Chapter 1

INTRODUCTION

1.1 General

Much of the environment consists of fluids. Many flows of interest in environmental fluid mechanics, e.g. flows in channels, rivers, lakes, estuaries and seas, are turbulent flows. Oceans and atmosphere consist of fluids in large scale motion. Many problems in fluvial geomorphology involve complex, multivariate situations, often at large spatial and temporal scales. These topics have traditionally been addressed through detailed fieldwork combined with experimental and theoretical modelling. Whilst mathematical models have promoted major advances in our understanding of the complex interrelationships involved in sediment production, transfer and deposition in dynamic fluvial environments (cf. Pickup 1988; Ikeda and Parker 1989; Kirkby 1994). They necessarily involve simplifications and use of empirical coefficients derived from limited input data. For example, Fig. 1.1 and 1.2 shows respectively the typical river flow and “Current Crescents” around pebble barriers in a recent stream bed at Subarnarekha River, Jharkhand, India. Rivers are the arteries of our planet: they shape our landscapes, irrigate our lands, supply drinking water and food and constitute important connecting links. But rivers also frequently cause devastation: they erode fertile land and endanger property, inundate vast areas of land and spread disease. Mankind has always tempted to tame its rivers by exploiting its resources and seeking protection against its threats.

The hydrologic cycle describes processes that contribute to the source and the yield of water and sediment from upland areas to the fluvial system. The process consists of condensation,
Chapter 1: INTRODUCTION

precipitation, interception, evaporation, transpiration, infiltration, subsurface flow, exfiltration, deep percolation, groundwater flow, surface flow, surface-detention storage, channel precipitation, and stream flow. All of these processes play a role in hydrology; however, precipitation, infiltration, overland flow, and stream flow are most important in surface runoff, upland erosion, and river mechanics. River basins or watersheds define areas of the Earth's surface where rainwater drains into a particular stream. The terms basin and catchment are synonymously used in the literature. Watershed characteristics can often be described in geographical terms, including physiography and topography, geology and pedology, and climatology and forestry. Watershed boundaries are delineated by drainage divides, usually located at high points, that separate different drainage areas.

It has long been understood that water flows downhill. This may be the only statement to be remembered until a river dries out and crops wilt. Droughts unfortunately threaten humanity with the constraint that, without water, life cannot be sustained. On the other hand, the devastating consequences of excess water through floods stem from the fact that humanity, crops, and cattle are not well adapted to submerged life. Although nomadic tribes coped with the continuously changing pulses of fluvial systems, sedentary conditions forced humanity to protect against floods and droughts. In arid lands, perennial streams with regulated flow and a year-round supply of water are so much more valuable to humanity and wildlife than are natural sequences of short floods that succeed long droughts in dry ephemeral streams. River engineers are facing the daunting challenge of optimizing the urban and environmental resources pertaining to rivers while minimizing the damages caused by floods and droughts.

In the early periods of civilization, humanity's cultural development was dominated by fear of thunder, lightning, rain, floods, storms, cyclones, and earthquakes. The lack of understanding of cause-and-effect relationships to explain natural phenomena such as floods has characterized earlier civilizations. Nonetheless, humanity was compelled to develop hydraulic engineering and domestic rivers in order to prevent famine and to survive. Today, several hydraulic structures from past civilizations serve as landmarks of excellence. Flood-control levees were constructed to protect fertile lands from destructive inundations. Basic principles underlying
natural processes were deduced by rational approaches, including reflection and speculation.

Today, in the discussions there is a simple question;- Why do rivers form? It is interesting to note the required physical processes that lead to river formation. The concept of a gravitational-force component should first come to mind. The need for erodible material or alluvium emanates from the discussion. The concept of an alluvial river usually is gradually becoming clear. However, all of these do not explain why rivers form. Do we understand the mechanics of formation of alluvial rivers? The effects of flow convergence and divergence allude to the concepts of continuity of water. Aggradation and degradation result from conservation of sediment mass. Does the converging flow tend to cause aggradation or degradation? In a simplified form, rivers form because sediment concentration increases with unit discharge. Flow convergence thus causes scour, and this clearly illustrates that river mechanics stems from an understanding of hydrodynamics and sediment transport. The proposed physical analysis of river mechanics is based on the concept of water and sediment transport down the rivers under the action of gravity from the upland areas to the oceans. The surface area of the land that drains into a particular river delineates the watershed, also termed the drainage basin or catchment.

