UTILIZATION OF RIVER CURRENT FOR SMALL SCALE ELECTRICITY GENERATION IN BANGLADESH

By

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To
My Parents & Sisters

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CONTENTS

ABSTRACT

The power crisis in Bangladesh and elsewhere in the Third World highlights the need for new technologies, which local communities can use to improve their lifestyle. Many arid areas are characterized by having large rivers or canals flowing through them. Under this project a study has been performed to assess the potential of electrical energy from river currents at different locations of Bangladesh. In this context 23 sites of different rivers have been considered as test cases.

After getting an idea about the river current velocity at different rivers in Bangladesh, this thesis describes the development of a new, simple, and relatively inexpensive technology, which if used in right circumstances, can generate power from the rivers. The water current turbine- just can be thought of as a wind turbine inserted into the river current- a model of which has been tried and tested for power generation. The technical details especially the aerodynamic design of the turbine rotor has been introduced in the thesis. The turbine model consisting of three NACA 4412 blades with average rotor radius of 221mm has been tested for harnessing the kinetic energy from water. It should be mentioned here that no twist angle has been introduced in the blade.

A chapter of this thesis devoted to analyze the performance of the model illustrates the working range of a water turbine in terms of tip speed ratio under certain river current velocity and the effect of pitch angle in power generation. It has been found that the turbine will run at tip speed ratios between 3.2 to 6 when the pitch angle is 5^0 and the river current velocity of 0.65 m/s. But this operating region squeezes if the pitch angle is reduced to 0^0. Also the peak value of the power coefficient (C_P) is 40% when the pitch angle is 5^0, but when there is no pitch angle power coefficient reduces by 10%. If the turbine is operated at a very low river current velocity in that case there is a remarkable shifting of the operating range. At a river current velocity of 0.25 m/s, the turbine will run at tip speed ratios between 0.7 to 2.

Hence, the conclusion is drawn that selection of the turbine rotor should be such that the rotor can rotate at a high speed as possible because the faster the loaded rotor turns the cheaper will be the transmission.

LIST OF SYMBOLS

a	axial interference factor
a'	tangential interference factor
A	turbine disk area, πR^2
A_1	cross sectional far ahead of the rotor
A_2	wake cross sectional area
B	number of blades
C	chord of the blade
C_d	blade drag coefficient, dD/ (0.5 ρ C W^2 dr)
C_l	blade lift coefficient, dL/ (0.5 ρ C W^2 dr)
C_P	power coefficient, P/ (0.5 ρ A V_α^3)
$(C_P)_{max}$	maximum power coefficient
dA	blade elemental area, C dr
dC_P	elemental power coefficient, dP/ (0.5 ρ A V_α^3)
dC_Q	elemental torque coefficient, dQ/ (0.5 ρ A V_α^2 R)
dC_T	elemental thrust coefficient, dQ/ (0.5 ρ A V_α^2)
dD	blade elemental drag force
dL	blade elemental lift force
dm	differential mass
dP	blade elemental power
dQ	blade elemental torque
dT	blade elemental thrust
F	Prandtl's loss factor
F_{tip}	tip loss factor
F_{hub}	hub loss factor
m	mass of water flowing through the rotor in unit time
N	rpm of the rotor
P	turbine power
P^+	pressure immediately in front of the rotor
P^-	pressure immediately behind the rotor

r	local blade radius
r_{hub}	hub radius
R	rotor radius
T	thrust force
U	water velocity through the turbine
V	water velocity far behind the rotor
V_{α}	undisturbed water velocity
W	relative water velocity

GREEK ALPHABETS

α	angle of attack
β_T	blade twist angle
η_{eff}	efficiency of the rotor
λ	tip speed ratio
λ_d	design tip speed ratio
λ_r	local tip speed ratio
ρ	density of water
σ	solidity, $BC/2\pi r$
ϕ	angle of relative water velocity
ω	wake rotational velocity
Ω	angular velocity of rotor

Chapter 1: INTRODUCTION

Bangladesh is a sub-tropical country located between $20^{\circ}34'$ and $26^{\circ}38'$N latitude and $88^{\circ}01'$ and $92^{\circ}41'$E longitude. It has an area of 148,393 Sq. km with a population of about 130 million. The percapita GDP of the country is US$240 whereas the per capita consumption of commercial energy is 67 KGOE (Kilogram of Oil Equivalent) and generation of electricity is 90 kWh, which is one of the lowest among the developing countries [1]. In total, only 10% of households have electricity connections [2]; whereas the rest of the population depend on some sort of renewable sources of energy for cooking, lighting etc. During the last few years some government and non-government organizations have attempted to introduce renewable energy technologies such as solar home systems, biogas etc. to the rural areas [3]. Some studies have also been reported for mini-hydro potential in the country [4,5] that has not been implemented yet.

Bangladesh is a riverine country. Energy extraction from river currents has not yet been studied extensively. A study has recently been undertaken to assess the potential of energy from river currents and this research illustrates a preliminary survey and suggests a suitable water turbine for small-scale electricity generation.

To meet high economic growth, the demand of electricity in developing economics has been growing at a remarkably high rate. But Bangladesh is at a very low level of electrification with 4.35 million consumers having the privilege of electricity use [6]. In Bangladesh, at present about 60% of total primary energy is supplied by renewable energy sources (e.g. biomass fuels, hydropower) [7]. Hydro is the original and the most exploited renewable source of electrical energy.

The world primary energy demand in 1992 was some 167 million barrels of oil equivalent per day of which 86% was provided by fossil fuels. The second largest source was hydro at about 6%, followed by nuclear at about 5% [8].

Many large rivers and canals in Bangladesh flow for hundreds of kilometers through terrain where the installation of conventional hydro plants is impossible because of lack of potential head. In these areas there is often a need for power for irrigation pumping or domestic use. But the demand is not concentrated enough to warrant connection to any centralized energy supply such as, a grid. In this situation the moving water in the canal or river can be used as an energy resource. Like most other renewable energies, this resource is diffuse but it is predictable, reliable and available 24 hours a day. A water current speed of 1 m/s represents a kinetic energy density of 500 W/m^2 of river cross-section. Speeds of this order are commonly found in rivers or canals throughout the world [9]. Water current turbines (WCT) make use of the kinetic energy in the flowing water to provide a power source for water pumping or electricity generation [10]. In Bangladesh, the majority of the rural population lives along the river or canal banks. Thus the power users live next to the resource.

The aim of this research is to design a turbine so that it can generate a reasonable amount of power at about 0.5m/s to 1.5m/s water flow. The focus here on electricity generation is primarily because it offers the greatest potential as an economic activity through which water current turbines can stimulate rural development. Other activities for which WCTs may have a role include:

i) Irrigation and raising water for live stock
ii) Providing water for village industries

Another possibility is pumping water for human consumption, but in view of the health problems associated with this use of river water, the viability of WCTs for village water supply applications is not considered.

Chapter 2 : LITERATURE REVIEW AND EXISTING THEORIES

2.1 LITERATURE REVIEW

The water current turbine extracts energy from the driving water and converts it into a mechanical power in contrast to a propeller, which adds energy into the air/water from another energy source. Because of the similarity of the water turbine and the propeller, it is possible to use the same theoretical development for the performance analysis. The propeller theory was based on two different independent approaches. One is the momentum theory approach and the other is the blade element theory approach.

The first description of the axial momentum theory was given by Rankine [11] in 1865 and was improved later by Froude [12]. The basis of the theory is the determination of the forces acting on the rotor, which produce the motion of the fluid. It also predicts the ideal efficiency of the rotor. Later on Betz [13] included the rotational wake effects in the theory.

Modern propeller theory has developed from the concept of free vortices being shed form the rotating blades. These vortices define a slipstream and generate induced velocities. The theory can be attributed to the work of Lanchester [14] and Flamm [15] for the original concept. Later, Joukowski [16] introduced the induced velocity analysis. Prandtl [17] and Goldstein [18] developed separately the circulation distribution or tip loss analysis. Recently, Wilson, Lissaman and

Walker [19] have further analyzed the aerodynamic performance of wind turbines (Basically the water current turbine can be thought of as an under water wind turbine which floats on the surface of a river with the rotor completely submerged). They have introduced a new method to apply tip loss, which is sometimes referred as the linear method. This method is based on the assumption that the axial and tangential induced velocities are localized at the blade and only a fraction of these occur in the plane of the rotor.

Modified blade element theory or strip theory is the most frequently used theory for performance analysis of horizontal axis wind turbine. The technique, which assumes local two dimensional flow at each radial rotor station, is a design analysis approach in which the airfoil sectional aerodynamics, chord and pitch angles are required in order to determine forces and the torque.

Walker [20] has developed a method to determine the blade shapes for maximum power. According to his method, the blade chord and twist are continuously varied at each radial station until the elemental power coefficient has been maximized. This is obtained when every radial element of the blade is operating at the airfoil's maximum lift to drag ration. This results in the lift coefficient and angle of attack being identical at each radial element. Anderson [21] has compared near-optimum and optimum blade shapes for turbines operating at both constant tip speed ratio and constant rotational speed. Shepherd [22] has suggested a simplified method for design and performance analysis, which can be carried out on a hand-held calculator by elimination of iteration processes. It is based on the use of the ideal and optimized analysis to determine the blade geometry.

Milborrow [23] worked out in the field of rotor performance, blade loadings, stresses and size limits of horizontal axis wind turbines. In order to identify the variables, which influence performance and blade loadings, simplified methods of analysis have been developed and used to illustrate the process of rotor design.

Garman [24] developed two water current turbine systems namely "Mark 1" machine swept area of which is up to 5 square meters depending on river speed. It can pump water through a lift of 5 meters at a maximum rate of some 24 cubic meters per hour. The another is the smaller "Low Cost" version swept area of which is up to 3.75 square meters. It can pump water through a lift of 5 mters ata a maximum rate of about 6 cubic meters per hour.

2.2 EXISTING THEORIES

2.2.1 Introduction

The performance calculation of water turbines is mostly based upon a steady flow, in which the influence of the turbulence of the atmospheric boundary layer is neglected. Most existing theoretical models are based on the combination of momentum theory and blade element theory. This combined theory is known as modified blade element theory or strip theory. It has been assumed that the strip theory approach is adequate for the performance analysis of water turbines. The basic theoretical development of strip theory has been incorporated in this chapter. Effects of wake rotation, tip and hub losses for maximum power are presented as well.

2.2.2 Axial Momentum Theory

The following assumptions are made in establishing the momentum theory.

a) incompressible and inviscid fluid
b) infinite number of blades
c) thrust loading is uniform over the disc
d) static pressure far ahead and far behind the rotor are equal to the undisturbed ambient static pressure
e) uniform flow far ahead and far behind of the turbine

2.2.2.1 Based on Non-rotating Wake

The axial momentum theory has been presented by Rankine in 1865 and has been modified by Froude. The basis of the theory is the determination of the forces acting on a rotor to produce the motion of the fluid. The theory has been found useful in predicting ideal efficiency of a rotor and may be applied for water turbines.

Considering the control volume in Figure 2.2.1, where the boundary of the control volume is far ahead and far behind the rotor, the conservation of mass may be expressed as,

$$m = \rho A_1 V_\infty = \rho A U = \rho A_2 V \qquad (2.2.2.1)$$

where,

m = mass of water flowing through the rotor in unit time

V_∞ = undisturbed water velocity

U = water velocity through the rotor

V = water velocity far behind the rotor

A = turbine disc area

A_1 = cross-sectional area far ahead of the rotor

A_2 = cross-sectional area at the wake region far behind the rotor

The thrust T on the rotor is obtained by equating the rate of change of momentum of the flow,

$$T = m(V_\infty - V) = \rho A_1 V_\infty^2 - \rho A_2 V^2 \qquad (2.2.2.2)$$

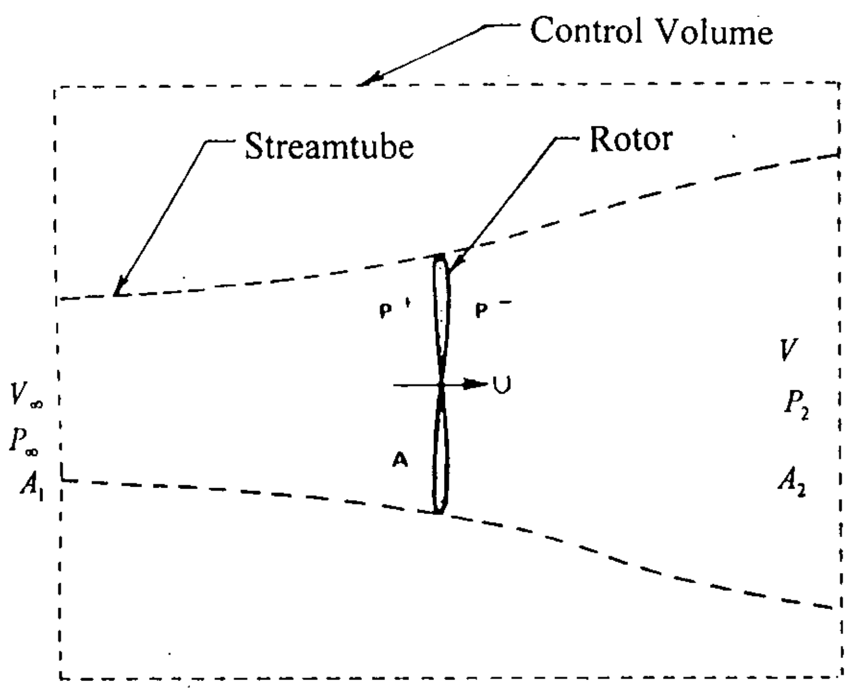


Figure 2.2.1 Control Volume of a Water Turbine

Introducing equation (2.2.2.1) leads to the expression

$$T = \rho A U(V_\infty - V) \qquad (2.2.2.3)$$

The thrust on the rotor can also be expressed from the pressure difference over the rotor area as,

$$T = A(P^+ - P^-) \qquad (2.2.2.4)$$

where,

P^+ = pressure immediately in front of the rotor

P^- = pressure immediately behind the rotor

Now applying Bernoulli's equation,

For upstream of the rotor: $P_\infty + \frac{1}{2}\rho V_\infty^2 = P^+ + \frac{1}{2}\rho U^2 \qquad (2.2.2.5)$

For downstream of the rotor: $P_\infty + \frac{1}{2}\rho V^2 = P^- + \frac{1}{2}\rho U^2 \qquad (2.2.2.6)$

Subtracting equation (2.2.2.6) from equation (2.2.2.5), one obtains

$$P^+ - P^- = \frac{1}{2}\rho(V_\infty^2 - V^2) \qquad (2.2.2.7)$$

Therefore, the expression for the thrust from equation (2.2.2.4) becomes,

$$T = \frac{1}{2}\rho A(V_\infty^2 - V^2) \qquad (2.2.2.8)$$

Balancing the equations (2.2.2.3) and (2.2.2.8),

$$\frac{1}{2}\rho A(V_\infty^2 - V^2) = \rho A U(V\infty - V)$$

or, $$U = \frac{V_\infty + V}{2} \qquad (2.2.2.9)$$

The velocity at the rotor U is often defined in terms of an axial interference factor 'a' as,

$$U = V_\infty(1 - a) \qquad (2.2.2.10)$$

Balancing equations (2.2.2.9) and (2.2.2.10), the wake velocity can be expressed as,

$$V = V_\infty(1 - 2a) \qquad (2.2.2.11)$$

The change in kinetic energy of the mass flowing through the rotor area in unit time is the power absorbed by the rotor,

$$P = \Delta KE / \sec = \frac{1}{2}m(V_\infty^2 - V^2) = \frac{1}{2}\rho A U(V_\infty^2 - V^2) \qquad (2.2.2.12)$$

With equations (2.2.2.10) and (2.2.2.11), the expressions for power becomes,

$$P = 2\rho A V_\infty^3 a(1-a)^2 \qquad (2.2.2.13)$$

Maximum power occurs when, $\dfrac{dP}{da} = 0$

Therefore, $\dfrac{dP}{da} = 2\rho A V_\infty^3 (1 - 4a + 3a^2) = 0$

which leads to an optimum interference factor,

$$a = \frac{1}{3}$$

Inserting this value in equation (2.2.2.13), maximum power becomes,

$$P_{max} = \frac{16}{27}\left(\frac{1}{2}\rho A V_\infty^3\right) \qquad (2.2.2.14)$$

The fraction 16/27 is related to the power of an undisturbed flow arriving at an area A, whereas, in reality the mass flow rate through A is not AV_∞ but AU. Hence, the maximum efficiency for maximum power can be written as,

$$\eta_{eff} = \frac{P_{max}}{\frac{1}{2}\rho A U V_\infty^2} = \frac{16}{27}\frac{V_\infty}{U} = \frac{16}{27}\frac{1}{(1-a)} = \frac{16}{27}\frac{1}{(1-\frac{1}{3})} = \frac{8}{9} \qquad (2.2.2.15)$$

This model does not take into account additional effects of wake rotation. As the initial stream is not rotational, interaction with a rotating water turbine will cause the wake to rotate in opposite direction. If there is rotational kinetic energy in the wake in addition to translational kinetic energy, then from the thermodynamic considerations one may expect lower power extraction than in the case of the wake having only translation. In the following section, the wake rotation will be taken into account.

2.2.2.2 Effect of Wake Rotation

Considering the effect of wake rotation, the assumption is made that at the upstream of the rotor, the flow is entirely axial and the downstream flow rotates with an angular velocity ω but remains irrotational. This angular velocity is considered to be small in comparison to the angular velocity Ω of the water turbine. This assumption maintains the approximation of axial momentum theory that the pressure in the wake is equal to the free stream pressure.

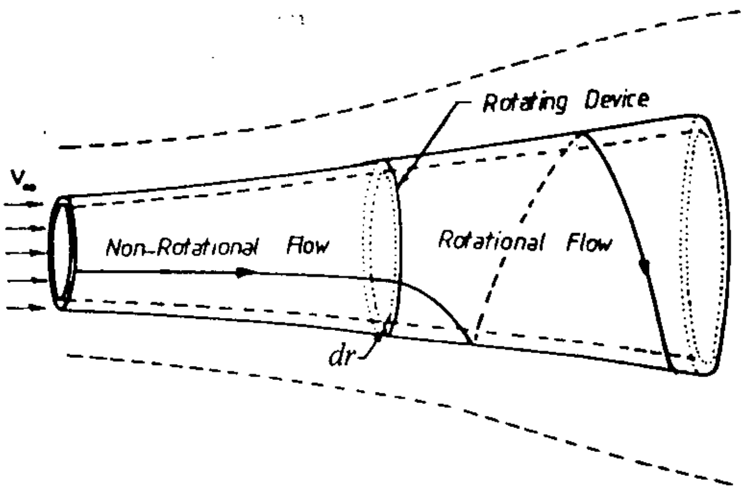


Figure 2.2.2 Streamtube Model Showing the Rotation of Wake

The wake rotation is opposite in direction of the rotor and represents an additional loss of kinetic energy for the water turbine rotor. Power is equal to the product of the torque Q acting on the rotor and the angular velocity Ω of the rotor. In order to obtain the maximum power it is necessary to have a high angular velocity and low torque because high torque will result in large wake rotational energy. The angular velocity ω of the wake and the angular velocity Ω of the rotor are related by an angular interference factor a',

$$a' = \frac{\text{angular velocity of the wake}}{\text{twice the angular velocity of the rotor}} = \frac{\omega}{2\Omega} \qquad (2.2.2.16)$$

The annular ring through which a blade element will pass is illustrated in Figure 2.2.3.

