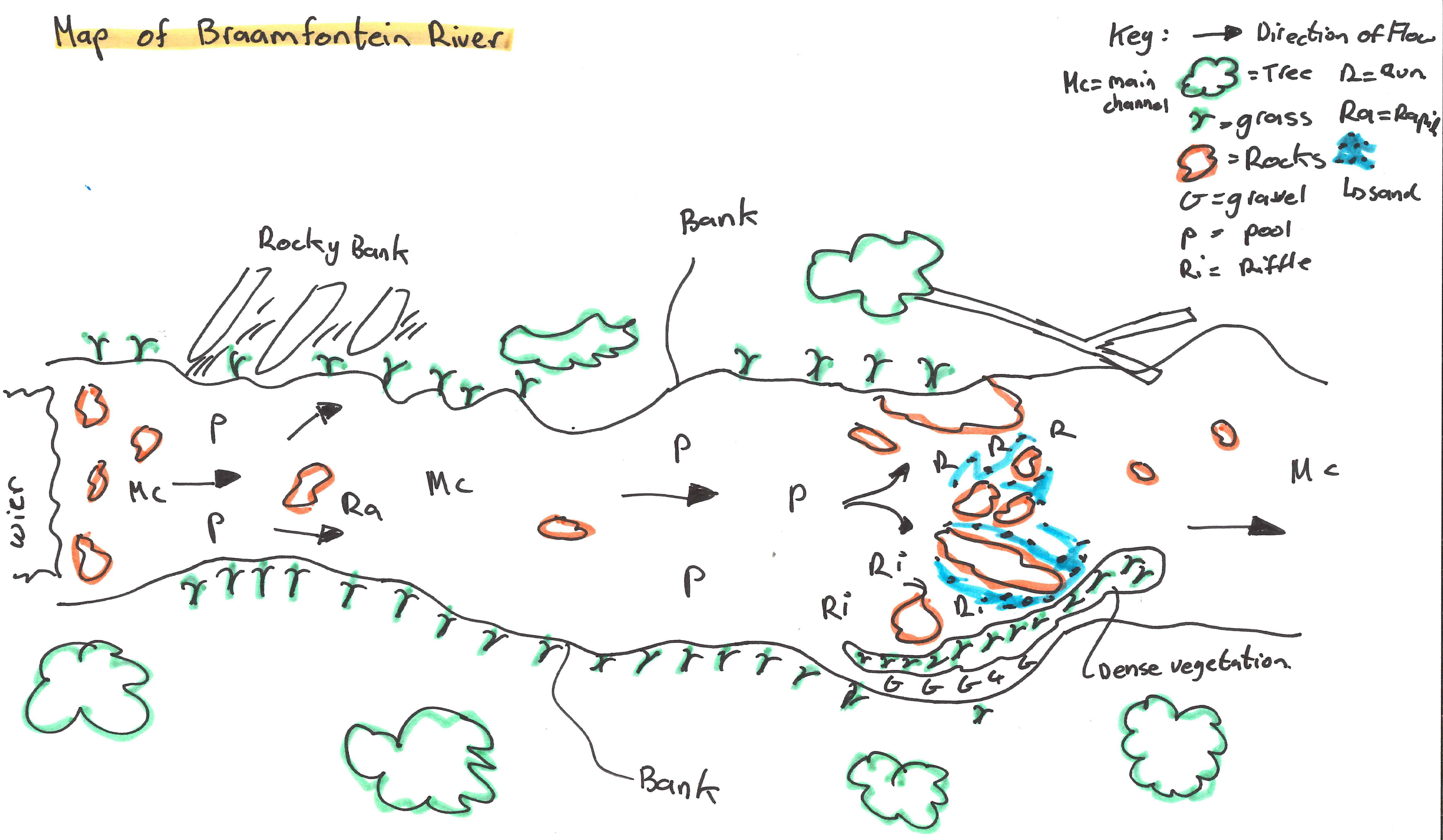

Run


Run

APPENDIX B

HAND DRAWN PICTURE OF THE RIVER REACH

Map of Braamfontein River



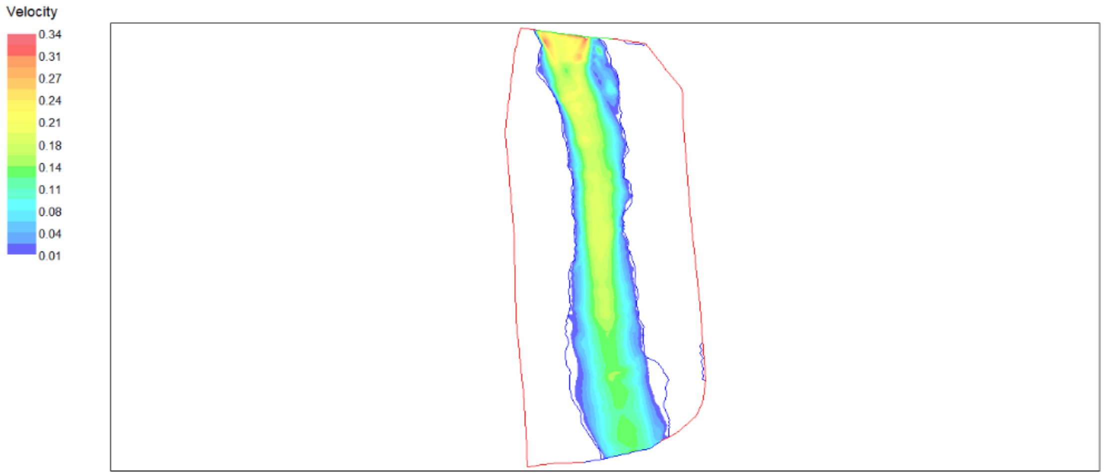
Not to scale.