River flow itself occurs on river beds that are typically turbulent, this means the flow incorporates the irregular eddying motion and thus the grains in the flow are subjected to a fluctuating impulsive force. Turbulence in a river occurs when rocks, holes, or sudden changes in the river channel obstruct the flow of the water. River dynamics involve complex, incompletely understood interactions among flow, sediment transport and channel form. The capacity to predict these interactions is essential for a variety of river management problems, including erosion/scouring and deposition, channel migration, width adjustment and habitat development. To address this need, statistical model increasingly are being used by river engineers, fluvial geomorphologists and river biologists to explore the complexity of river dynamics and predict fluvial behavior.

Erosive action of water in streams by excavating and transporting the bed materials along downstream caused by the swirling of water and the reverse current, when water flows past an
obstacle. River process is known as “fluvial” (e.g. fluvial erosion/scour and deposition patterns are related to running water, etc.). The importance of the inherent resistance of bed materials to the erosional process, or erodibility, is generally recognized in obstacle-shape and fluvial geomorphology, but the full implications of the dynamics of sand properties that affect erodibility are seldom considered. The rate of scour is a key problem for understanding of scour process.

Turbulent flow has always been a challenge for scientists, that is common in nature and has an important role in several geophysical processes related to a variety of phenomena such as river morphology, landscape modelling, atmospheric dynamics and ocean currents. As the turbulent flows are irregular, seemingly random (chaotic) and complex, till today no analytical solutions exist for turbulent flows. We believe that even after 150 years, turbulence studies are still in their infancy. We are still discovering how turbulence behaves, in many respects. We do have a crude, practical, working understanding of many turbulent phenomena but certainly not a comprehensive theory, and nothing that provide predictions of an accuracy demanded by designers. While coherent phenomena have long been familiar in the context of turbulent flow, intensive research on the dynamics of bursting process in the water and air flows over smooth and rough surfaces has been performed to investigate the nature of coherent structures.

In the light of the above, this thesis examines the nature of fluvial processes using applied mathematical tools to predict the natural phenomena.
Chapter 1: INTRODUCTION

Flow Direction

Figure 1.1: Subarnarekha River, Jharkhand, India.

Figure 1.2: A series of “Current Crescents” around pebble barriers in a recent stream bed at Subarnarekha River. Most of the pebbles are covered by leaves and other plant materials carried by the stream.
1.2 Motivation

For centuries the behavior of fluid flows has captured the attention of some of history’s most esteemed minds. Indeed, almost all of us have been captivated at times by the intriguing patterns observed in smoke rising from a fire or in the wakes of ships or boats, or even in water simply draining out of a basin. It is perhaps not surprising to learn, that those responsible for some of the earliest known scientific activities were similarly captivated by these phenomena.

Many flows of interest in environmental fluid mechanics, e.g. flows in channels, rivers, lakes, estuaries and seas, are turbulent. The most obvious common example of a fluid in motion is the river flow dynamics. In a perpetual dynamic process of river, mankind has always tempted to adapt the river network to its requirements: with every intervention, mankind not only enhanced its understanding of the river system, but inadvertently also discovered new unresolved problems and additional requirements, leading to an ever-extending list of concerned disciplines: physics, fluid dynamics, hydraulics, hydrology, erosion and sedimentation, geomorphology, geology, biology, chemistry, mathematics, statistical inference, etc. Recent nominations such as computational fluid dynamics, morpho-dynamics, eco-hydraulics, fluvial geomorphology, etc., readily indicate that these different disciplines, which cover a wide range of time and length scales, are strongly interrelated. Due to their complexity, a sound understanding of the relevant physical mechanisms and processes will always be essential in river projects, and this irrespective of the available computational capacity.