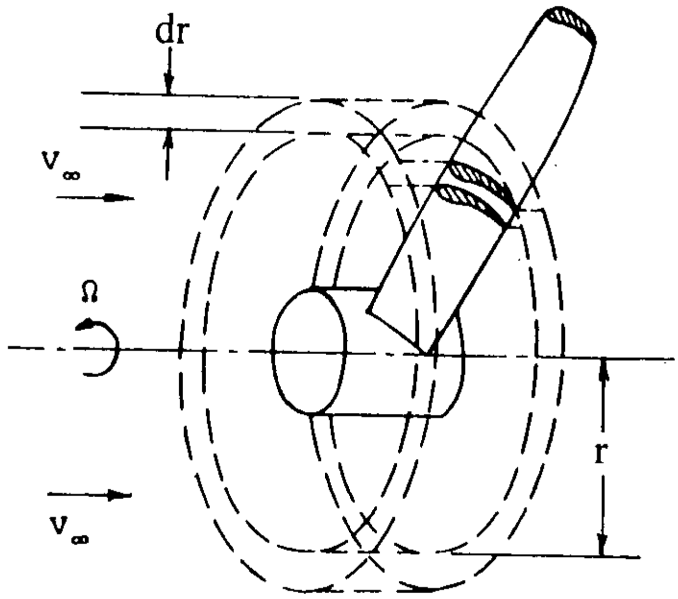


Figure 2.2.3 Blade Element Annular Ring

Using the relation for momentum flux through the ring the axial thrust force dT can be expressed as,

$$dT = dm\,(V_\infty - V) = \rho\, dA\; U\,(V_\infty - V) \qquad (2.2.2.17)$$

Inserting equations (2.2.2.10) and (2.2.2.11)

$$U = V_\infty(1 - a) \qquad (2.2.2.10)$$

$$V = V_\infty(1 - 2a) \qquad (2.2.2.11)$$

and expressing the area of the annular ring dA as,

$$dA = 2\pi r\, dr \qquad (2.2.2.18)$$

The expression for the thrust becomes,

$$dT = 4\pi r \rho V_\infty^2 a(1 - a)\, dr \qquad (2.2.2.19)$$

The thrust force may also be calculated from the pressure difference over the blades by applying Bernoulli's equation. Since the relative angular velocity changes from Ω to $(\Omega + \omega)$, while the axial components of the velocity remain unchanged, Bernoulli's equation gives,

$$P^+ - P^- = \frac{1}{2}\rho(\Omega + \omega)^2 r^2 - \frac{1}{2}\rho\Omega^2 r^2$$

or, $$P^+ - P^- = \rho(\Omega + \frac{1}{2}\omega)\omega r^2$$

The resulting thrust on the annular element is given by,

$$dT = (P^{+} - P^{-})dA$$

or, $$dT = \rho(\Omega + \frac{1}{2}\omega)\omega r^{2} 2\pi r\, dr$$

Inserting equation (2.2.2.16)

$$dT = 4a'(1 + a')\frac{1}{2}\rho\Omega^{2} r^{2} 2\pi r\, dr \qquad (2.2.2.20)$$

Balancing equations (2.2.2.19) and equation (2.2.2.20), leads to the expression,

$$\frac{a(1-a)}{a'(1+a')} = \frac{\Omega^{2} r^{2}}{V_{\infty}^{2}} = \lambda_{r}^{2} \qquad (2.2.2.21)$$

where, λ_r is known as the local tip speed ratio which is given by,

$$\lambda_{r} = \frac{r\Omega}{V\infty} \qquad (2.2.2.22)$$

To derive an expression for the torque dQ acting on the rotor the change in angular momentum flux through the annular ring is considered. Thus the torque dQ is given by,

$$dQ = dm V_{t} r$$

or, $$dQ = \omega r \rho dA\, U r$$

where, V_t is the wake tangential velocity.

Considering the equations (2.2.2.10), (2.2.2.16) and (2.2.2.18), the expression for the torque acting on the annular ring is given by,

$$dQ = 4\pi r^{3} \rho V_{\infty}(1 - a)a'\Omega\, dr \qquad (2.2.2.23)$$

The generated power through the annular ring is equal to $dP = \Omega\, dQ$, so the total power becomes,

$$P = \int_{0}^{R} \Omega\, dQ \qquad (2.2.2.24)$$

Introducing the tip speed ratio λ as,

$$\lambda = \frac{R\Omega}{V_{\infty}} \qquad (2.2.2.25)$$

Equation for total power from the equations (2.2.2.23) and (2.2.2.24) becomes,

$$P = \int_{0}^{R} 4\pi r^{3} \rho V_{\infty}(1 - a)a'\Omega^{2} dr$$

This can be written as,

$$P = \frac{1}{2}\rho A V_\infty^3 \frac{8}{\lambda^2}\int_0^\lambda a'(1-a)\lambda_r^3\, d\lambda_r \qquad (2.2.2.26)$$

where, A is the turbine swept area which is given by $A = \pi R^2$.

The power coefficient is defined as,

$$C_P = \frac{P}{\frac{1}{2}\rho A V_\infty^3}$$

Inserting equation (2.2.2.26) power coefficient can be written as,

$$C_P = \frac{8}{\lambda^2}\int_0^\lambda a'(1-a)\, \lambda_r^3\, d\lambda_r \qquad (2.2.2.27)$$

Rearranging equation (2.2.2.21),

$$a' = -\frac{1}{2} + \frac{1}{2}\sqrt{1 + \frac{4}{\lambda_r^2} a(1-a)} \qquad (2.2.2.28)$$

Substituting this value in equation (2.2.2.27) and taking the derivative equal to zero, the relation between λ_r and a for maximum power becomes,

$$\lambda_r = \frac{(1-a)(4a-1)^2}{(1-3a)} \qquad (2.2.2.29)$$

Introducing equation (2.2.2.29) into equation (2.2.2.21) the relationship between a and a' is obtained as,

$$a' = \frac{1-3a}{4a-1} \qquad (2.2.2.30)$$

This relation will be used later for design purposes.

2.2.3. Blade Element Theory

With the blade element theory, the forces acting on a differential element of the blade may be calculated. Then integration is carried out over the length of the blade to determine the performance of the entire rotor.

The assumptions in establishing blade element theory are :

(a) There is no interference between adjacent blade elements along each blade.

(b) The forces acting on a blade element are solely due to the lift and drag characteristics of the sectional profile of the element.

(c) The pressure in the far wake is equal to the free stream pressure.

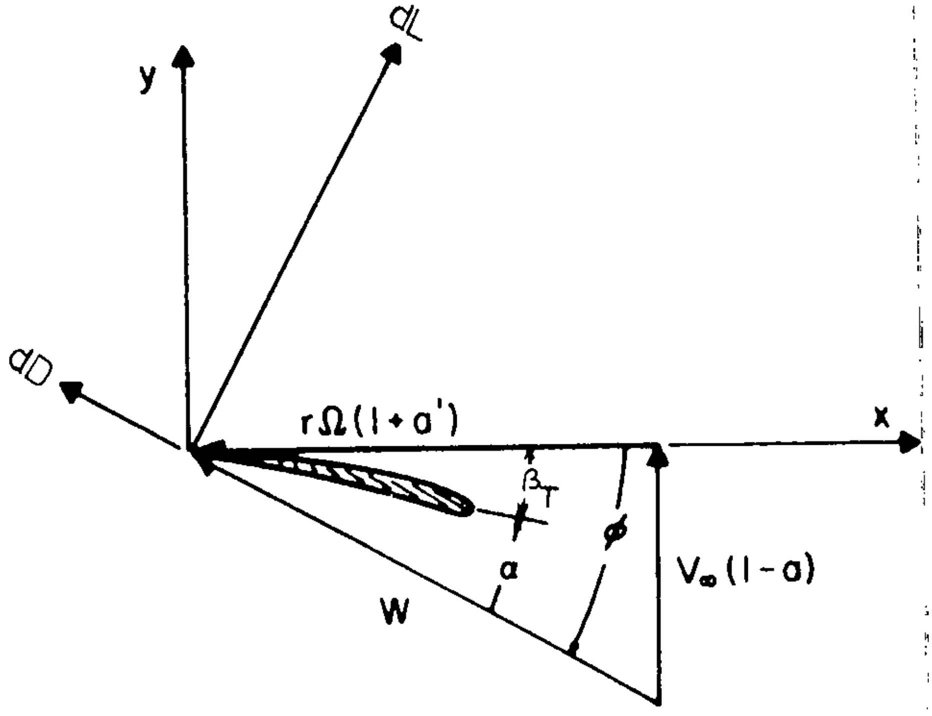


Figure 2.2.4 Velocity Diagram of a Blade Element.

The aerodynamic force components acting on the blade element are the lift force dL, perpendicular to the resulting velocity vector and the drag force dD acting in the direction of the resulting velocity vector. The expressions for the sectional lift and drag forces may respectively be introduced as,

$$dL = C_l \frac{1}{2} \rho W^2 C\, dr \qquad (2.2.3.1)$$

$$dD = C_d \frac{1}{2} \rho W^2 C\, dr \qquad (2.2.3.2)$$

The thrust and torque experienced by the blade element are respectively expressed as,

$$dT = dL \cos\phi + dD \sin\phi \qquad (2.2.3.3)$$

$$dQ = (dL \sin\phi - dD \cos\phi) r \qquad (2.2.3.4)$$

where, ϕ is the angle of relative water velocity.

Assuming that the rotor has B blades, the expressions for the thrust and torque become,

$$dT = BC\frac{1}{2}\rho W^2(C_l\cos\phi + C_d\sin\phi)\,dr$$

or, $$dT = BC\frac{1}{2}\rho W^2 C_l\cos\phi\left(1+\frac{C_d}{C_l}\tan\phi\right)dr \qquad (2.2.3.5)$$

and $$dQ = BC\frac{1}{2}\rho W^2(C_l\sin\phi - C_d\cos\phi)r\,dr$$

or, $$dQ = BC\frac{1}{2}\rho W^2 C_l\sin\phi\left(1-\frac{C_d}{C_l}\frac{1}{\tan\phi}\right)r\,dr \qquad (2.2.3.6)$$

According to the Figure 2.2.4 the expression for relative velocity W can be written as,

$$W = \frac{(1-a)V_\infty}{\sin\phi} = \frac{(1+a')\Omega r}{\cos\phi} \qquad (2.2.3.7)$$

Introducing the following trigonometric relations based on Figure 2.2.4,

$$\tan\phi = \frac{(1-a)V_\infty}{(1+a')\Omega r} = \frac{1-a}{1+a'}\frac{1}{\lambda_r} \qquad (2.2.3.8)$$

and $$\beta_T = \phi - \alpha \qquad (2.2.3.9)$$

where, β_T is the blade twist angle and α is the angle of attack.

The local solidity ratio σ is given by,

$$\sigma = \frac{BC}{2\pi r} \qquad (2.2.3.4)$$

The equations of elemental thrust and torque for the blade element theory become respectively,

$$dT = (1-a)^2\frac{\sigma C_l\cos\phi}{\sin^2\phi}\left(1+\frac{C_d}{C_l}\tan\phi\right)\frac{1}{2}\rho V_\infty^2\,2\pi r\,dr \qquad (2.2.3.5)$$

and

$$dQ = (1+a')^2\frac{\sigma C_l\sin\phi}{\cos^2\phi}\left(1-\frac{C_d}{C_l}\frac{1}{\tan\phi}\right)\frac{1}{2}\rho\Omega^2 r^3\,2\pi r\,dr \qquad (2.2.3.6)$$

2.2.4 Strip Theory

From the axial momentum and blade element theories a series of relationships can be developed to determine the performance of a water turbine.

By equating the thrust, determined from the momentum theory equation (2.2.2.19) to equation (2.2.3.5) of blade element theory for an annular element at radius r, one obtains,

$$dT_{momentum} = dT_{blade\ element}$$

or,
$$\frac{a}{1-a} = \frac{\sigma C_l \cos\phi}{4\sin^2\phi}\left(1 + \frac{c_d}{c_l}\tan\phi\right) \quad (2.2.4.1)$$

Equating the angular momentum, determined from the momentum theory equation (2.2.2.23) with equation (2.2.3.6) of blade element theory, one finds,

$$dQ_{momentum} = dQ_{blade\ element}$$

or,
$$\frac{a'}{1+a'} = \frac{\sigma C_l}{4\cos\phi}\left(1 - \frac{C_d}{C_l}\frac{1}{\tan\phi}\right) \quad (2.2.4.2)$$

Equations (2.2.4.1) and (2.2.4.2), which determine the axial and angular interference factors contain drag terms. It has been suggested in [25] and [26] that the drag terms should be omitted in calculation of a and a' on the basis that the retarded air due to drag is confined to thin helical sheets in the wake and have little effects on the induced flow. However, in reference [27] and [28] drag terms have been included. Omitting the drag terms the induction factors a and a' may be calculated with the following equations,

$$\frac{a}{1-a} = \frac{\sigma C_l \cos\phi}{4\sin^2\phi} \quad (2.2.4.3)$$

$$\frac{a'}{1+a'} = \frac{\sigma C_l}{4\cos\phi} \quad (2.2.4.4)$$

Considering the equations (2.2.4.3) and (2.2.3.5), elemental thrust can be written as,

$$dT = 4a(1-a)\left(1 + \frac{C_d}{C_l}\tan\phi\right)\frac{1}{2}\rho V_\infty^2 2\pi r\, dr \quad (2.2.4.5)$$

From equations (2.2.4.4) and (2.2.3.6), elemental torque can be obtained as,

$$dQ = 4a'(1-a)\left(1 - \frac{C_d}{C_l}\frac{1}{\tan\phi}\right)\frac{1}{2}\rho V_\infty \Omega 2\pi r^3\, dr \quad (2.2.4.6)$$

Elemental power is given by,

$$dP = dQ\Omega$$

or,
$$dP = 4a'(1-a)\left(1 - \frac{C_d}{C_l}\frac{1}{\tan\phi}\right)\frac{1}{2}\rho V_\infty \Omega^2 2\pi r^3\, dr \quad (2.2.4.7)$$

Introducing the local tip speed ratio λ_r,

$$\lambda_r = \frac{r\Omega}{V_\infty} \qquad (2.2.2.22)$$

Equations of total thrust, torque and power become,

$$T = \frac{1}{2}\rho A V_\infty^2 \frac{8}{\lambda^2}\int_0^\lambda a(1-a)\left(1+\frac{C_d}{C_l}\tan\phi\right)\lambda_r\, d\lambda_r \qquad (2.2.4.8)$$

$$Q = \frac{1}{2}\rho A V_\infty^2 R \frac{8}{\lambda^3}\int_0^\lambda a'(1-a)\left(1-\frac{C_d}{C_l}\frac{1}{\tan\phi}\right)\lambda_r^3\, d\lambda_r \qquad (2.2.4.9)$$

and

$$P = \frac{1}{2}\rho A V_\infty^3 \frac{8}{\lambda^2}\int_0^\lambda a'(1-a)\left(1-\frac{C_d}{C_l}\frac{1}{\tan\phi}\right)\lambda_r^3\, d\lambda_r \qquad (2.2.4.10)$$

These equations are valid only for a water turbine having infinite number of blades. The effect of the finite blade number will be discussed in the next section.

2.2.5 Tip and Hub Losses

In the preceding sections, the rotor was assumed to have possessed an infinite number of blades with an infinitely small chord. In reality, however, the number of blades is finite. According to the theory discussed previously, the water imparts a rotation to the rotor, thus dissipating some of its kinetic energy or velocity and creating a pressure difference between one side of the blade and the other. At tip and hub, however, this pressure difference leads to secondary flow effects. The flow becomes three-dimensional and tries to equalize the pressure difference as shown in Figure 2.2.5. This effect is more pronounced as one approaches the tip. It results in a reduction of the torque on the rotor and thus in a reduction of the power output.

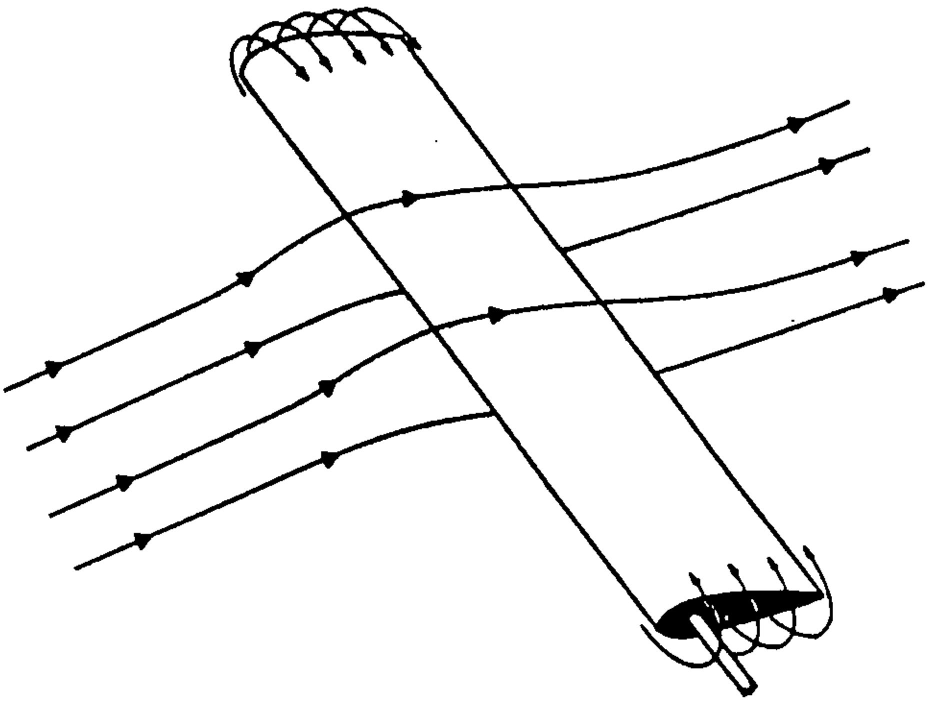


Figure 2.2.5 Tip and Hub Losses Flow Diagram.