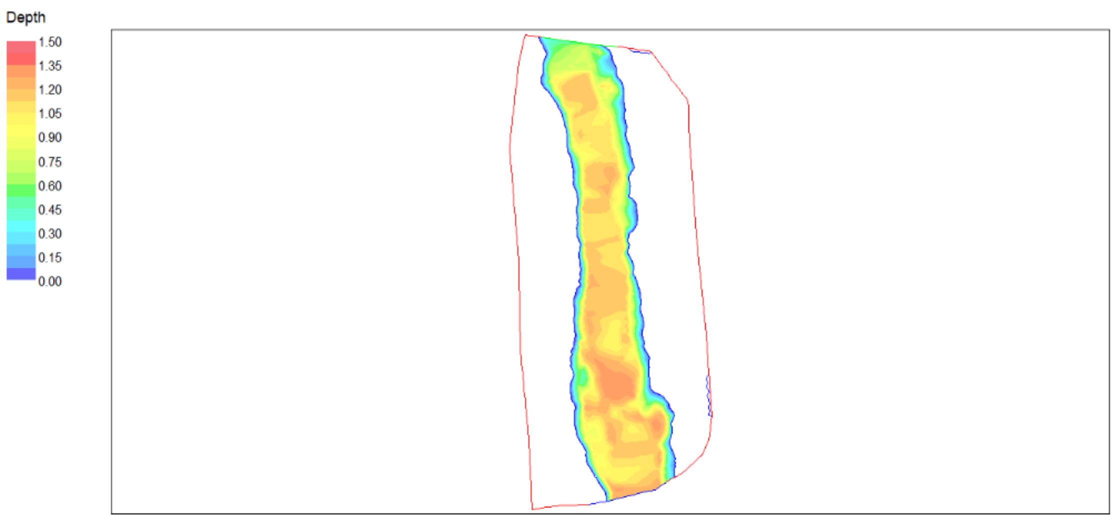
APPENDIX C

SIMULATION RESULTS

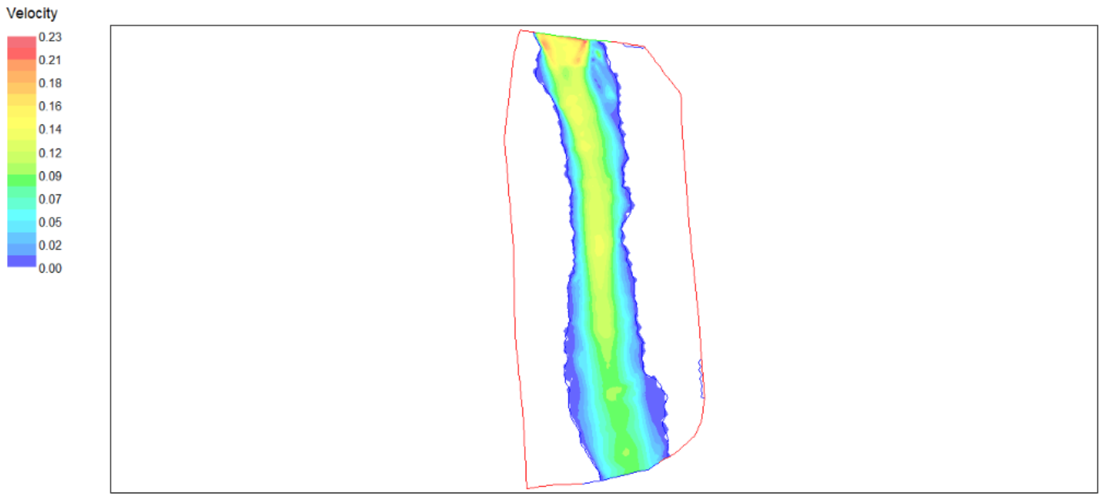
LIDAR Simulation Model Results

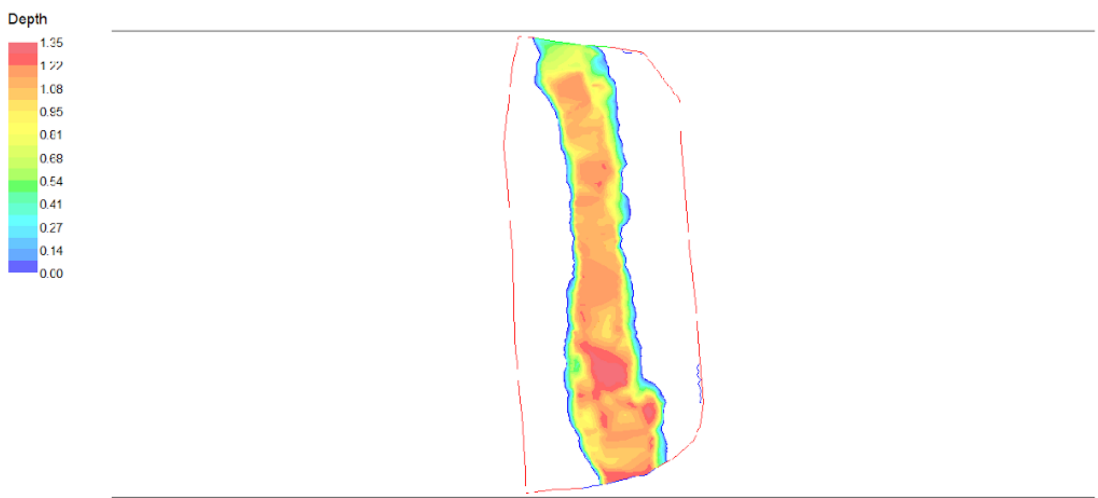
Discharge=1.5m^3/s



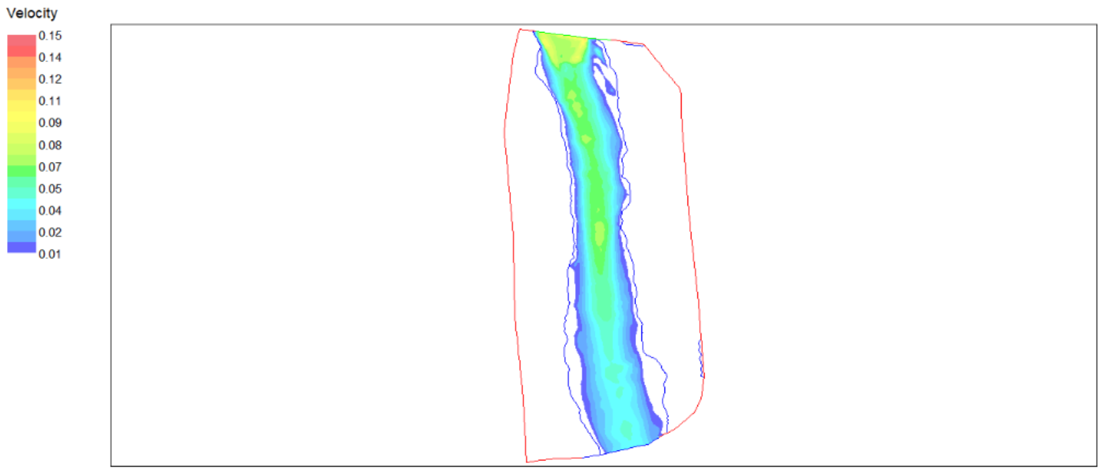