This dissertation can be considered in the discipline of fluid dynamics applied to river flow, i.e. it investigates the dynamics of mean-flow and the turbulence in the river environment. More specifically, this study is examined the dynamic of scouring process around obstacles in river and try to predict the trend of coherent phenomena over the scour holes, thereby always keeping in mind the interactions with other disciplines. For example, some details of the three-dimensional flow field are relevant for the geomorphologic development of the river, some turbulence characteristics are relevant for the ancient geological structure formations, some characteristics of the turbulence are relevant for the water quality and the spreading and mixing of pollutants, or some flow and turbulence characteristics are relevant in mathematical...
Chapter 1: INTRODUCTION

Simulation techniques. Moreover, there are mutual interactions with other related fields of fluid dynamics such as meteorology, aeronautics, turbo-machinery, etc.

Some of the present results have similarities with large-scale geophysical flows where bed forms are important, such as in atmospheric and oceanic flows around obstacles. Better prediction tools of sediment transport and river dynamics processes are needed to provide optimal river management decisions. Presently, well-controlled laboratory experiments are the main source of information on open-channel turbulence and are used in the interpretation of river phenomena. However, laboratory open-channel studies are typically carried out under idealized conditions of uniform flow and flat beds (with sand and without sand) with a fairly homogeneous bed roughness distribution rarely found in rivers. Thus, discrepancies are observed between concepts used in routine engineering applications and actual field measurements.

Few field studies have been made in fluvial hydraulics mainly due to the lack of adequate instrumentation. However, these measurements are essential to confirm hypothesis and models used regularly by engineers. Field observations of natural processes allow us to identify and characterize unknown or less known features, and consequently upgrade the existing knowledge. The research deals with turbulence mechanisms closely related to scouring, sediment transport and river morphology.

1.3 Objectives of the study

The main purpose of the present work is to study experimentally the scour formation due to obstacles like short cylinder in fluvial environments, to observed coherent phenomena over fluvial scours, and also to develop theoretical model for validation with the experimental data. More precisely, I would like to emphasis my study on the following points:

- Experimental set-up and data acquisition,
- Experimental observations,
- Empirical prediction of scour hole formations related to the obstacle sizes,
- Statistical analysis of velocity data over and within the scour holes,
Chapter 1: INTRODUCTION

- Analysis of turbulent bursting and coherent structures,
- Variation of Turbulent Kinetic Energy (TKE) fluxes and conditional shear stress within and across the equilibrium scour structures, and
- Theoretical modelling and validation with experimental data.

1.4 Scope

This investigation deals with an experimental study of flows over fluvial scours induced by obstacles like short cylinder carried out in a laboratory flume under controlled conditions. The mean flow and turbulence characteristics of the flow are analyzed in order to study the flow pattern due to different obstacle sizes and shapes. The conditional statistics and quadrant analysis are applied to visualize the turbulent bursting phenomena occurring in the given flow conditions considered in the present study. This aspect of the problem is studied experimentally in the Fluvial Mechanics Laboratory at ISI-Kolkata. The thesis includes the theoretical modelling of the velocities (stream-wise and vertical directions) and the stress fraction due to various turbulent events and its validations with the present experimental data.

1.5 Structure of the thesis

The scope of the thesis is presented in the following section. Chapter 2 presents a brief introduction of the background and literature review of related to the work. The information of fluid flow and fluid sediment interactions; and a brief explanation on the 3-D Micro acoustic Doppler velocimeter (ADV) have been discussed. In Chapter 3, detailed description of the experimental set-up, instrumentations used in the present study and the data acquisition methods are presented. Velocity data analysis, results and empirical predictions are presented in Chapter 4. Theoretical modelling and validation with experimental data in Chapter 5. In Chapter 6, the conclusions that can be extracted from the data analysis are summarized along with the recommendations for further research in the form of experiments or additional numerical techniques implementation.