Several alternate models to take this loss into account exist and are outlined in the reference [29]. The method suggested by Prandtl will be used here. The idea in Prandtl's method is to replace the system of vortices at the tip with a series of parallel planes for which the flow is more easily calculated. It should however be remembered that this approximation was developed for a lightly loaded propeller under optimum conditions which may differ somewhat from the conditions of a water turbine.

The correction factor suggested by Prandtl is,

$$F_{tip} = \frac{2}{\pi} arc \cos e^{-f} \qquad \text{where, } f = \frac{B}{2} \frac{R-r}{R \sin\phi}$$

It may also be applied for the hub region and f is then defined as,

$$f = \frac{B}{2} \frac{r - r_{hub}}{r_{hub} \sin\phi}$$

Hence, a correction factor F for total losses is applied as,

$$F = F_{tip} . F_{hub} \qquad (2.2.5.1)$$

The loss factor F may be introduced in several ways for the rotor performance calculation. In the method adopted by Wilson and Lissaman [30], the induction factors a and a' are multiplied with F, and thus the axial and tangential velocities in the rotor plane as seen by the blades are modified. It is further assumed that these corrections only involve the momentum formulas.

Thus the thrust and torque from momentum theory become,

$$dT = 4\pi r \rho V_\infty^2 aF(1-aF)\,dr \tag{2.2.5.2}$$

$$dQ = 4\pi r^3 \rho V_\infty a' F(1-aF)\Omega\,dr \tag{2.2.5.3}$$

The results of the blade element theory remain unchanged.

$$dT = (1-a)^2 \frac{\sigma C_l \cos\phi}{\sin^2\phi}\left(1 + \frac{C_d}{C_l}\tan\phi\right)\frac{1}{2}\rho V_\infty^2 2\pi r\,dr \tag{2.2.3.5}$$

and $$dQ = (1+a')^2 \frac{\sigma C_l \tan\phi}{\cos\phi}\left(1 - \frac{C_d}{C_l}\frac{1}{\tan\phi}\right)\frac{1}{2}\rho\Omega^2 r^4 2\pi\,dr \tag{2.2.3.6}$$

Equation (2.2.3.6) can also be written as,

$$dQ = (1-a)^2 \frac{\sigma C_l}{\sin\phi}\left(1 - \frac{C_d}{C_l}\frac{1}{\tan\phi}\right)\frac{1}{2}\rho V_\infty^2 2\pi r^2\,dr \tag{2.2.5.4}$$

Balancing the equations (2.2.5.2) with (2.2.3.5) one finds,

$$aF(1-aF) = \frac{\sigma C_l \cos\phi(1-a)^2}{4\sin^2\phi}\left(1 + \frac{C_d}{C_l}\tan\phi\right) \tag{2.2.5.5}$$

and considering the equations (2.2.5.3) and (2.2.5.4)

$$a' F(1-aF) = (1-a)^2 \frac{\sigma C_l}{4\sin\phi}\left(1 - \frac{C_d}{C_l}\frac{1}{\tan\phi}\right) \tag{2.2.5.6}$$

Omitting the drag terms in equations (2.2.5.3) and (2.2.5.4) the following expressions yield,

$$aF(1-aF) = \frac{\sigma C_l \cos\phi(1-a)^2}{4\sin^2\phi} \tag{2.2.5.7}$$

$$a' F(1-aF) = \frac{\sigma C_l (1-a)^2}{4\sin\phi} \tag{2.2.5.8}$$

From the equations (2.2.5.7) and (2.2.5.8), the final expressions for elemental thrust and torque become respectively,

$$dT = 4aF(1-aF)\left(1 + \frac{C_d}{C_l}\tan\phi\right)\rho V_\infty^2 \pi r\,dr \tag{2.2.5.9}$$

and

$$dQ = 4a' F(1 - aF)\left(1 - \frac{C_d}{C_l}\frac{1}{\tan\phi}\right)\rho V_\infty^2 \pi r^2\, dr \qquad (2.2.5.10)$$

2.2.6 Thrust, Torque and Power Coefficients

Elemental thrust, torque and power coefficients are respectively defined as,

$$dC_T = \frac{dT}{\frac{1}{2}\rho A V_\infty^2} \qquad (2.2.6.1)$$

$$dC_Q = \frac{dQ}{\frac{1}{2}\rho A V_\infty^2 R} \qquad (2.2.6.2)$$

and $$dC_P = \frac{dP}{\frac{1}{2}\rho A V_\infty^3} = \frac{dQ\,\Omega}{\frac{1}{2}\rho A V_\infty^3}$$

or $$dC_P = \frac{dQ\,\Omega R}{\frac{1}{2}\rho A V_\infty^2 R V_\infty} = dC_Q\,\lambda \qquad (2.2.6.3)$$

Considering the equations (2.2.5.9) and (2.2.6.1), elemental thrust coefficient can be written as,

$$dC_T = \frac{8}{R^2} aF(1 - aF)\left(1 + \frac{C_d}{C_l}\tan\phi\right) r\, dr \qquad (2.2.6.4)$$

Again, from the equations (2.2.5.10) and (2.2.6.3), elemental torque coefficient is given by,

$$dC_Q = \frac{8}{R^3} a' F(1 - aF)\left(1 - \frac{C_d}{C_l}\frac{1}{\tan\phi}\right) r^2\, dr \qquad (2.2.6.5)$$

Elemental power coefficient can be obtained from the equation (2.2.6.3) as,

$$dC_P = \frac{8\Omega}{R^2 V_\infty} a' F(1 - aF)\left(1 - \frac{C_d}{C_l}\frac{1}{\tan\phi}\right) r^2\, dr \qquad (2.2.6.6)$$

Finally, total thrust, torque and power coefficients can be obtained by the following equations,

$$C_T = \frac{8}{R^2}\int_0^R aF(1 - aF)\left(1 + \frac{C_d}{C_l}\tan\phi\right) r\, dr \qquad (2.2.6.7)$$

$$C_Q = \frac{8}{R^3} \int_0^R a' F(1 - aF)\left(1 - \frac{C_d}{C_l}\frac{1}{\tan\phi}\right) r^2\, dr \qquad (2.2.6.8)$$

$$C_P = \frac{8}{R^2}\frac{\Omega}{V_\infty} \int_0^R a' F(1 - aF)\left(1 - \frac{C_d}{C_l}\frac{1}{\tan\phi}\right) r^2\, dr \qquad (2.2.6.9)$$

2.2.7 Relations for Maximum Power

For maximum power output the relation between a and a' may be expressed by the equation (2.2.2.30) as,

$$a' = \frac{1 - 3a}{4a - 1}$$

Introducing the equations of induction factors from equations (2.2.4.3) and (2.2.4.4) as,

$$\frac{a}{1-a} = \frac{\sigma C_l \cos\phi}{4\sin^2\phi}$$

and

$$\frac{a'}{1+a'} = \frac{\sigma C_l}{4\cos\phi}$$

From the above equations the following expression yields,

$$\sigma C_L = 4(1 - \cos\phi) \qquad (2.2.7.1)$$

The local solidity σ can be written as,

$$\sigma = \frac{BC}{2\pi r}$$

Equation (2.2.7.1) transforms into,

$$C = \frac{8\pi r}{BC_l}(1 - \cos\phi) \qquad (2.2.7.2)$$

Local tip speed ratio λ_r is given by,

$$\lambda_r = \frac{r\Omega}{V_\infty}$$

The relationship between local tip speed ratio and induction factors may be expressed by the equation (2.2.3.8) as,

$$\tan\phi = \frac{1-a}{1+a'}\frac{1}{\lambda_r}$$

Now replacing the values of $(1-a)$ and $(1+a')$ from the equations (2.2.4.3) and (2.2:4.4) and inserting the value of σC_L from the equation (2.2.7.1), the following relation can be deduced,

$$\lambda_r = \frac{\sin\phi(2\cos\phi - 1)}{(1-\cos\phi)(2\cos\phi + 1)} \qquad (2.2.7.3)$$

and this can be reduced to,

$$\phi = \frac{2}{3} arc\tan\frac{1}{\lambda_r} \qquad (2.2.7.4)$$

Equation of blade twist angle from equation (2.2.3.9) can be written as,

$$\beta_T = \phi - \alpha$$

The equations (2.2.7.2), (2.2.2.22), (2.2.7.4) and (2.2.3.9) may be used to calculate the blade configurations.

Chapter 3 : RIVER CURRENT POTENTIAL IN BANGLADESH

3.1 LOCATION

Bangladesh is located between 20^0 34′ and 26^0 38′ north latitudes and 88^0 01′ and 92^0 41′ east longitudes with and an area of 148,393 square kilometers. It is bordered on the west, north and east by India, on the southeast by Burma and on the south by the Bay of Bengal.

Except the hilly regions in the northeast and southeast the whole country consists of low and flat land formed mainly by the great Ganges and Brahmaputra River systems. A network of rivers with their tributaries and distributaries crisscross the country. The major rivers are the Padma, Jamuna, Teesta, Brahmaputra, Surma, Meghna and Modhumoti.

3.2 THE RIVER SYSTEM

Bangladesh has about 15000 miles (24000 km) of rivers, streams and canals. These together cover about 7 per cent of country's surface [25]. The discharge carried by these river systems has a wide seasonal fluctuation peaking at the monsoon (July to September). The River systems of Bangladesh is shown in Appendix- A. A list of rivers with their location and length has been given in Appendix B. All the rivers in Bangladesh belong to the following three river systems:

a) ***The Ganges-Padma River System:*** Starting from the Southern slopes of the Himalayas it travels 2400km of Indian territory and enters

Bangladesh near Rajshahi. While in India the Ganges is charged by water from many tributaries including the Karnali, the Gandak and the Kosi.

From the entrance into Bangladesh territory, the river flows another 70 miles (112 km) before joining the Brahmaputra-Jamuna at Goalundo, 170 miles (270 km) north of the Bay of Bengal. In Bangladesh, the river receives one tributary, the Mahnanda, joining it at the left bank in Rajshahi. The Ganges drains a total area of 430,000 sq. miles (1.1 million sq. km).

b) ***The Brahmaputra-Jamuna:*** It reaches Bangladesh from the State of Assam, forming the border with India over a distance of 45 miles (72 km). Upon entering Bangladesh, the Brahmaputra Jamuna branches into two. The main course flows to the south through a wide and highly unstable channel, filled with islands and sand bars, built from its own movement, until it meets the Ganges-Padma at Goalundo. From here the confluents flow in south-easterly course to join the Meghna at Chandpur. The minor channel, the Old Brahmaputra, was the main course of the river only 200 years ago. It flows southeast to meet the Meghna at Bhairab Bazar.

The Brahmaputra-Jamuna drains an area of 360,000 sq. mile (930,000 sq. km). Peak flows of up to 2500,000 cusecs are reached between mid June and early September [30].

c) ***The Meghna System:*** The headwaters of the Meghna enter through two arms, the Surma and the Kushiyara, both of which have similar origins. The annual average discharge is around 125,000 cusecs, about the same as that of the Nile. Flood flow is in the order of 420,000 cusecs.

The Ganges, the Brahmaputra and the Meghna river basin is shown in Appendix C.

3.3 THE RIVER SITES

3.3 THE RIVER SITES

Under this project, different sites of different rivers have been studied. They are as follow:

i. The Ganges at Hardinge Bridge
ii. The Ganges at Gorai Railway Bridge
iii. The Bengali River at Shimulbari
iv. The Tulshiganga River at Naogaon
v. The Atrai River at Atrai
vi. The Bengali River at Khanpur
vii. The Mohananda River at Chapainawabganj
viii. The Mohananda River at Rohanpur
ix. The Tulshiganga River at Sonamukhi
x. The Atrai River at Chakharihorpur
xi. The Nagar River at Bogra
xii. The Atrai River at Singra
xiii. The Atrai River at Nowhata
xiv. The Atrai River at Mohadevpur
xv. The Kushiyara River at Sheola
xvi. The Piyan River at Jaflong
xvii. The Ichamoti River at Thandachari
xviii. The Matamuhuri River at Lama
xix. The Sangu River at Bandarban
xx. The Halda River at Panchapukuria
xxi. The Bogkhali River at Ramu
xxii. The Atrai River at Noldangar Hat
xxiii. The Brahammaputra River at Bahdurabad

The river current data (Appendix D) of the above mentioned stations have been collected from the Bangladesh Water Development Board, Dhaka. These data are from mostly from the year 1997 to 2000. But except 2/3 stations, other stations don't have a complete set of data for the year round. So it is very difficult to take a concrete decision on the river current potential of a particular station.

At almost all the stations the river current velocity is above 0.4 m/s from July to October. Nawhata, Bogra, Sonamukhi, and Chapainawabgonj show very poor river current velocity. At these stations the river current velocity is less than 0.5 m/s.

Rohanpur, Singra, Chakharihorpur, Khanpur, Atrai, Noagaon, Noldargarhat and Mohimagonj show moderate river current velocity. At these stations the river current is between 0.5 m/s to 0.75 m/s from July to November.

River current is more than 0.9 m/s at Ramu, Panchapukuria, Lama, Bandarban, Sheola, Jaflong, Hardinge Bridge, and Gorai Railway Bridge stations. So these stations are very good potential in river current.

The average river current velocity distributions over the year at the above mentioned stations have been shown from Figure 3.1 to 3.23.

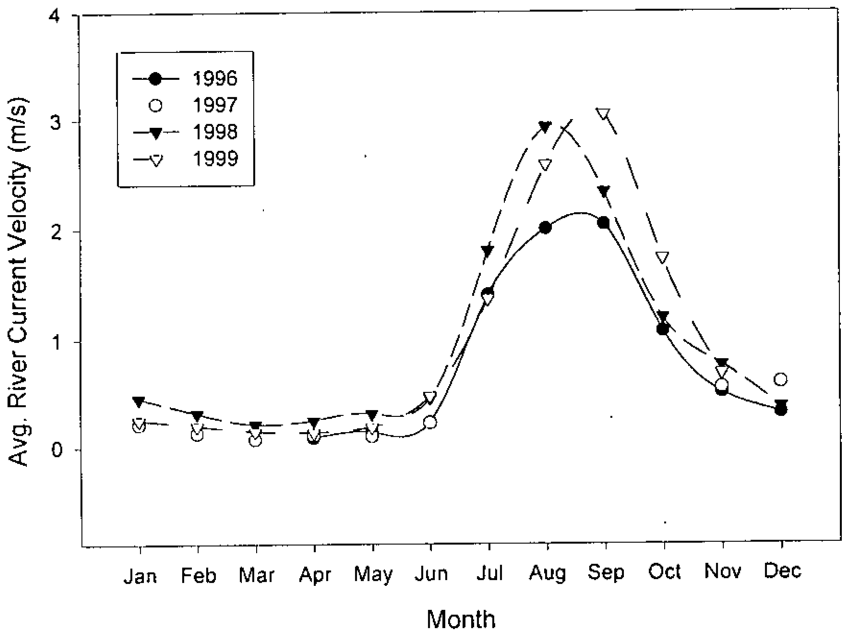


Figure 3.1 : Average river current velocity in different months at the Hardinge Bridge of the Ganges

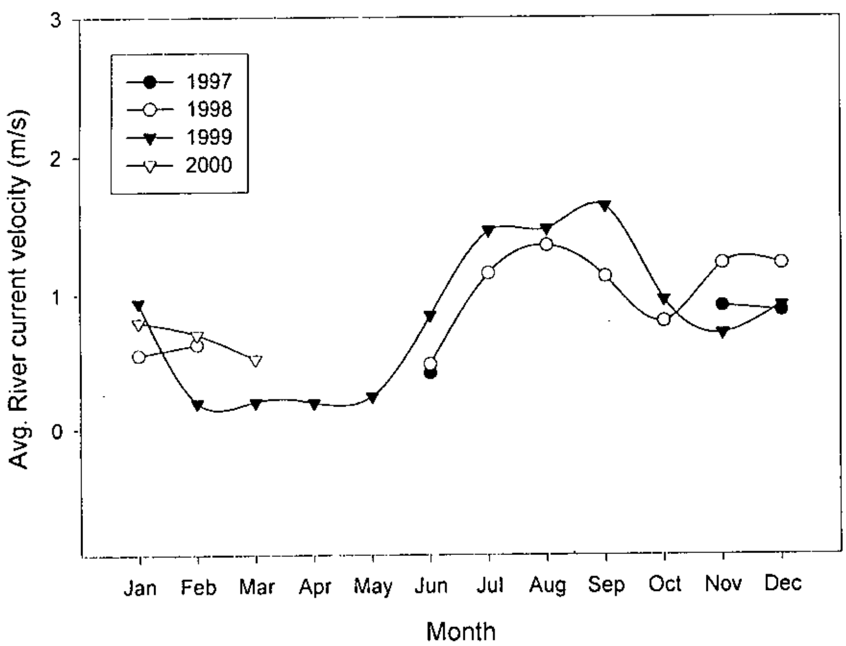


Figure 3.2 : Average river current velocity in different months at the Gorai Bridge of the Gorai River

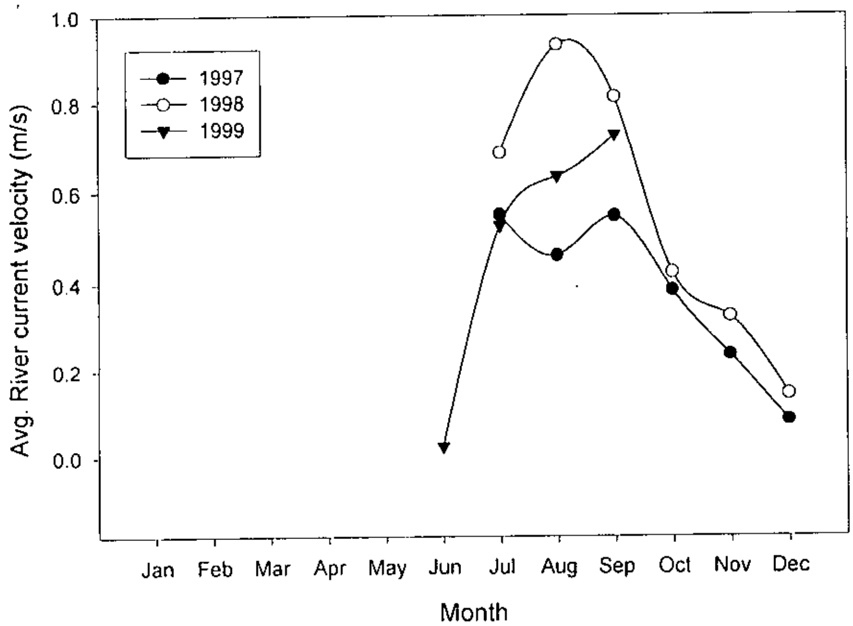


Figure 3.3 : Average river current velocity in different months at Singra of theAtrai River