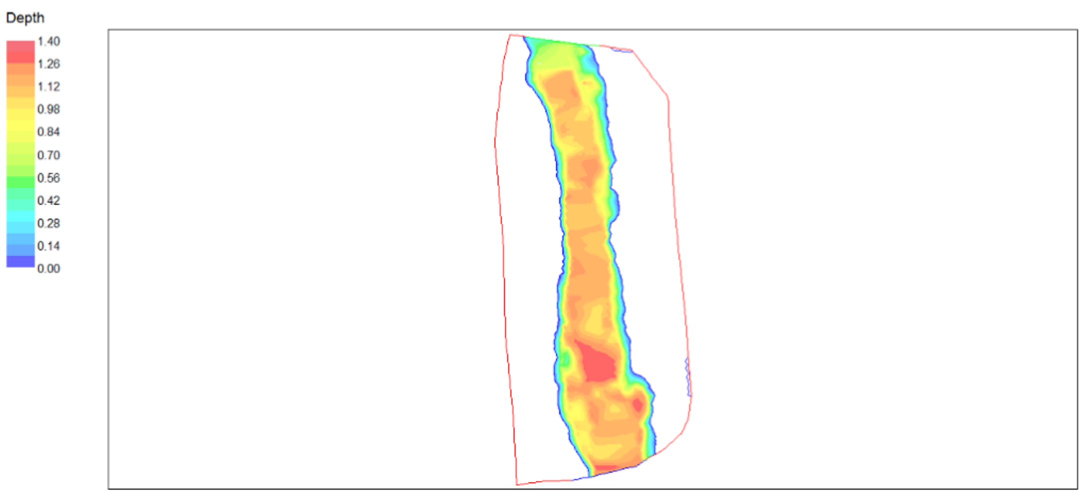
Discharge=1m^3/s





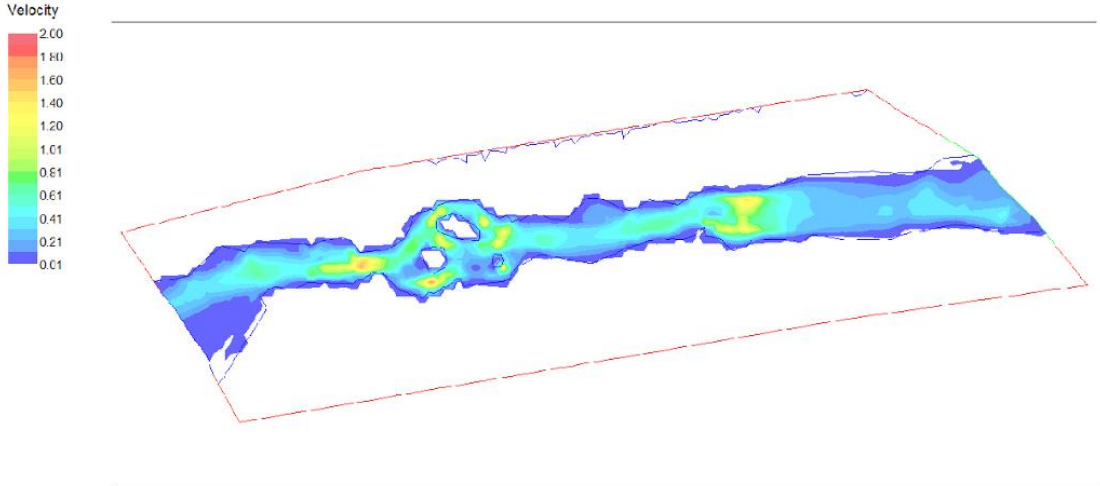
Discharge=0.5 m^3/s

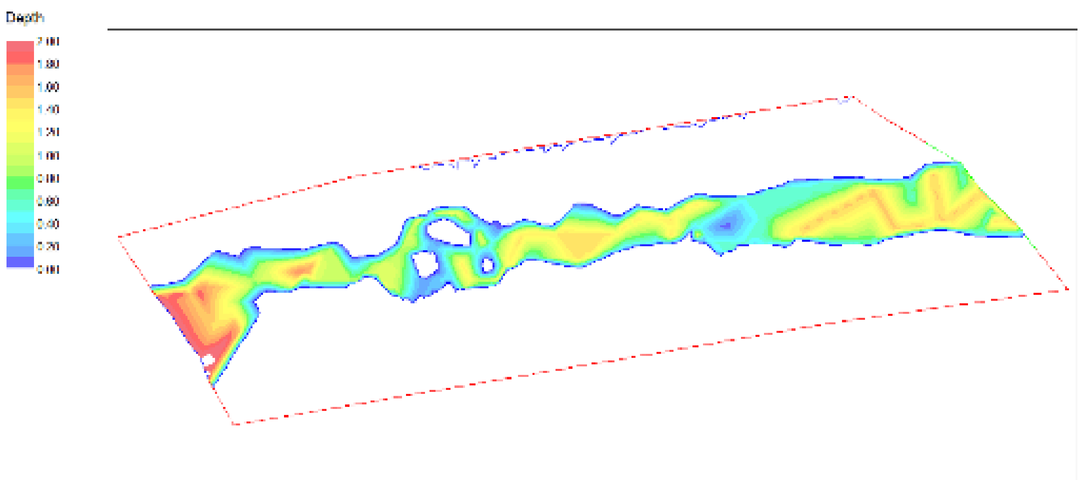




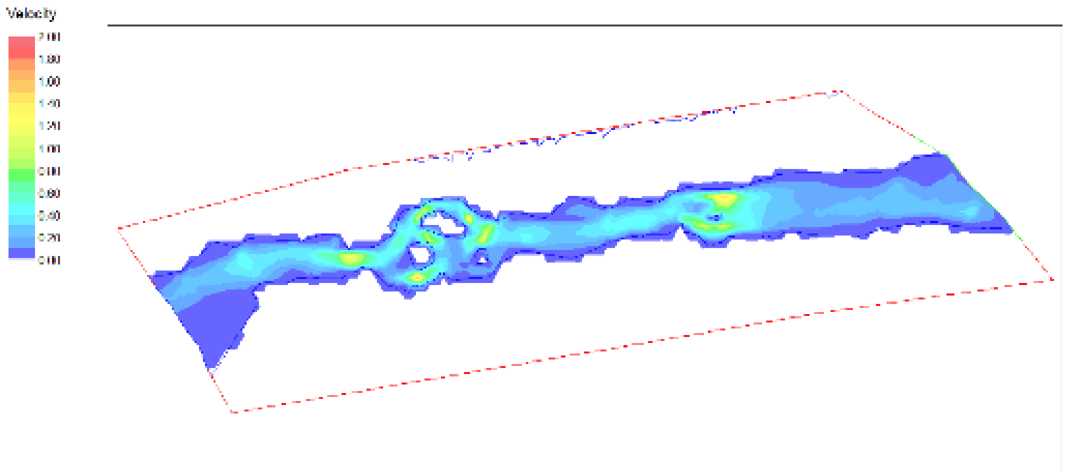
Handheld GPS Simulation Model Results

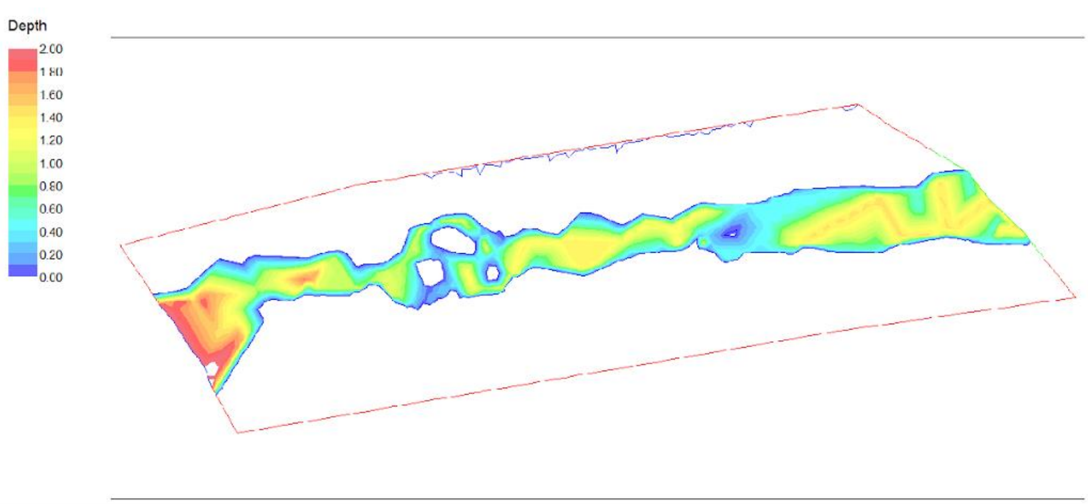
Discharge=1.5m^3/s



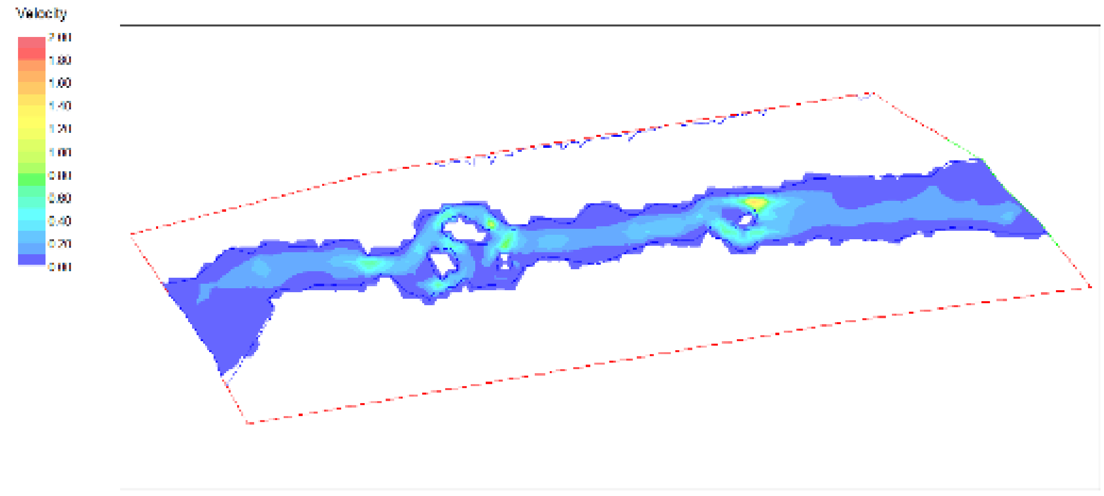


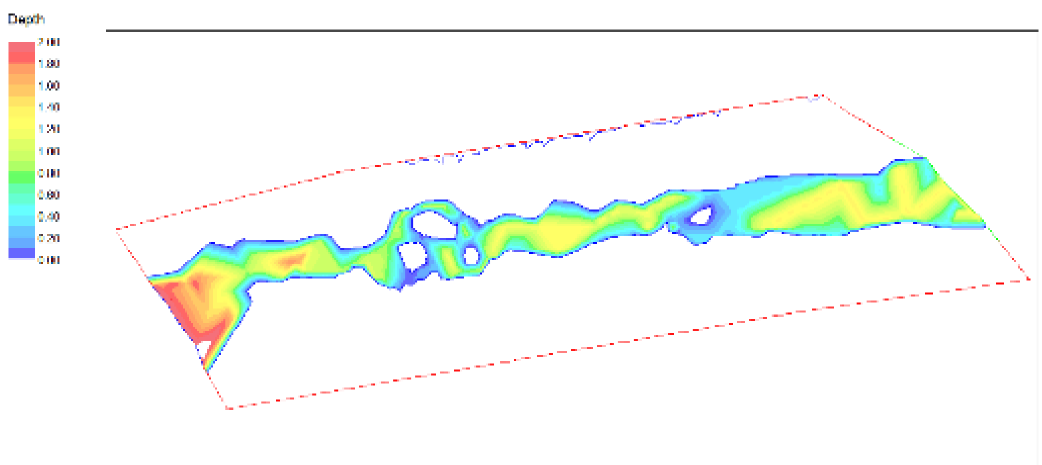
Discharge=1m^3/s





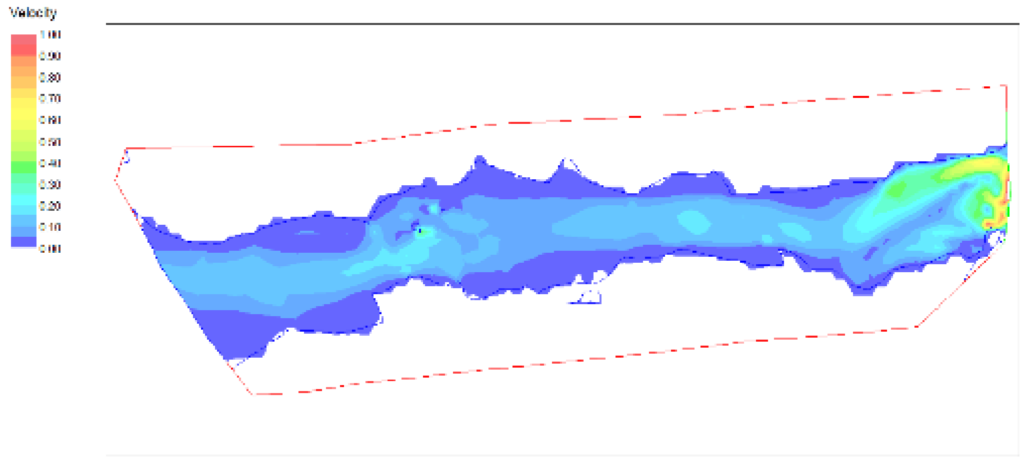
Discharge=0.5 m3/s