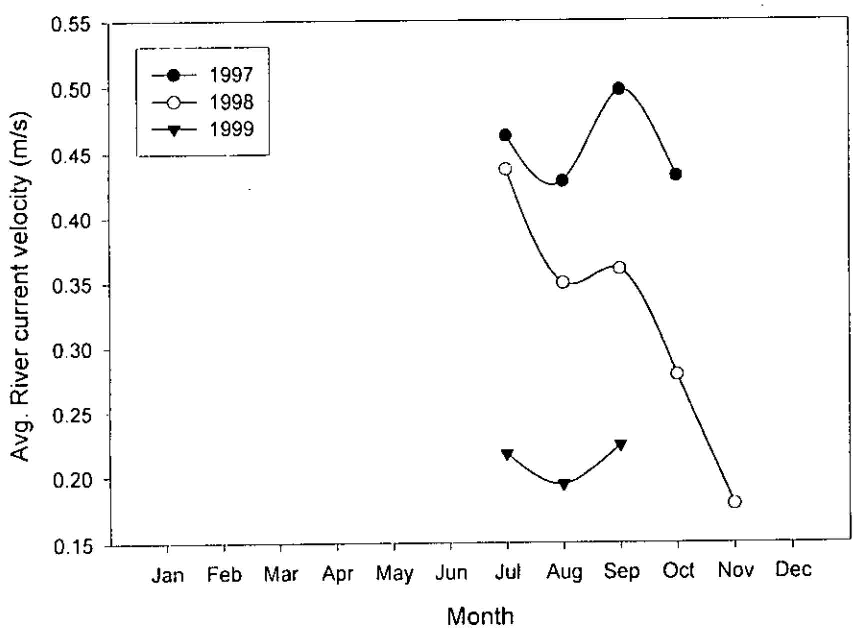


Figure 3.4 : Average river current velocity in different months at Nowhata of the Atrai River

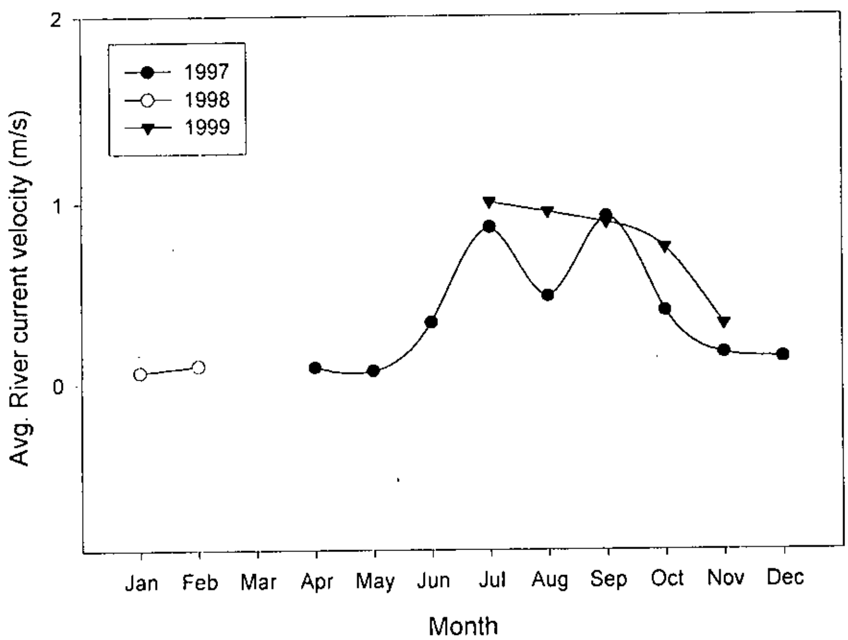


Figure 3.5 : Average river current velocity in different months at Shimulbari of theBengali River

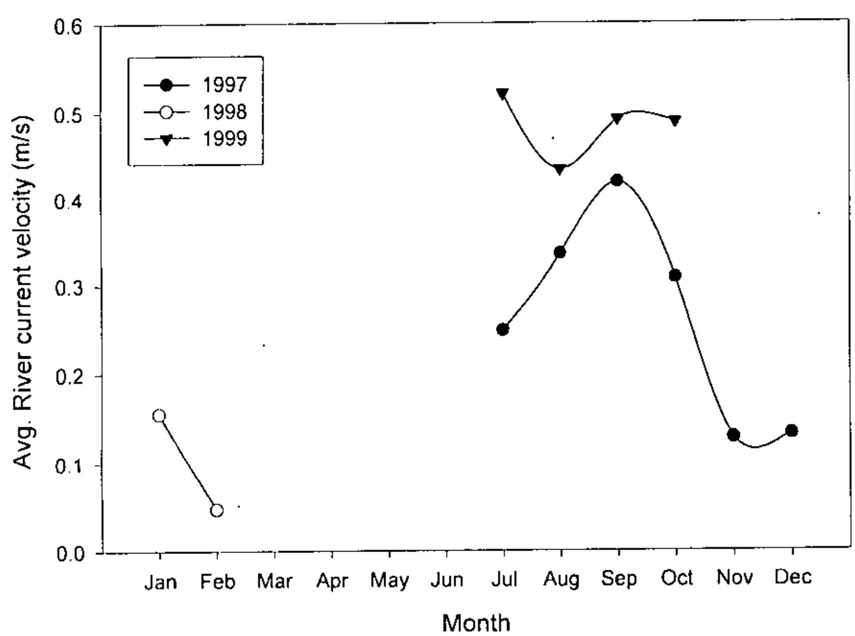


Figure 3.6 : Average river current velocity in different months at Bogra of the Nagar River

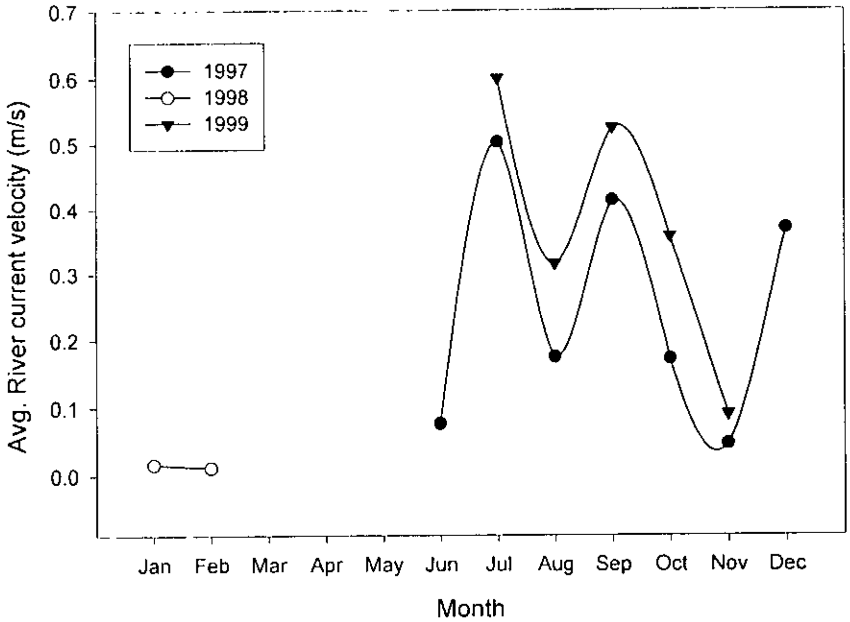


Figure 3.7 : Average river current velocity in different months at Sonamukhi of the Tulshiaanaa River

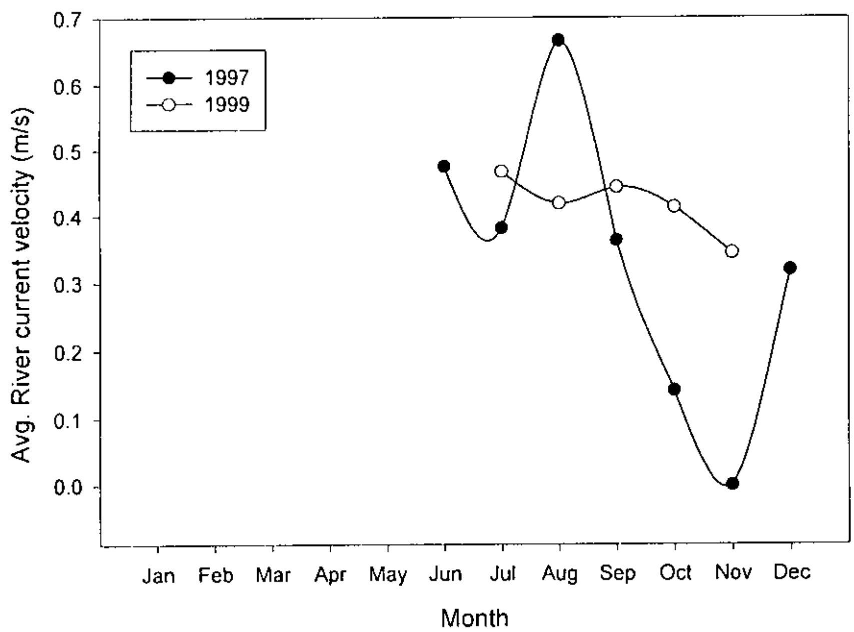


Figure 3.8 : Average river current velocity in different months at Naogaon of the Tulshiganga River

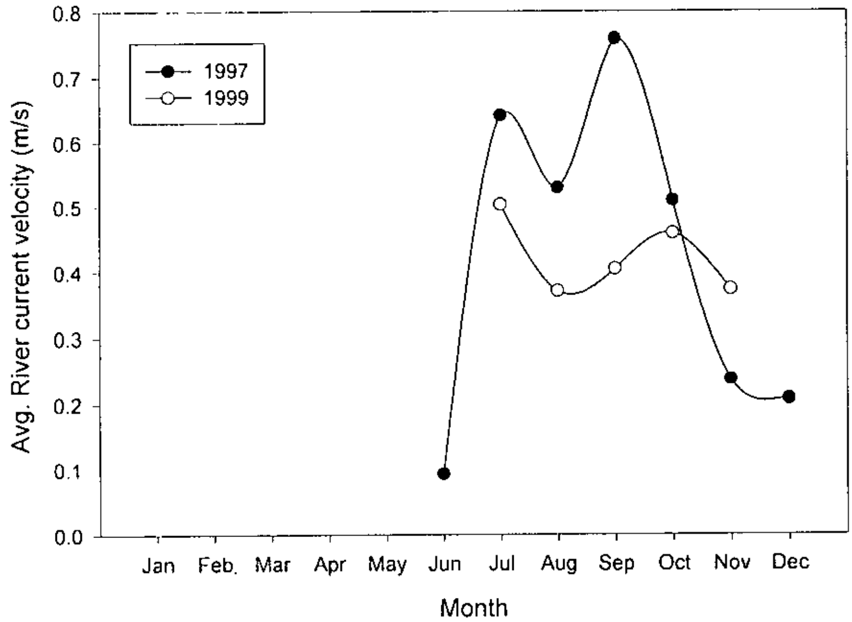


Figure 3.9 : Average river current velocity in different months at Atrai of the Atrai River

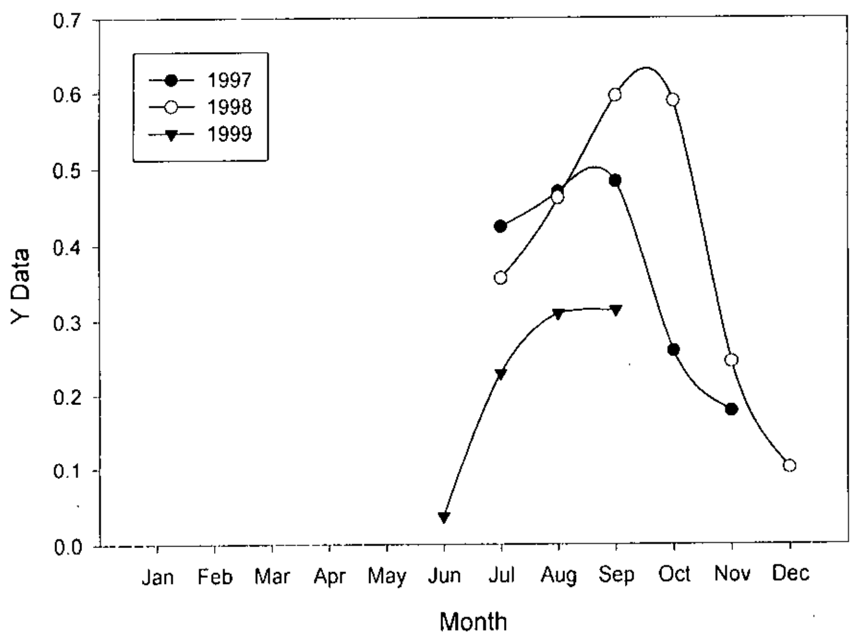


Figure 3.10 : Average river current velocity in different months at Rohanpur of the Mohananda River

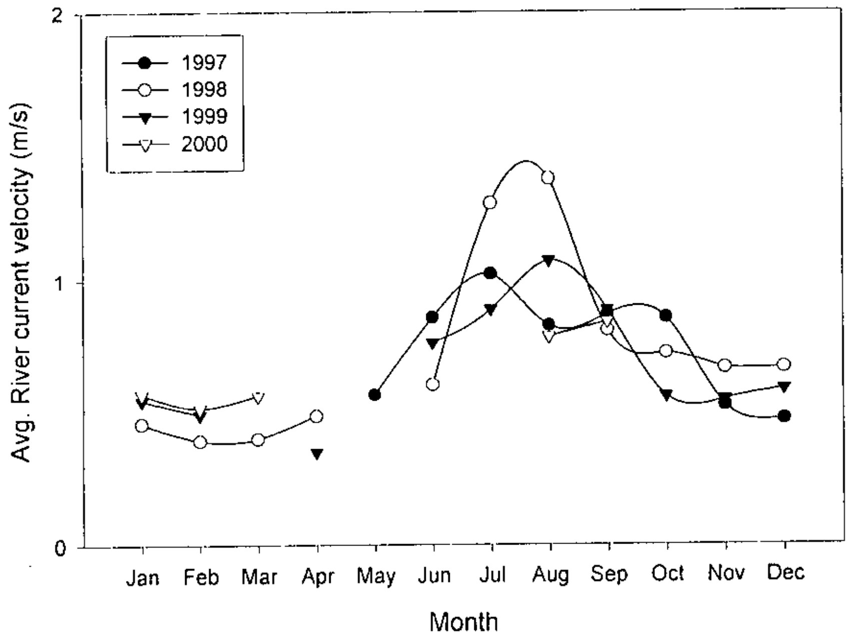


Figure 3.11 : Average river current velocity in different months at Ramu of the Bogkhali River

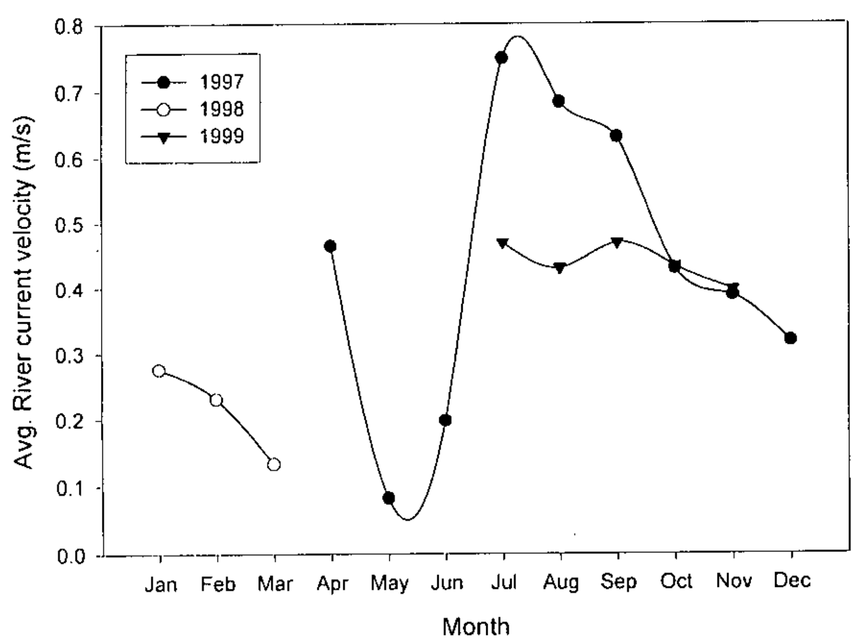


Figure 3.12 : Average river current velocity in different months at Chakharihorpur of the Atrai River

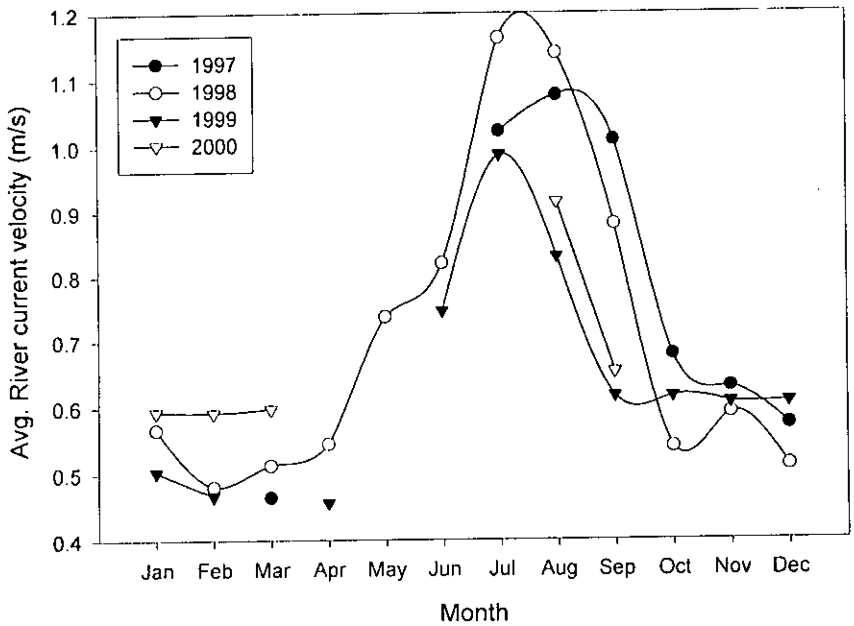


Figure 3.13 : Average river current velocity in different months at Panchapukuria of the Halda River