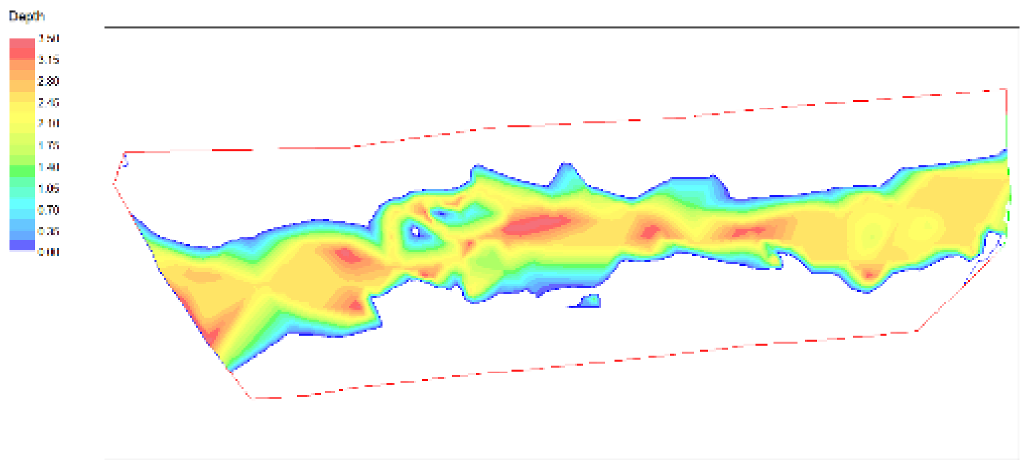




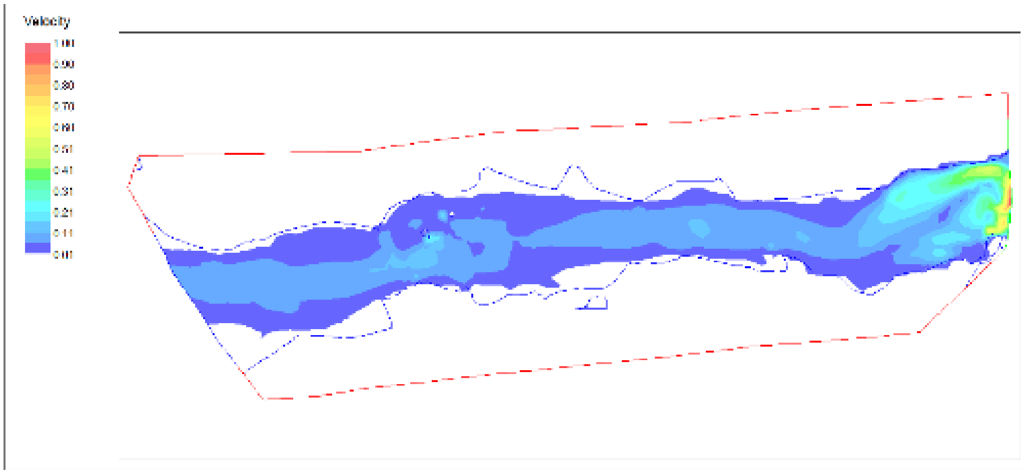
Smartphone Simulation Model Results

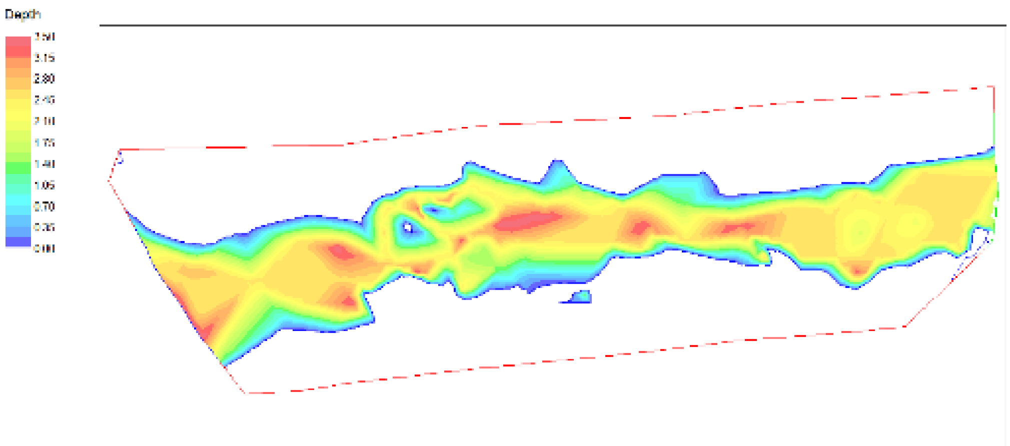
Discharge=1.5m^3/s



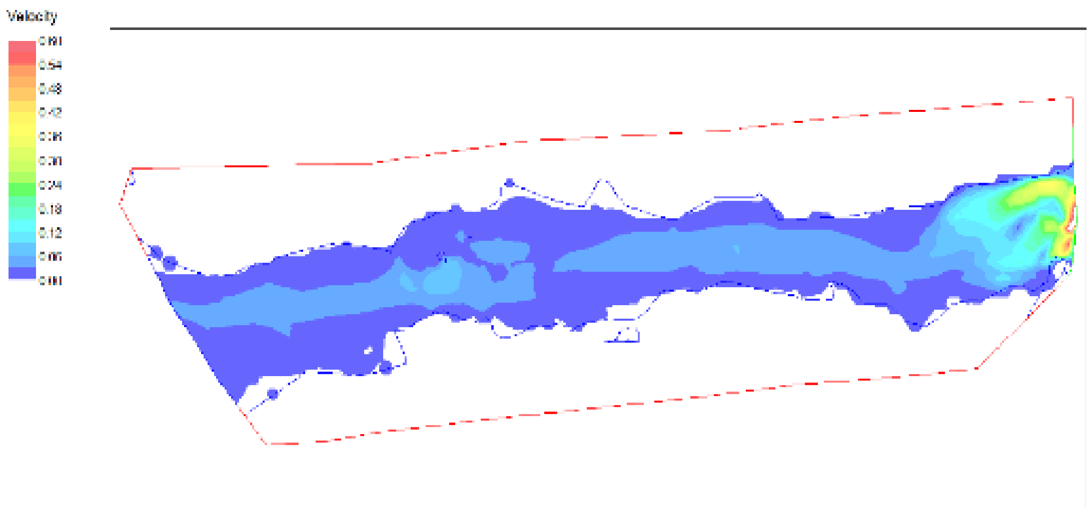


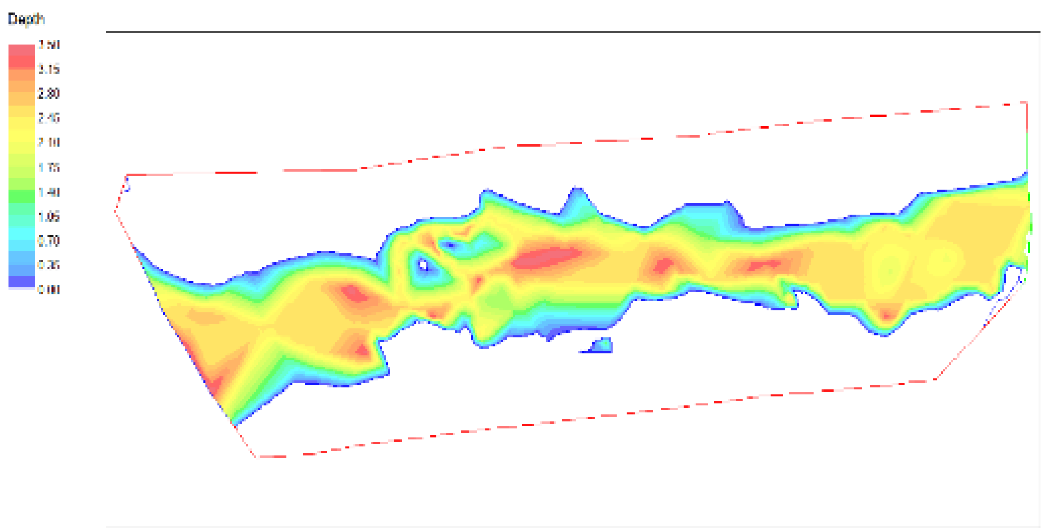
Discharge=1 m^3/s





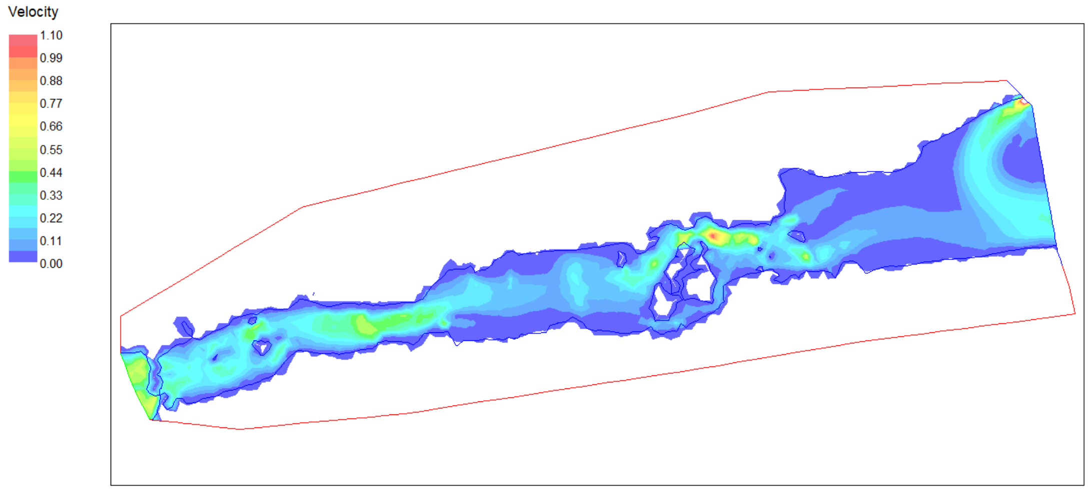
Discharge=0.5 m^3/s

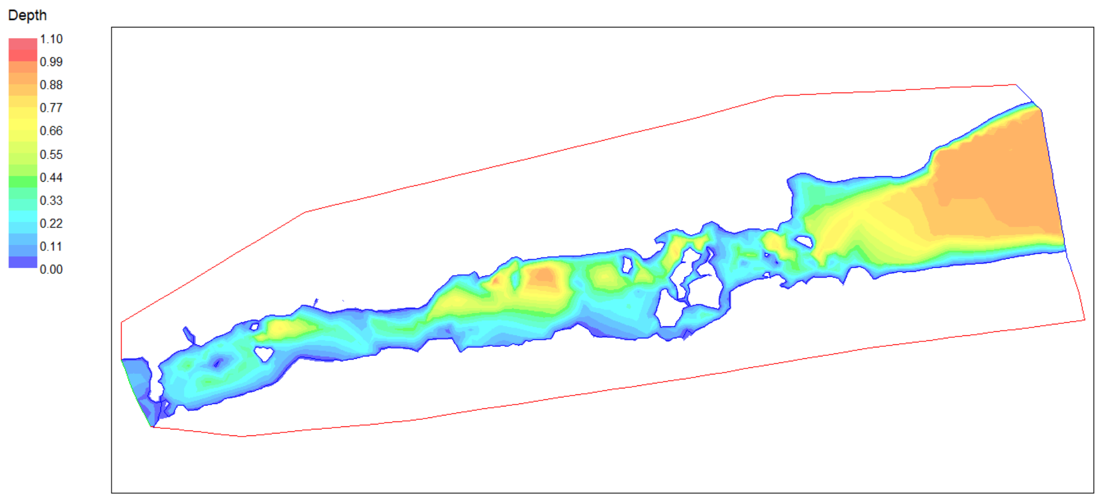




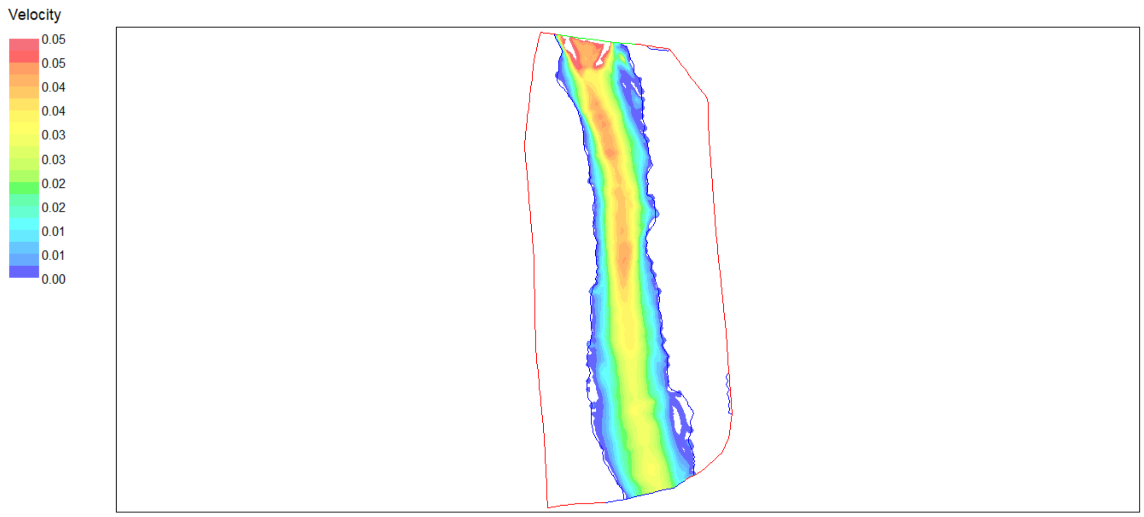
Field Measurement Simulation Model Results