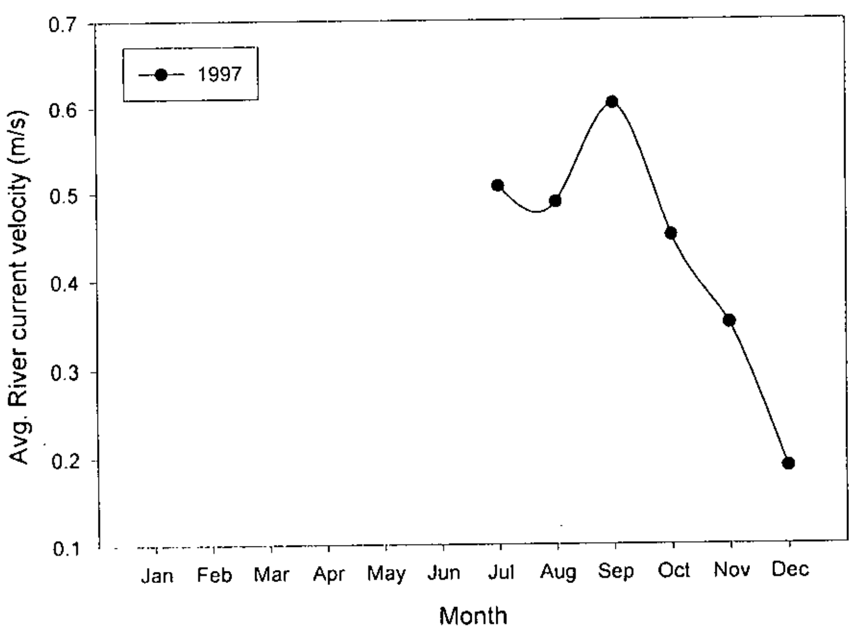


Figure 3.14 : Average river current velocity in different months at Noldangar Hat of the Atrai River

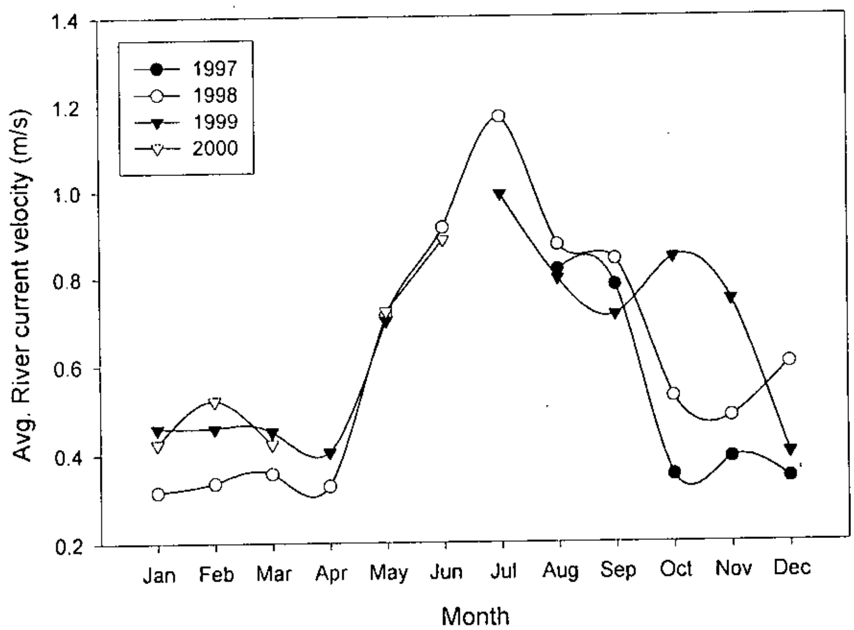


Figure 3.15 : Average river current velocity in different months at Jaflong of the Piyan River

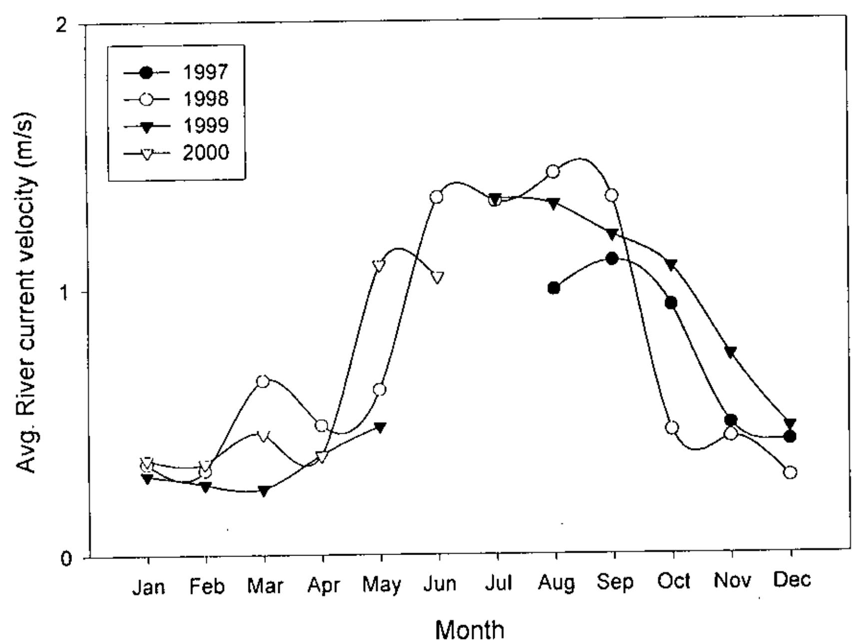


Figure 3.16 : Average river current velocity in different months at Sheola of the Kushiyara River

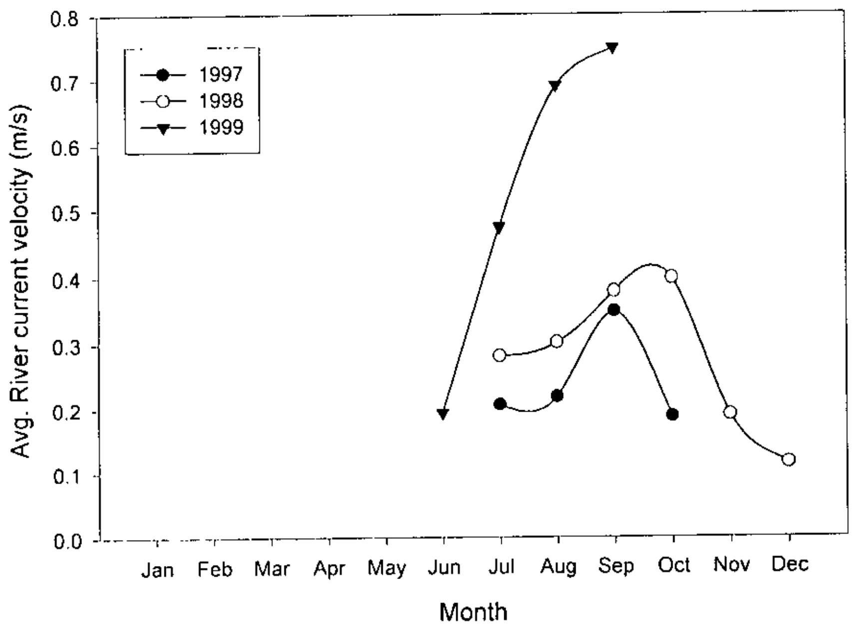


Figure 3.17 : Average river current velocity in different months at Chapainawabgonj of the Mohananda River

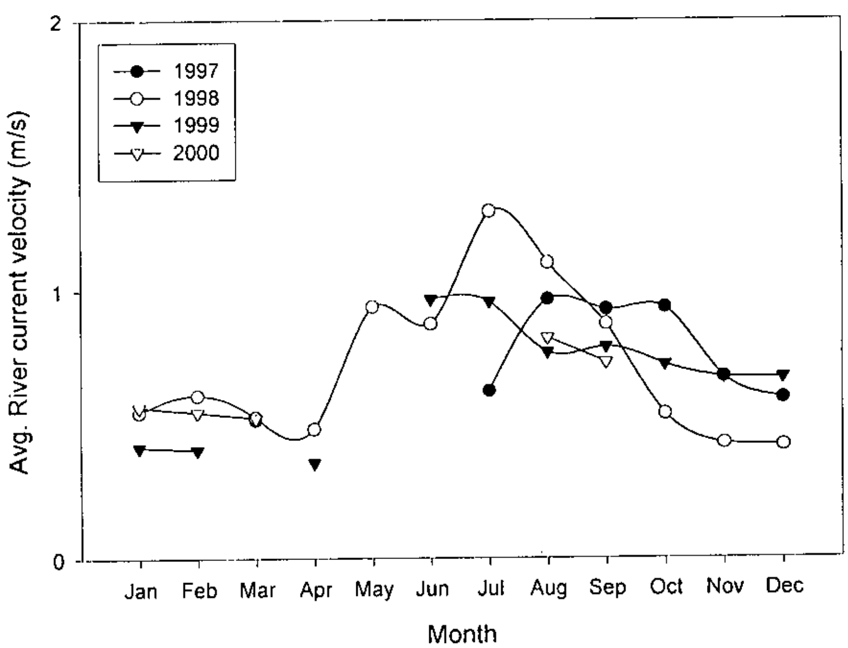


Figure 3.18 : Average river current velocity in different months at Bandarban of the Sangu River

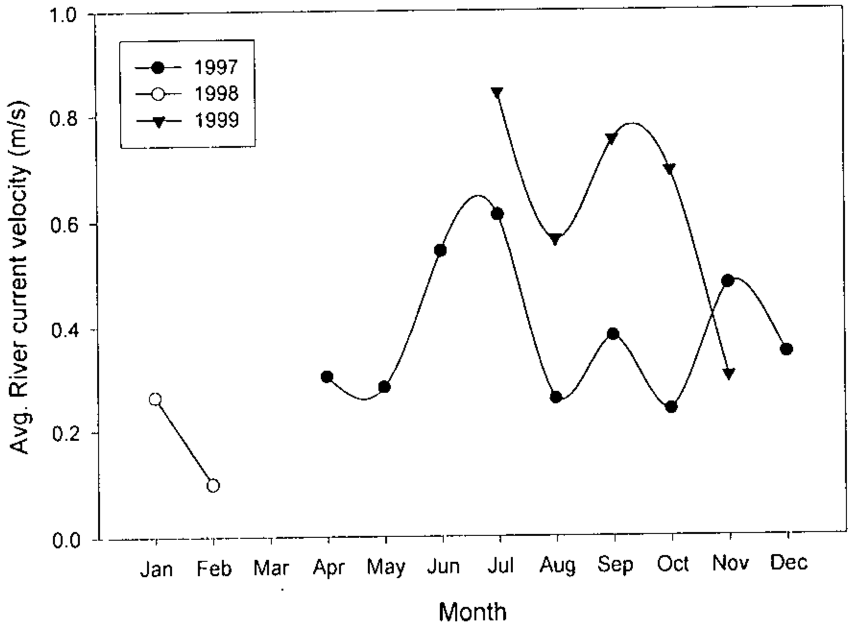


Figure 3.19 : Average river current velocity in different months at Mohimagonj of the Bengali River

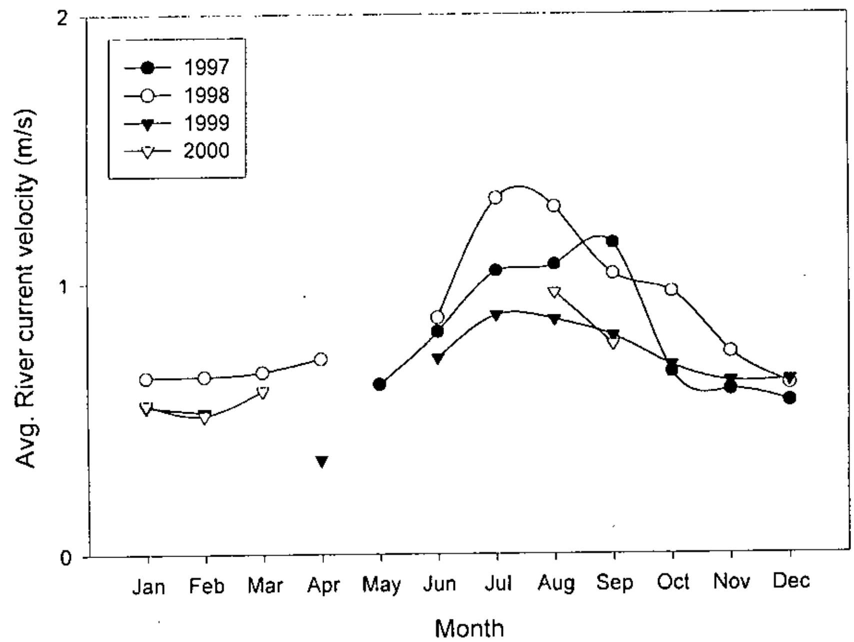


Figure 3.20 : Average river current velocity in different months at Lama of the Matamuhuri River

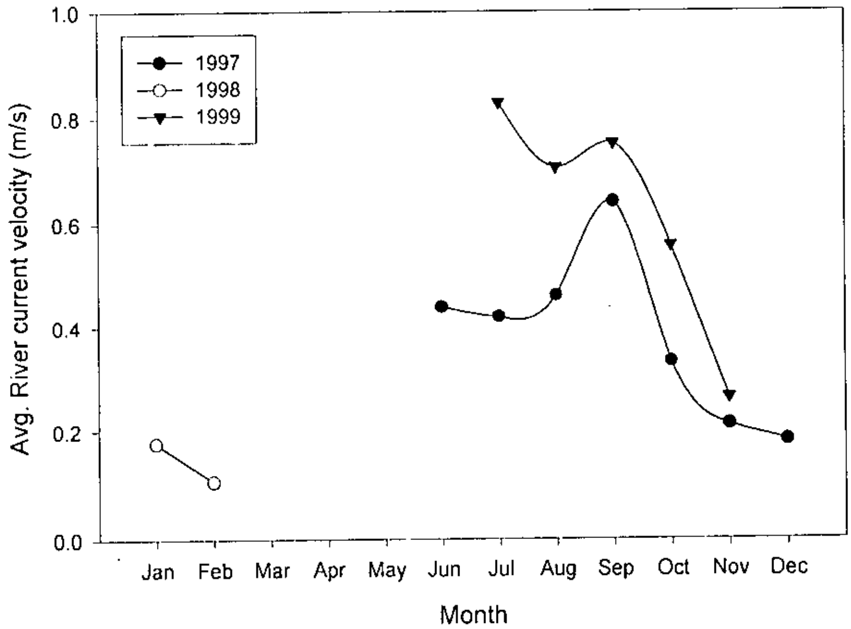


Figure 3.21 : Average river current velocity in different months at Khanpur of the Bengali river

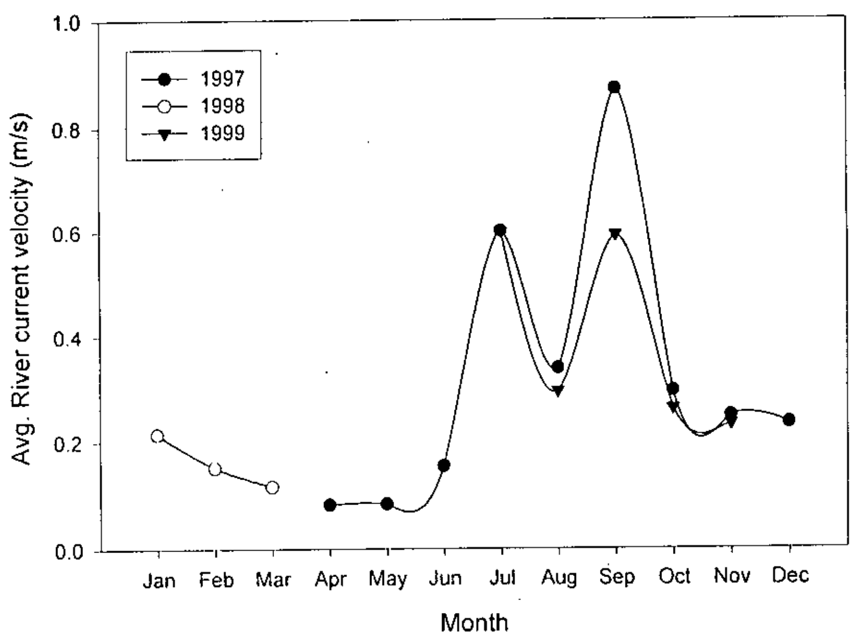


Figure 3.22 : Average river current velocity in different months at Mohadevpur of the Atrai River

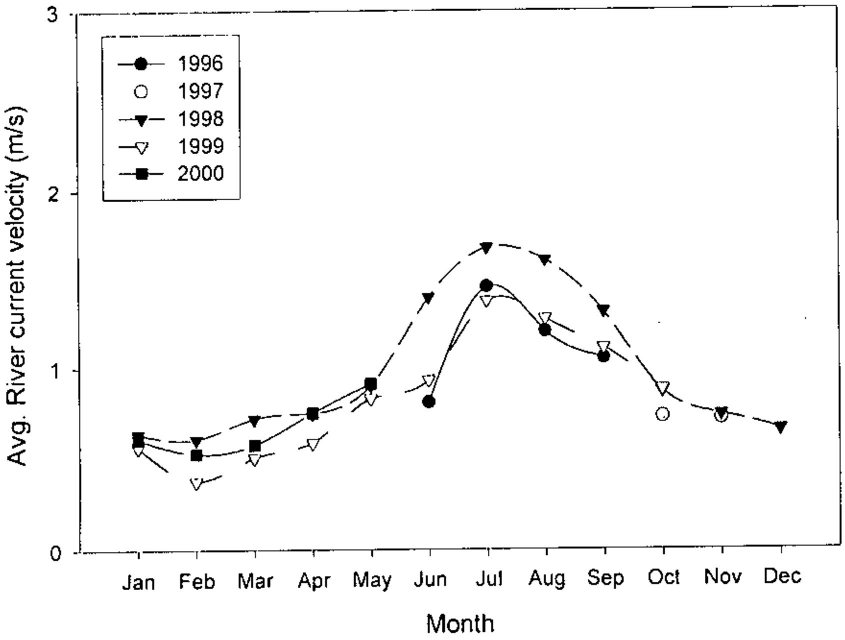


Figure 3.23 : Average river current velocity in different months at Bahadurabad of the Brhammaputra River

Chapter 4 : RIVER CURRENT: A SOURCE OF ENERGY

It should be mentioned here that this research is dealing with the extraction of kinetic energy from a freely flowing river or canal in situations where it is impractical, both on engineering or economic grounds, to create a static head of water by the construction of any sort of dam or barrage. Compared to the energy available from a static head of water, river currents are a very diffuse energy source. For example, a river speed of one meter per second is equivalent, in energy terms, to a static head of only 50mm [24]. Thus any static head of water available should always be exploited (using the relevant technology) in preference to a freely flowing river or canal. But river currents have many advantages as an energy source. Besides of providing a reliable and predictable energy supply over the 24 hrs per day, relatively simple technologies can convert river current energy to provide electrical energy or provide pumped water in sufficient quantities for economically viable small-scale irrigated agriculture.

4.1 Power From Flowing Water

The power available from the flowing water can be calculated from the following equation:

$$P_a = \frac{1}{2}\rho A V_a^3 \qquad [4.1.1]$$

P_a available power (watts)

ρ density of water (1000 kg/m^3)

A area of flow perpendicular to the current direction from which power is to be extracted (m^2)

V_α water velocity (m/s)

In practice, it is not possible to extract all the power available in a river current for two reasons:

(i) to give up all its kinetic energy the water would have to stop, which clearly can't be done;

(ii) turbine rotor must be used to convert the water's kinetic energy into shaft power, and this rotor is bound to be subject to drag forces which will dissipate some of the power.

Adding a constant to represent the conversion efficiency from energy flux in the flowing water to power output of the turbine shaft, equation [4.1.1] becomes:

$$P_s = \frac{1}{2}\rho A_s V_s^3 C_p \qquad [4.1.2]$$

P_s turbine shaft power (watts)

A_s area of water current (perpendicular to the current direction) interrupted by the turbine rotor (m^2)

V_s free stream velocity measured at the upstream from the turbine (m/s)

C_p coefficient of performance of the turbine rotor

From this equation it can be seen that there are three factors that affect the shaft power output of the turbine:

(i) The turbine shaft power is proportional to the cube of the upstream velocity. This means that, if the water speed is doubled, the rotor power output will be increased by a factor of eight. Figure 4.1 shows how the power output of a rotor of 3.14m^2 swept area (rotor radius is 1m) and coefficient of performance 0.25 would vary with the river current.

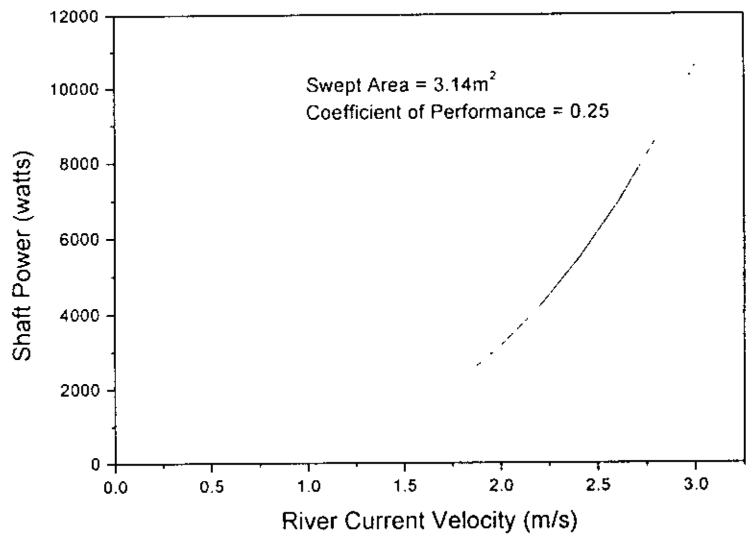


Figure 4.1 Shaft Power as a function of River Current

(ii) The turbine shaft power is directly proportional to the rotor swept area. Thus a turbine of swept area 1.57 m^2 would have a power output of half that of the machine in Figure 4.1.

(iii) The power output is also directly proportional to the coefficient of performance. As already mentioned, it is impossible to extract all the energy from the flowing water because the water which has passed through the rotor must move away from it and therefore must still have some kinetic energy. It can be shown theoretically that the maximum coefficient of performance is 0.59 for a machine operating on lift forces such as a propeller or Darrieus rotor and 0.33 for a machine operating on drag forces such as a floating undershot water wheel in free stream [31]. The performance coefficient depends on the type of blade, river speed and manufacturing quality [32,33].

From the above discussion it is evident that to obtain the maximum shaft power output the rotor must be the most efficient type, make it sweep as large a cross sectional area of water current as possible and most importantly, place it in the fastest current speed which can be found.

4.2 Minimum Useful River Current

To extract a given amount of power the machine becomes larger as the current speed decreases. A machine in a river current of 0.5 m/s would have to be eight times the size of one in current of 1m/s to produce the same shaft power as evident from Figure 4.1.

As can be seen from Figure 4.1, the level of energy flux in river currents of less than 0.4m/s is so low that there would have to be very special economic conditions to justify the construction of a machine large enough to extract useful amount of power.

Using a duct to artificially increase the water velocity through the turbine rotor might be an improvement in energy extracted per unit area of current intercepted. However, the considerable increase in capital cost and the increased difficulties of transporting and maneuvering the machine eliminate the ducted free stream turbine from further consideration as a low cost water current turbine.

4.3 Site Selection

In the last section it has been established the minimum river speed for any form of kinetic energy extraction to be viable. Like conventional water powered devices, river current turbine is a site- specific technology. For example, the diameter of the machine rotor will depend on the river current.

Before starting work on the construction of a turbine, it is necessary to survey the proposed site for the machine to provide the following basic information:

(i) the maximum and minimum river current over the months that the machine will be used;

(ii) environmental hazards such as floating debris, river traffic, etc.;

(iii) river depth at the position where the turbine will operate.

4.4 Measurement of River Current

The river current can vary by as much as 10 percent within 30 or 40 meters up or down stream from a given spot [24]. Bearing in mind that a 10 percent increase in river speed gives a 33 percent increase in rotor shaft power, the importance of accurate river current measurement for selecting the best site will clearly be appreciated.

Accurate speed measurement is also necessary to select the correct rotor swept area to ensure that the required amount of power is produced.

Chapter 5 : DESIGN AND FABRICATION OF WATER CURRENT TURBINE

5.1 Choice of Turbine Rotor

The function of the turbine rotor is to convert as much as possible of the kinetic energy flux through it into useable shaft power. The range of possible turbine rotors is similar to the different types use to extract energy from the wind. There are two basic types of rotor operating on different principles:

(i) Rotors, which have their effective surfaces moving in the direction of the current and are pushed round by the drag of the water, e.g., under shot water wheel as shown in Figure 5.1.

(ii) Rotors, which have their effective surfaces moving at an angle to the direction of the water and operate on lift forces, e. g., propeller rotor and Darrieus rotor as shown in Figure 5.2.

In this research, the inclined axis rotor is of propeller type with 3 blades of airfoil shaped.

5.2 Design of turbine blade

The design of a rotor consists of two steps:

1. Choice of basic parameters such as
    - number of blades B
    - radius of the rotor R

- type of airfoil and
- selection of design tip speed ratio λ_d.

2. Calculations of the blade twist angle β_T and the chord C at a number of positions along the blade, in order to produce maximum power at a given tip speed ratio by each section of the blade.

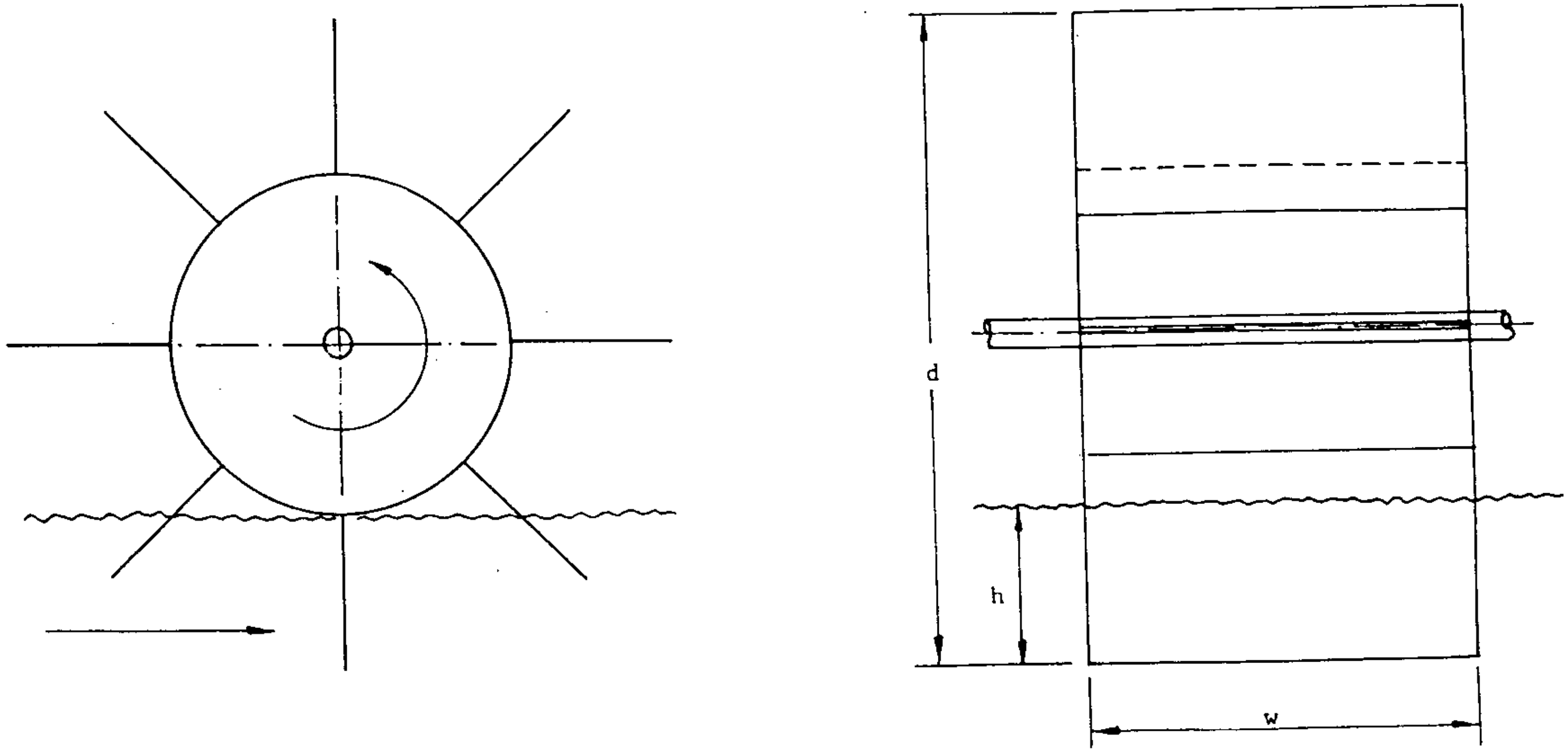
The design procedure is described in the following sections:

The selection of the number of blades B affects the power coefficient. Although B has no influence on the tip speed ratio of a certain windmill, for the lower design tip speed ratios, in general, a higher number of blades is chosen table A. This is done because the influence of B on C_P is larger at lower tip speed ratios. A second reason is that choice of a high number of blades B for a high design tip speed ratio will lead to very small and thin blades which results in manufacturing problems and a negative influence on the lift and drag properties of the blades.

Table A

Design tip speed ratio, λ_d	Number of blades, B
1	6 - 20
2	4 - 12
3	3 - 6
4	2 - 4
5 – 8	2 - 3
8 – 15	1 - 2

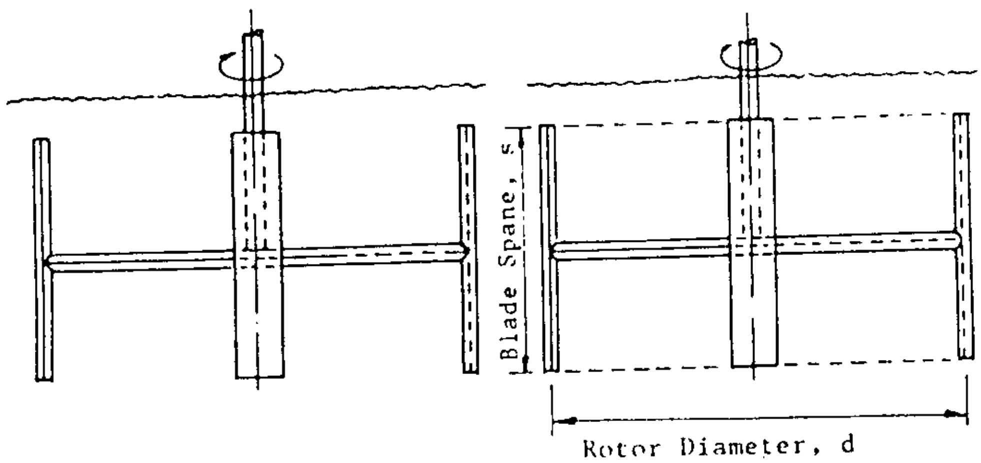
A second important factor that affects the power coefficient is the drag. Drag affects the expected power coefficient via the C_d/C_l ratio. This will influence the size and, even more, the speed ratio of the design. Promising airfoils have a minimum C_d/C_l ratio between 0.1-0.01 (Appendix E).



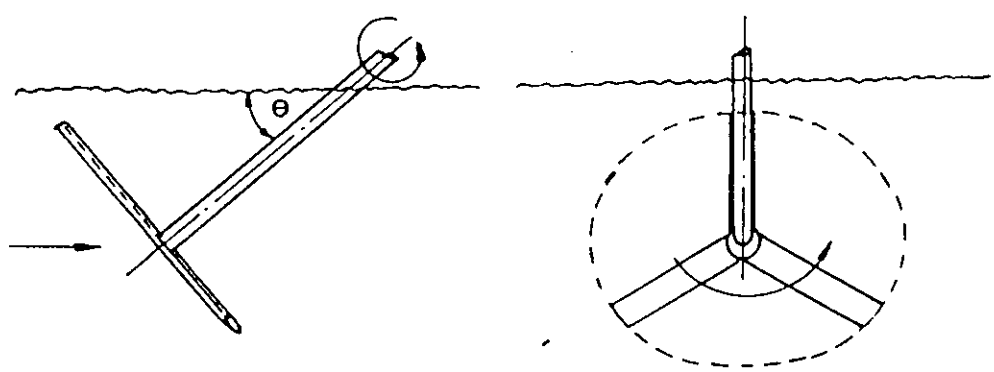
FLOATING UNDERSHOT WATERWHEEL
(SWEPT AREA = w x h)

Figure 6.1 Sketch of Floating Undershot Waterwheel

Figure 5.1 Sketch of Floating Undershot Waterwheel



(a) **VERTICAL** AXIS DARRIEUS ROTOR
(SWEPT AREA = s x d)



(b) INCLINED AXIS PROPELLER ROTOR
(SWEPT AREA = $[3.14d^2/4]\cos\theta$)

Figure 5.2 Sketches of Darrieus and Propeller Turbine Rotors

A large C_d/C_l ratio restricts the design tip speed ratio. At lower tip speed ratios the use of more blades compensates the power loss due to drag (Appendix F). In this collection of maximum power coefficients it is seen that for a range of design speeds $1\leq \lambda_d \leq 10$ the maximum theoretically attainable power coefficients lie between $0.35\leq (C_P)_{max}\leq 0.5$.

Due to deviations, however, of the ideal geometry and hub losses for example, these maximums will lie between 0.3 and 0.4. This result shows that the choice of the design tip speed ratio hardly affects the power output.

The design of an airfoil blades for a given water current velocity V_α and power demand P can be performed now.

Let us first chose the airfoil of ***NACA 4412***.

Appendix E : $(C_d/C_l)_{min} = 0.01$

Appendix F : $1\leq \lambda_d \leq 10$; let $\lambda_d = 4$

Table A : Number of blades, B = 3

Appendix F : $(C_p)_{max} = 0.5$

For conservative design, $C_p = (C_p)_{max} \times 0.8 = 0.5 \times 0.8 = 0.4$

Now,

$$Rotor\ Radius, R = \sqrt{\frac{2P}{\pi \rho V_\alpha^3 C_p}} \qquad (5.2.1)$$

For Power output, P = 8.5 watt

Free stream velocity, $V_\alpha = 0.65$ m/s

Then from Eq. (5.2.1), the rotor radius be 223 mm. The density of water has been considered as 1000 kg/m^3.

Thus the Design values for the model are:

Blade airfoil type	: NACA 4412
Rotor radius	: 223mm
Blade length	: 170 mm
Hub radius	: 38 mm
Root Chord	: 143 mm
Tip Chord	: 68 mm

Number of Blades : 3

5.3 Choice of Turbine Rotor

Different blade materials can be used for rotor construction. Some have been tested by Peter Garman [24]:

(i) solid aluminium alloy;

(ii) laminated hardwood sheathed with glass fiber reinforced plastic (GRP);

(iii) steel spar with polyurethane foam filled GRP fairing;

(iv) untreated hardwood;

(v) ferrocement (a) untreated, (b) painted, (c) sheathed with Al alloy sheet;

(vi) steel spar, timber fairing sheathed with Al alloy sheet.

From the performance point of view surface finish is critical, and any deterioration causes drastic shaft power reduction. This is because the blade velocity of lift- powered rotors is twice (in the case of the Darrieus rotors) or three times (in the case of propeller rotors) that of the river current and so drag produced by surface friction is a very important consideration [24]. In consideration of this Al alloy maintains its surface highly finished and hence, high level of performance can be maintained. For this reason Al- blades have been used to fabricate the model.

5.4 Rotor Shaft Bearing

The rotor shaft must be carried in bearings, which support it in the correct position relative to the river current and allow it to rotate as freely as possible. If the shaft is to be supported at each end by a bearing mounted on a frame, at least one of the bearings must allow some axial movement to take up flexing of the frame.

The inclined axis propeller rotor has one bearing above the water for which a single row ball bearing is suitable. The bearing used is the grease- lubricated self- aligning type. The bearing at the bottom of the rotor shaft is under water and hence must be sealed. This bearing locates just behind the rotor shaft, takes a small radial load and allows some axial movement of the shaft relative to the frame.