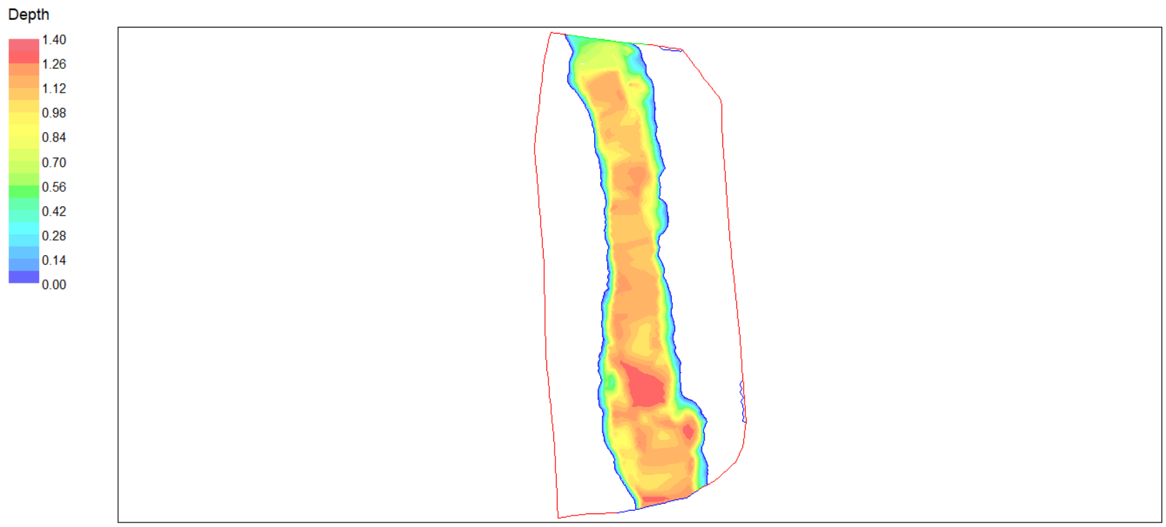
Field measurement - Total Station



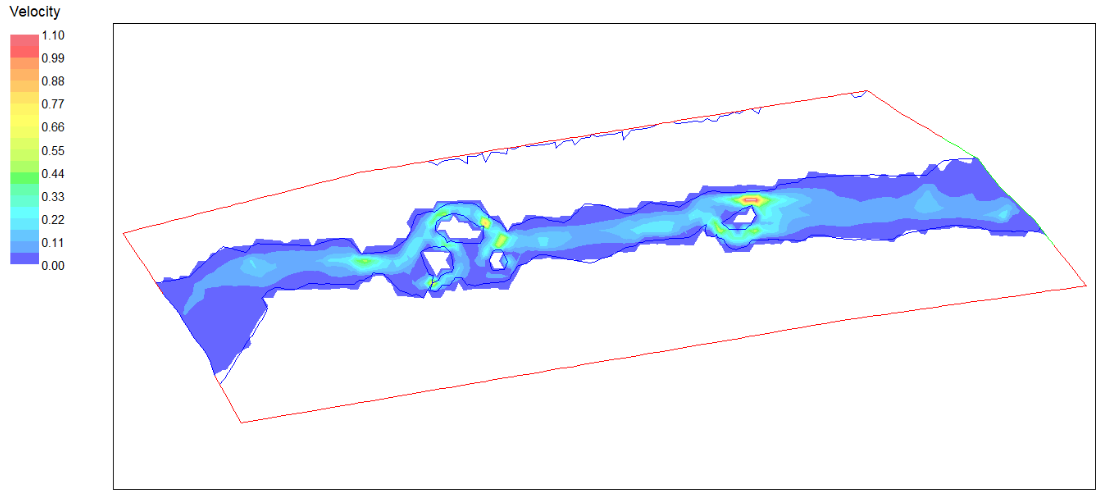


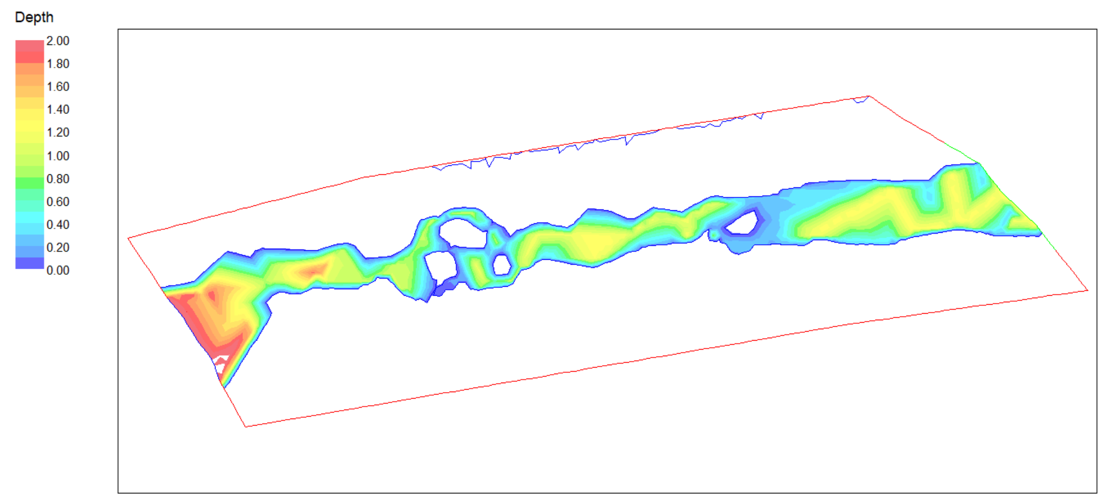
Field measurement - LIDAR



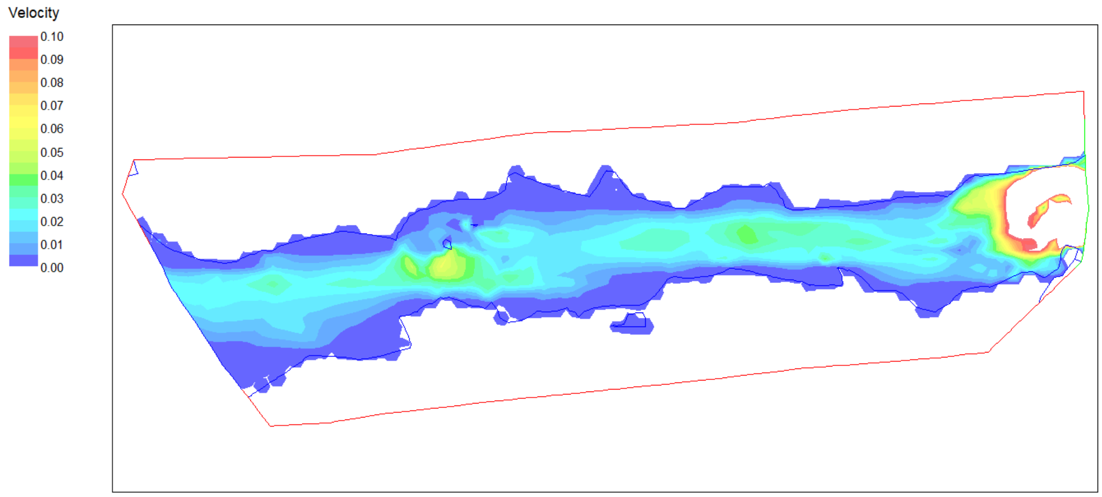


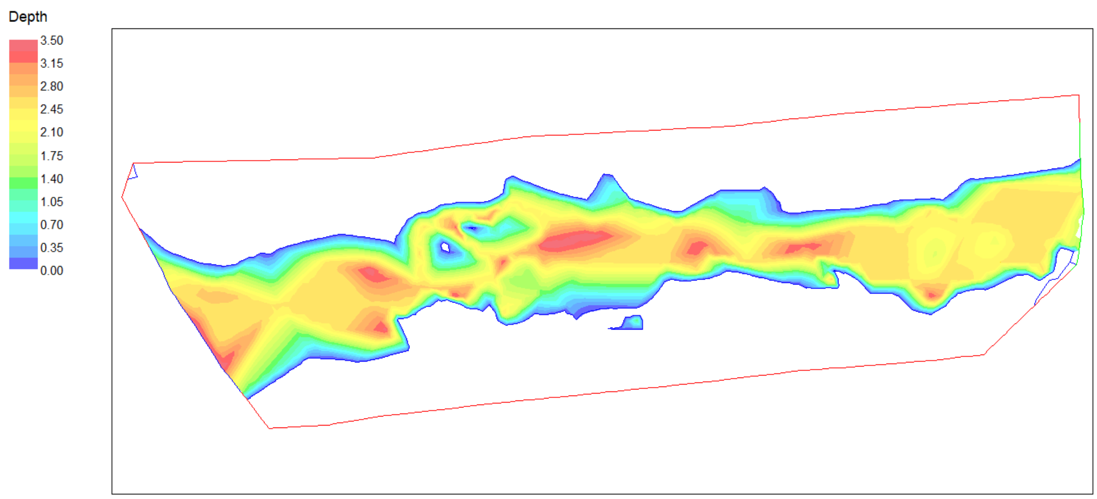
Field measurement – Handheld GPS





Field measurement - Smartphone





APPENDIX D

FIELD MEASUREMENT RESULTS

Left Run					
	Point 1	Point 2	Point 3	Point 4	Average
depth (m)	0.72	0.77	0.78	0.72	0.69
velocity (m/s)	0.16	0.14	0.16	0.16	0.16
Discharge (m3/s)					0.3
Right Rapid					
	Point 1	Point 2	Point 3	Point 4	Average
depth (m)	0.13	0.11	0.12	N/A	0.12
velocity (m/s)	0.18	0.18	0.19		0.14
Discharge (m3/s)					0.03
Left Rapid					
	Point 1	Point 2	Point 3	Point 4	Average
depth (m)	0.24	0.18	0.17	N/A	0.20
velocity (m/s)	1.43	0.55	0.56		0.85
Discharge (m3/s)					0.30
Upstream of Run					
	Point 1	Point 2	Point 3	Point 4	Average
depth (m)	0.50	0.40	0.50	N/A	0.47
velocity (m/s)	0.51	0.49	0.48		0.49
Discharge (m3/s)					0.41
					Average
Total Discharge (m3/s)					0.26
Round-up Discharge (m3/s)					0.3

APPENDIX E

Percentage Differences between the each Biotope

Discharge =1.5 m³/s																
	True Positive				**True Negative**				**False Positive**				**False Negative**			
	Total Station	**LIDAR**	**Smart Phone**	**Handheld GPS**	**Total Station**	**LIDAR**	**Smart Phone**	**Handheld GPS**	**Total Station**	**LIDAR**	**Smart Phone**	**Handheld GPS**	**Total Station**	**LIDAR**	**Smart Phone**	**Handheld GPS**
Pools (%)	81	100	100	100	51	77	87	71	0	48	62	37	19	0	0	0
Run (%)	100	81	51	52	9	9	8	8	21	0	0	0	0	19	49	48