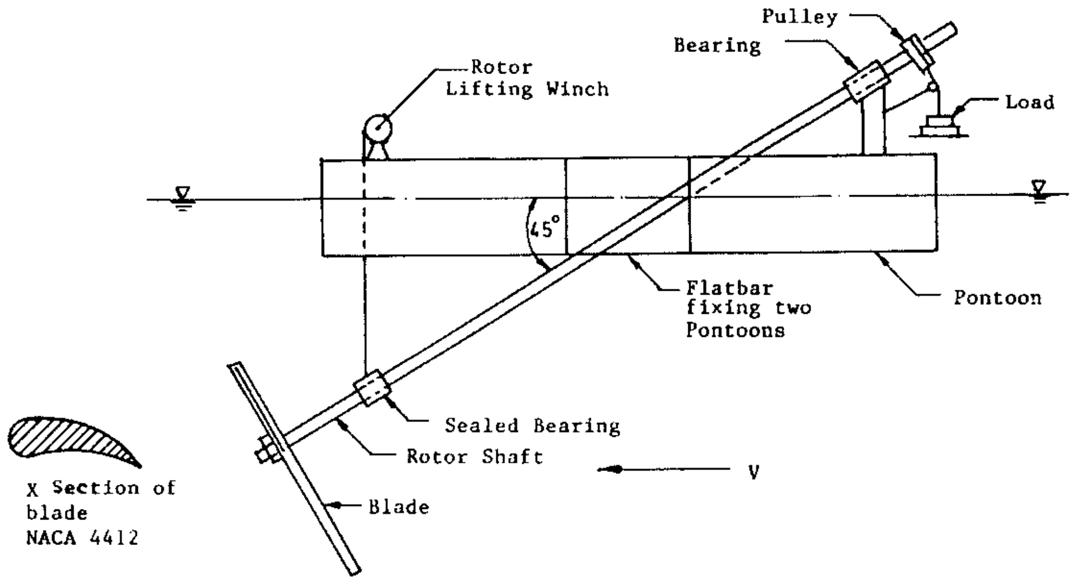


Figure 5.3 Schematic Diagram of the Zero Head Water Current Turbine

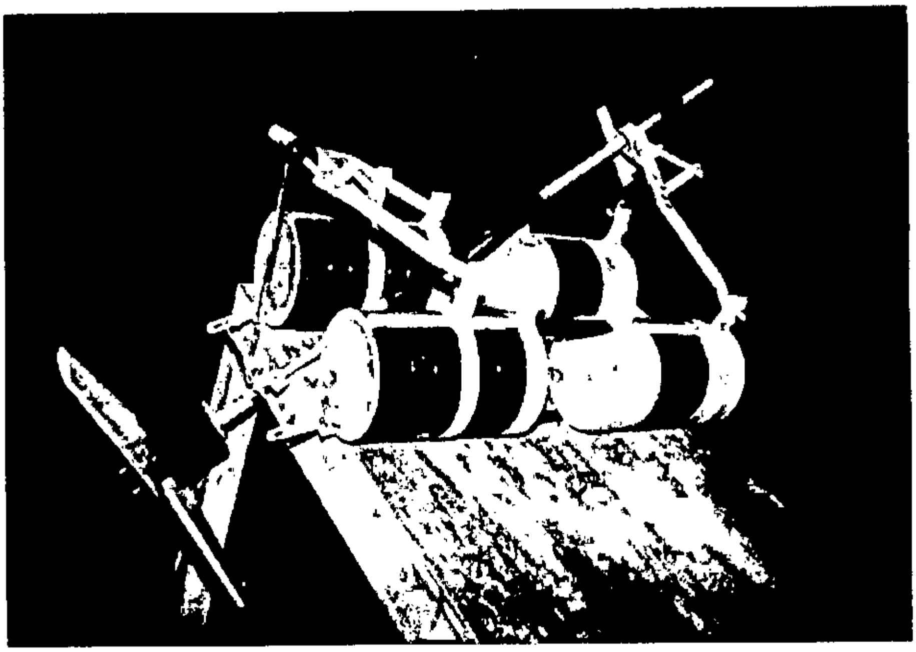


Figure 5.4 Water Current Turbine Model

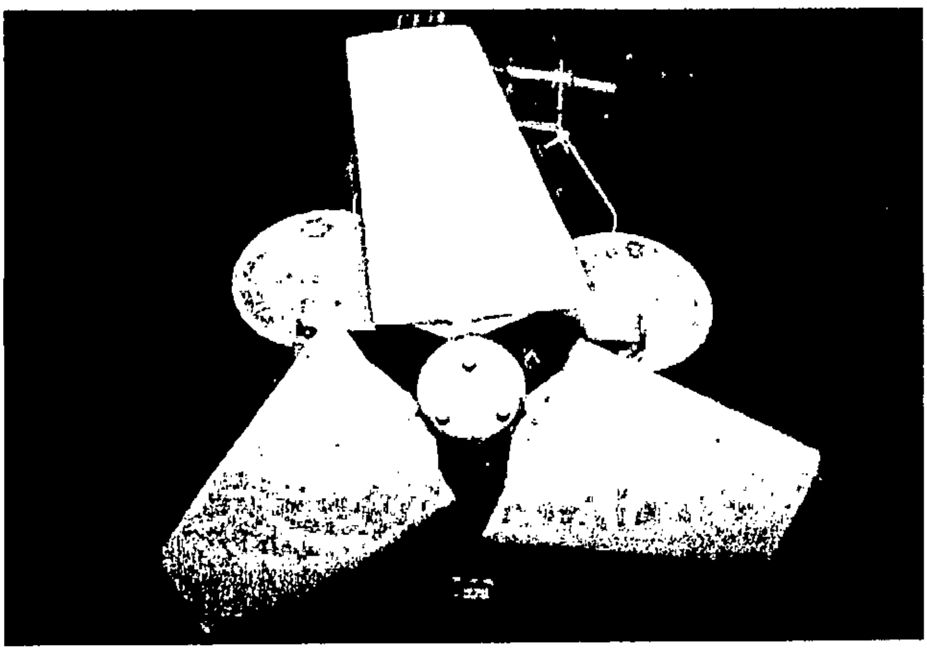


Figure 5.5 Blades of the Turbine Model

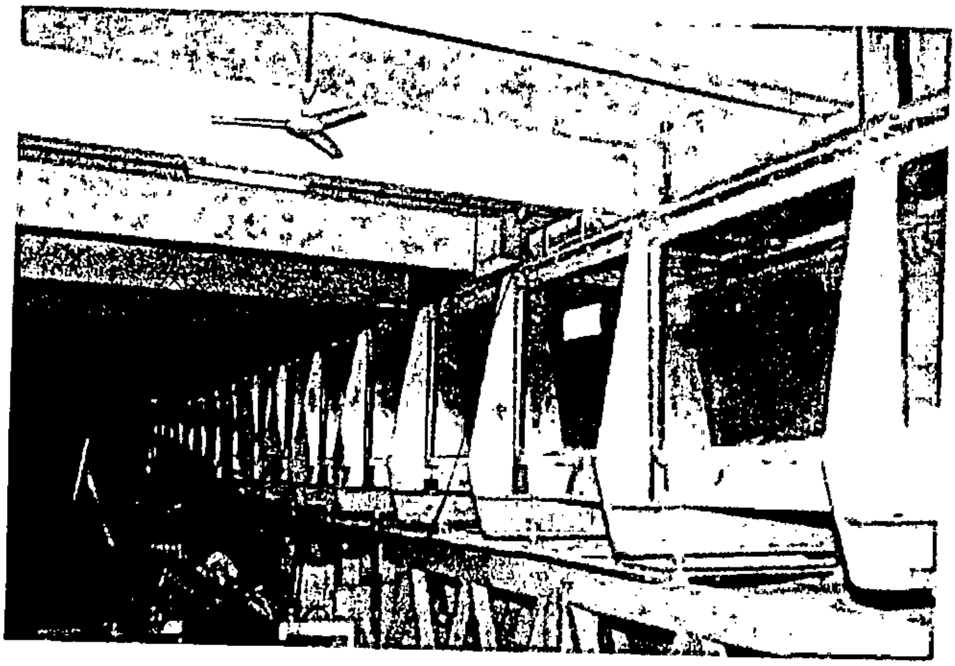


Figure 5.6 Flume where the Turbine Model has been tested

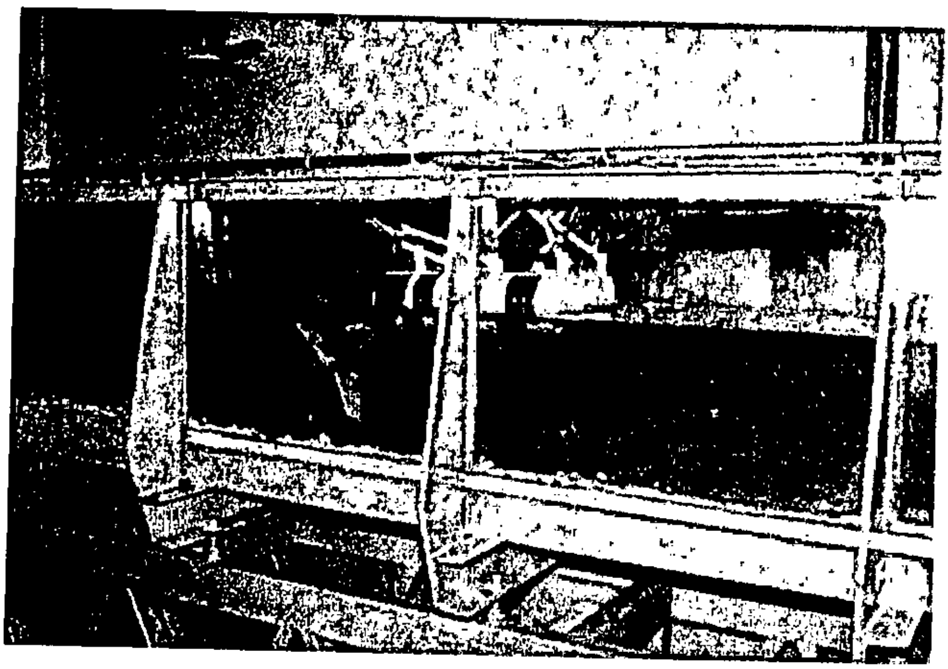


Figure 5.7 Turbine Model in the Flume

Chapter 6 : PERFORMANCE ANALYSIS

In analyzing the rotor performance, an important parameter that comes in front is the tip speed ratio (TSR) which is used in setting the correct transmission ratio. It is the ratio of the free stream velocity and the blade tip velocity. Mathematically,

$$TSR = \frac{velocity\ at\ the\ blade\ tip}{velocity\ of\ free\ stream}$$

$$Velocity\ at\ the\ blade\ tip = \frac{2\pi N R}{60}$$

$$\begin{aligned} where \quad & N = rpm\ of\ the\ rotor \\ & R = rotor\ radius \end{aligned}$$

The value of tip speed ratio depends on the type of rotor, the number of blades, and the load on it.

It has been mentioned earlier that the propeller type rotors operate on lift forces. The turbine blades having an airfoil cross section which when moves at an angle relative to the current direction, produces a lift force at right angles to the relative velocity of the water as seen from the blade. Figure 6.1 shows how the relative velocity is found by vector addition of the stream velocity and blade tip velocity.

As can be seen from Figure 6.1 the lift force acting on the blade can be resolved into two components: parallel and normal to the plane of rotation. The parallel component makes the rotor turn and the normal component bends the blade. The lift force is proportional to the angle of attack (α) up to the stall angle of the hydrofoil. As load is applied to the turbine, it slows down. This has the effect of increasing α (the angle between the blade chord and the velocity of water relative to the blade, V_R) and hence, increasing the lift force. As further load is applied, α increases until eventually it exceeds the stall angle of the hydrofoil section and that part of the blade no longer contributes to the power output of the rotor. Once large areas of the blades are in the stalled condition, the turbine simply stops. This is evident from Figures 6.2 (a), 6.2 (b) and 6.2 (c).

Figure 6.2 shows the performance curves for the turbine model. These curves are equivalent to power versus rotational speed curves but by plotting C_P vs. tip speed ratio curves become independent of river speed and therefore, more widely applicable.

From the curves of Figure 6.2 (a) it can be seen that the model consisting of NACA 4412 airfoil blades will run at tip speed ratios between 3.2 to 6 when the pitch angle is 5^0. But this operating region squeezes if the pitch angle is reduced to 0^0 i.e. the pitch angle is absent in this case. This is also true for the Figure 6.2 (b) where the range of tip speed ratio for turbine operation is 0.7 to 3.5.

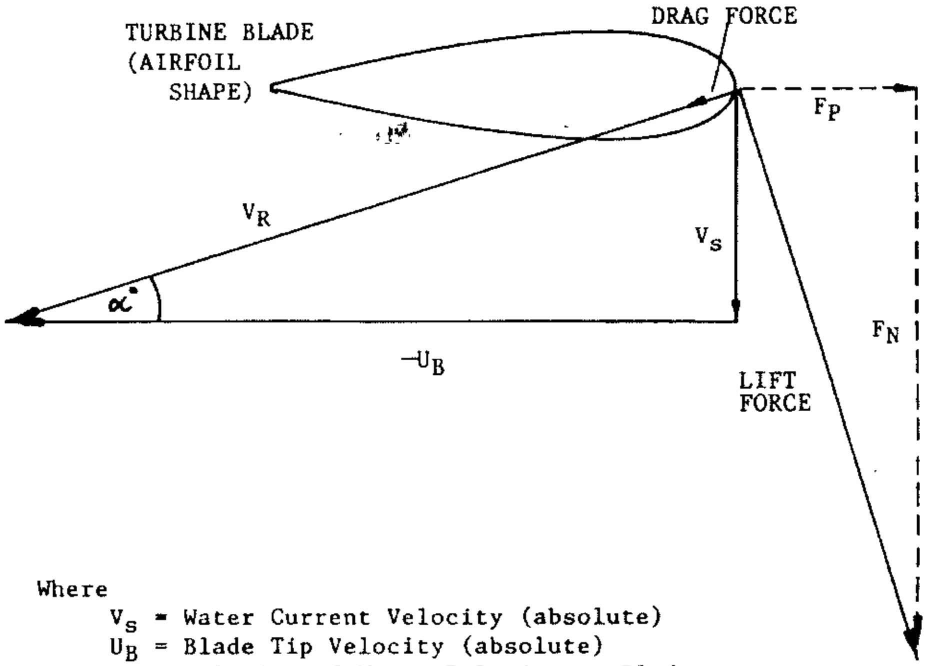
At a very low water velocity power coefficient is not more than 15% giving no pitch angle. If a pitch angle is introduced, then C_P will increase but at the same time the operating range will decrease. This is apparent in Figure 6.2 (b). To obtain the maximum power output from a rotor it should be loaded until it is running as close to the tip speed ratio for maximum C_P.

Figure 6.3 (a), 6.3 (b) and 6.3 (c) show the power generated by the rotor at different tip speed ratio at 0.65 m/s, 0.25 m/s and 0.43 m/s water velocity respectively for both 0^0 and 5^0 pitch angles. The generated power is very low (less than 0.5 watt) when the velocity is 0.25 m/s but when it is 0.65 m/s the output power increases sharply. It should be mentioned here that the average rotor radius is taken as 221 mm in input power calculation.

Due to the change of water velocity the change rpm at no load conditions has been shown in Figure 6.4. No doubt the rpm would be higher at a particular water current velocity when a pitch angle is introduced at the rotor blade.

Increase of input power with the increase of water velocity has been shown in Figure 6.5. Power input changes in cube with the water velocity.

Figure 6.6 shows the velocity profile in the flume. The velocity is zero at the bottom surface of the flume. While moving upward from the surface the velocity increases and it is constant at the boundary layer. But again the velocity decreases at the upper surface of the water.



Where

V_S = Water Current Velocity (absolute)
U_B = Blade Tip Velocity (absolute)
V_R = Velocity of Water Relative to Blade
F_P = Component of Lift Force in Plane of Rotor Rotation
F_N = Component of Lift Force Normal to Plane of Rotor Rotation

Figure 6.1 Airfoil Hydrodynamics

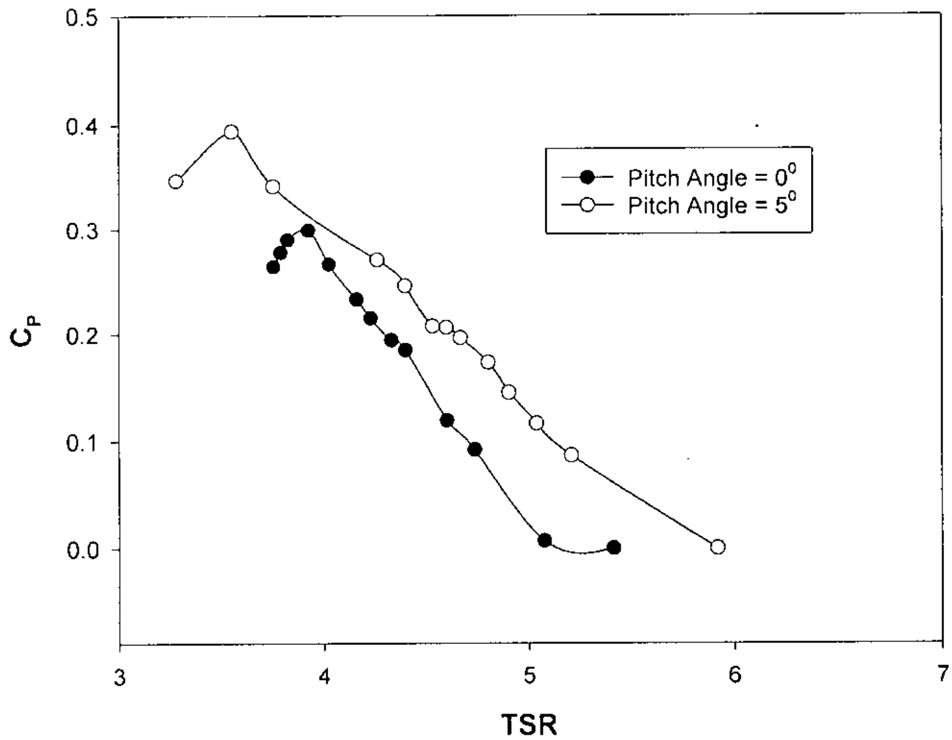


Figure 6.2 (a) C_P vs. TSR at water velocity of 0.65m/s for the pitch angle of 0^0 and 5^0

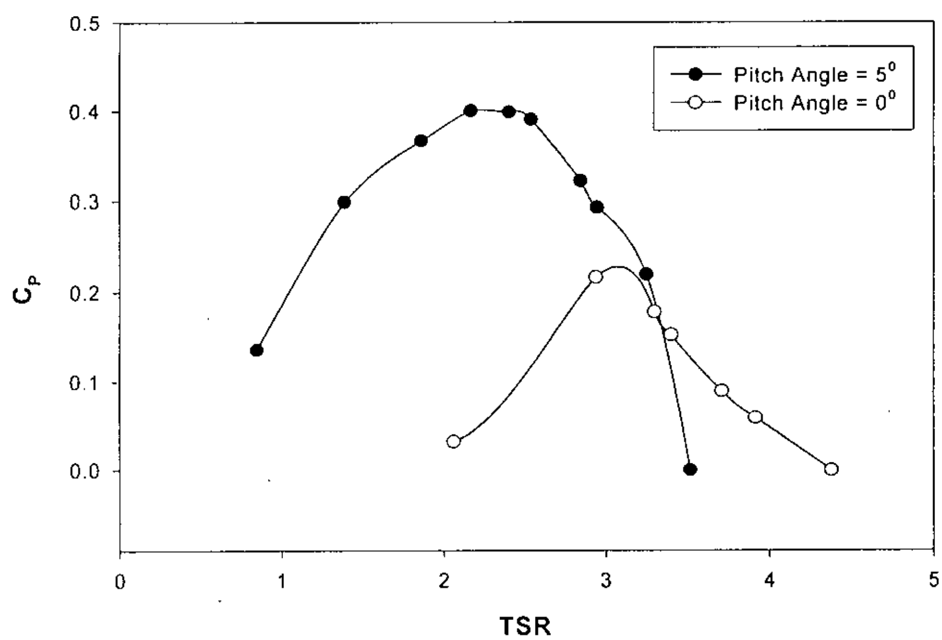


Figure 6.2 (b) C_p Vs. TSR at the water velocity of 0.43 m/s for the pitch angle of 0^0 and 5^0