Riffle (%)	87	22	17	36	15	14	14	14	0	0	0	0	13	78	83	64
Rapid (%)	100	52	32	100	5	4	4	4	80	0	0	40	0	48	68	0

Discharge 1 m³/s																
	True Positive				True Negative				False Positive				False Negative			
	Total Station	**LIDAR**	**Smart Phone**	**Handheld GPS**	**Total Station**	**LIDAR**	**Smart Phone**	**Handheld GPS**	**Total Station**	**LIDAR**	**Smart Phone**	**Handheld GPS**	**Total Station**	**LIDAR**	**Smart Phone**	**Handheld GPS**
Pools (%)	85	100	100	100	52	83	94	71	0	57	71	36	15	0	0	0
Run (%)	100	52	23	72	9	8	8	9	29	0	0	0	0	48	77	28
Riffle (%)	93	19	15	40	16	14	14	14	0	0	0	0	7	81	85	60
Rapid (%)	100	52	29	93	4	4	4	4	65	0	0	0	0	48	71	7

Discharge =0.5 m³/s																
	True Positive				True Negative				False Positive				False Negative			
	Total Station	LIDAR	Smart Phone	Handheld GPS	Total Station	LIDAR	Smart Phone	Handheld GPS	Total Station	LIDAR	Smart Phone	Handheld GPS	Total Station	LIDAR	Smart Phone	Handheld GPS
Pools (%)	98	100	100	100	56	90	97	72	0	66	74	38	2	0	0	0
Run (%)	100	22	16	78	9	8	8	9	6	0	0	0	0	78	84	22
Riffle (%)	98	19	14	38	16	14	14	14	0	0	0	0	2	81	86	62
Rapid (%)	100	51	27	73	4	4	4	4	8	0	0	0	0	49	73	27

Discharge =0.5 m³/s (Field)																
	True Positive				True Negative				False Positive				False Negative			
	Total Station	LIDAR	Smart Phone	Handheld GPS	Total Station	LIDAR	Smart Phone	Handheld GPS	Total Station	LIDAR	Smart Phone	Handheld GPS	Total Station	LIDAR	Smart Phone	Handheld GPS
Pools (%)	97	100	100	100	55	90	73	98	0	66	40	75	3	0	0	0
Run (%)	97	21	64	13	9	8	9	8	0	0	0	0	3	79	36	87
Riffle (%)	100	19	41	14	16	14	14	14	13	0	0	0	0	81	59	86
Rapid (%)	89	52	79	26	4	4	4	4	0	0	0	0	11	48	21	74