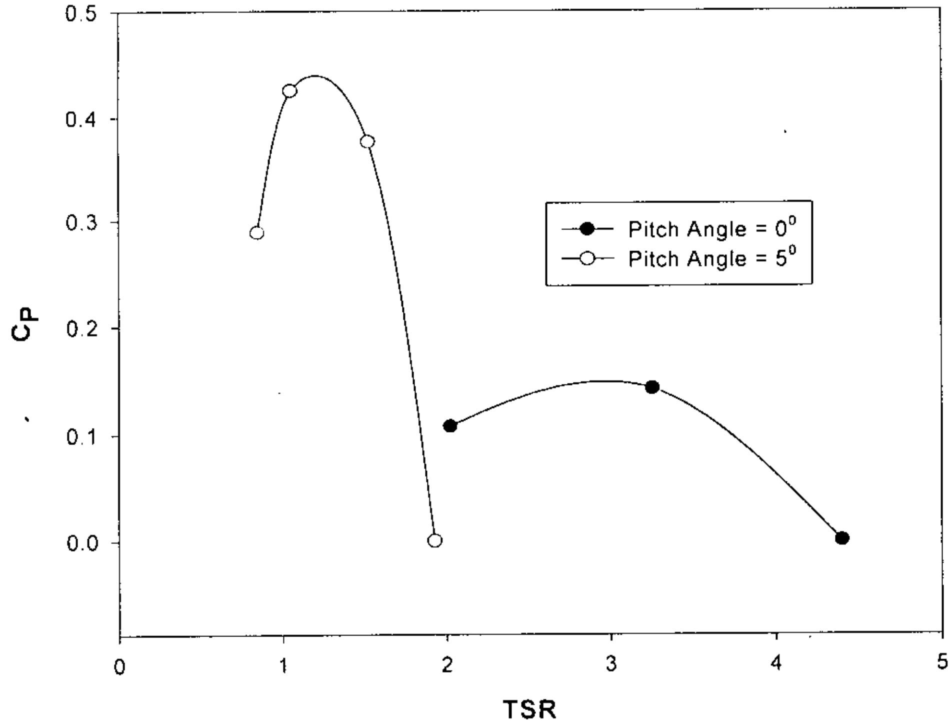


Figure 6.2 (c) C_P vs. TSR at water velocity of 0.25m/s for the Pitch Angle of 0^0 and 5^0

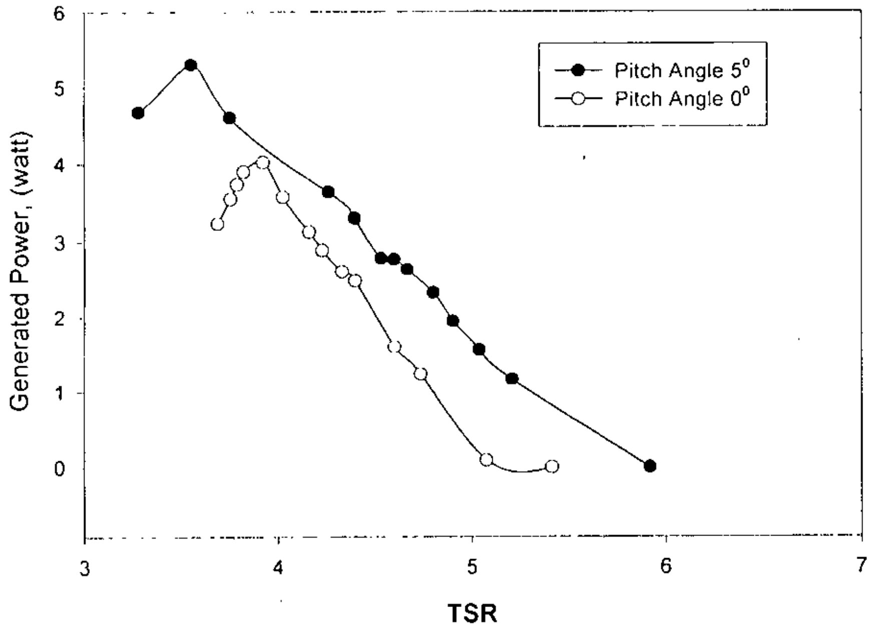


FIGURE 6.3 (a) Generated Power vs. TSR at the Water Velocity of 0.65 m/s

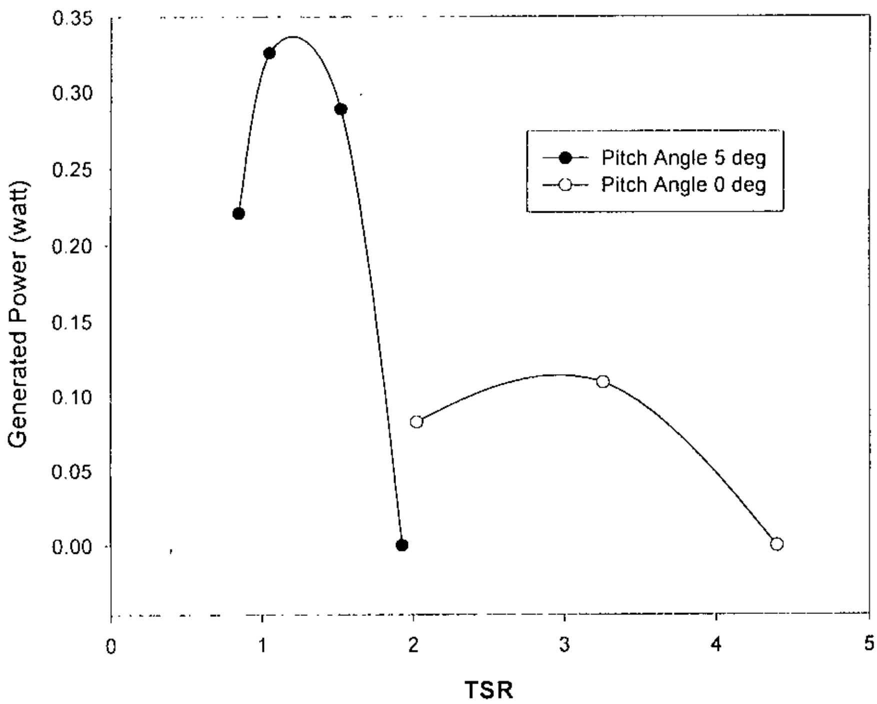


FIGURE 6.3 (b) Generated Power Vs. TSR at the Water Velocity of 0.25 m/s

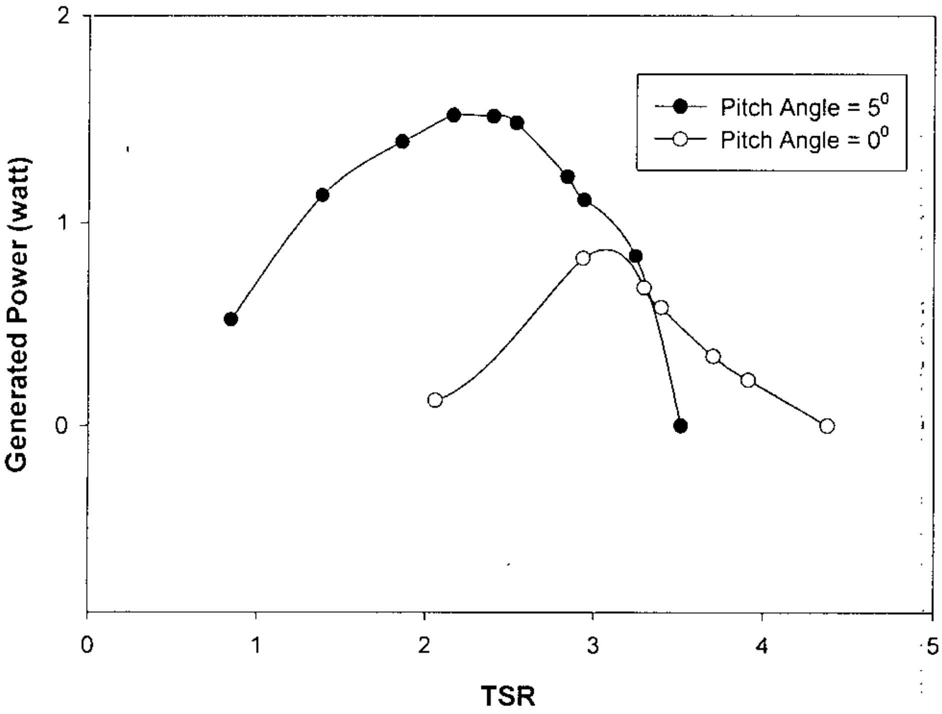


Figure 6.3 (c) Generated Power Vs. TSR at the Water Velocity of 0.43 m/s

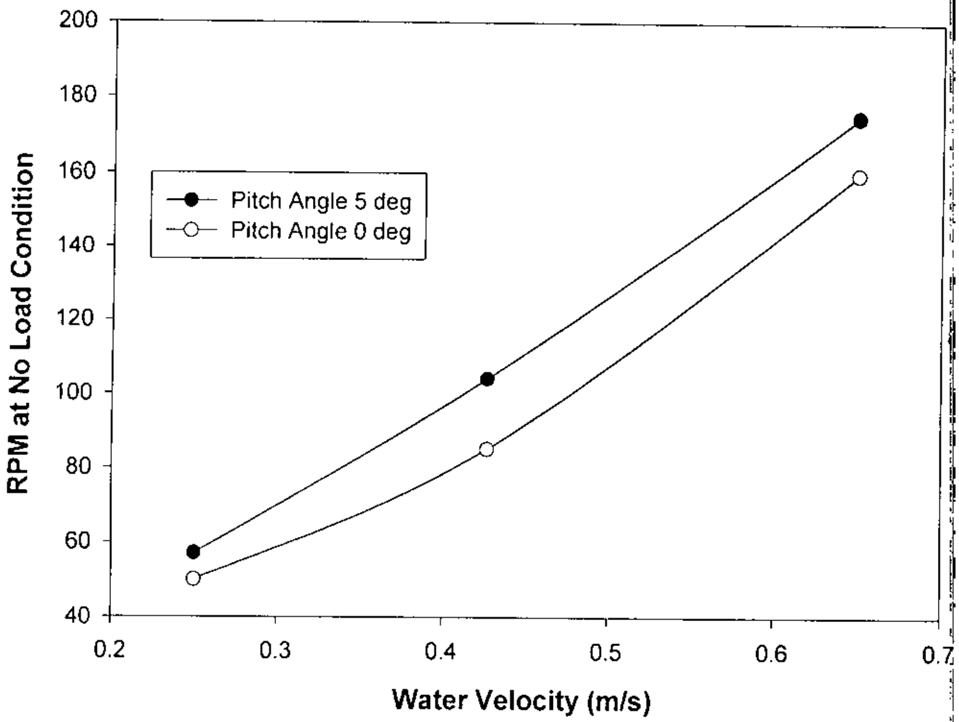


FIGURE 6.4 Change of rpm of the rotor at no load condition due to change of water velocity

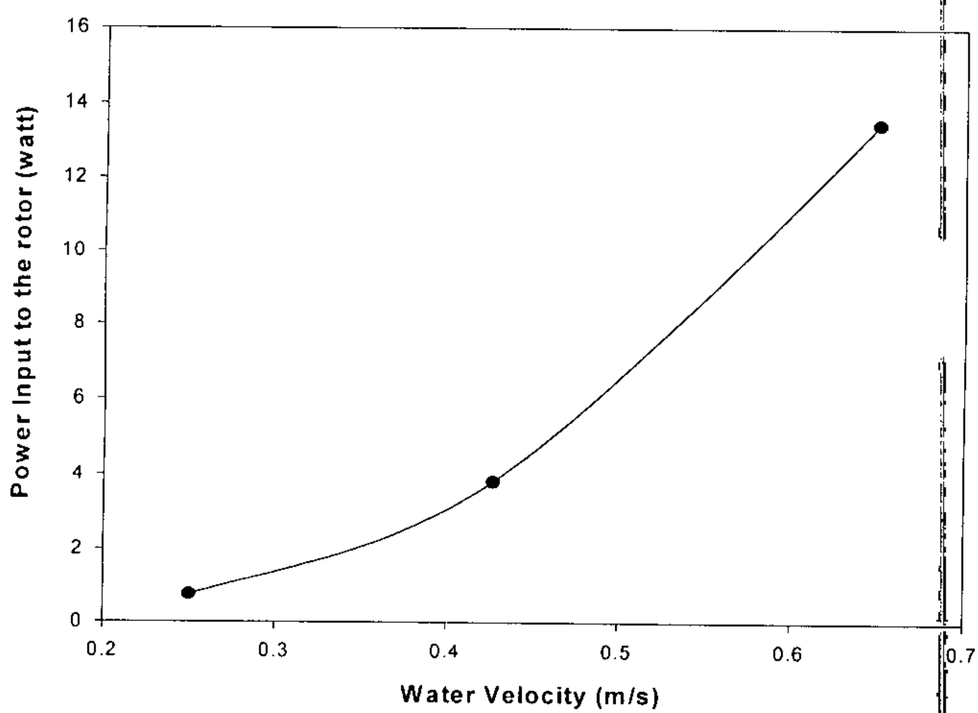


FIGURE 6.5 Input Power to the Rotor vs. Water Velocity

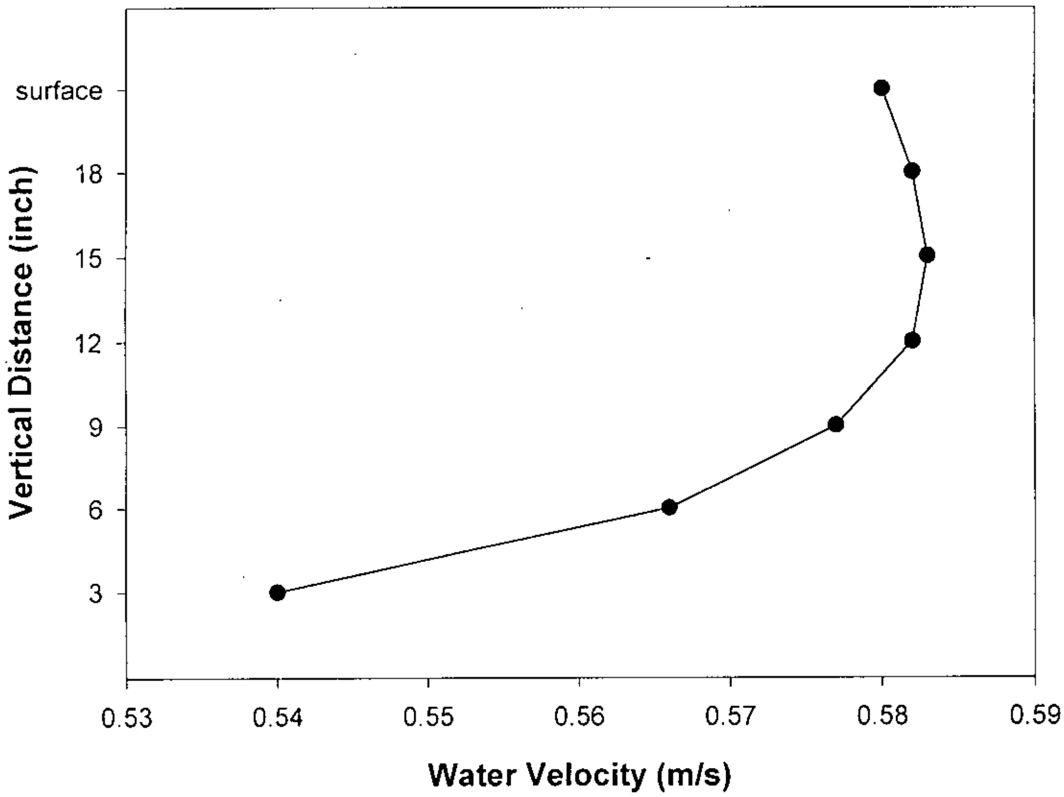


Figure 6.6 Water Velocity Profile in the Flume

Chapter 7 : COST ESTIMATION

Cost of Power Generated by the Water Current Turbine Model

There are three main aspects to the socio-economic appraisal of the water current turbines for power generation. These are:

(i) **economic analysis**- to establish the maximum costs above which water current turbines are unlikely to be economically attractive to the consumers;

(ii) consideration of social factors; and

(iii) if they do appear to the economically viable and socially acceptable, then the systematic comparison of water current turbines with alternative renewable energy systems technology to determine which system is likely to be the most socially acceptable and constitute the best value for money.

But this section just focuses on the cost of manufacturing the water current turbine model and then estimates the cost of energy generated by the turbine model.

Table 7.1: Construction Cost of the Water Current Turbine Model

Item	Price
3 aerodynamic shaped blades	Tk. 500.00
Shaft, Hub and Bearings	Tk. 400.00
Floats	Tk. 100.00
Flat bars	Tk. 50.00

12V DC Generator and Transmission Mechanism	Tk. 400.00
Manufacturing Cost	Tk. 450.00
Others	Tk. 200.00
Total	Tk. 2100.00

Water Current Turbine size:

Rotor Radius	223mm
Blade Length	170mm
Water Velocity	0.65m/s
Shaft Inclination	45^0
Swept Area	$0.1104m^2$
Pitch Angle	5^0

The generated power by the model is 5.3 watt while the tip speed ratio is 3.55. Then

$$\text{Cost of Power} = \frac{Tk.2100.00}{5.3\,watt} = \text{Tk. 396.00 per watt}$$

$$\text{Cost of Energy} = \frac{Tk2100.00}{\left(\frac{5.3}{1000}x\,3600\right)kWh} = \text{Tk. 110.00 per kWh}$$

Unit energy cost is highly sensitive to water current speed. This has been shown in figure 7.1 (considering C_P =0.39). The plot shows that increase of water current velocity decreases the cost of energy dramatically.

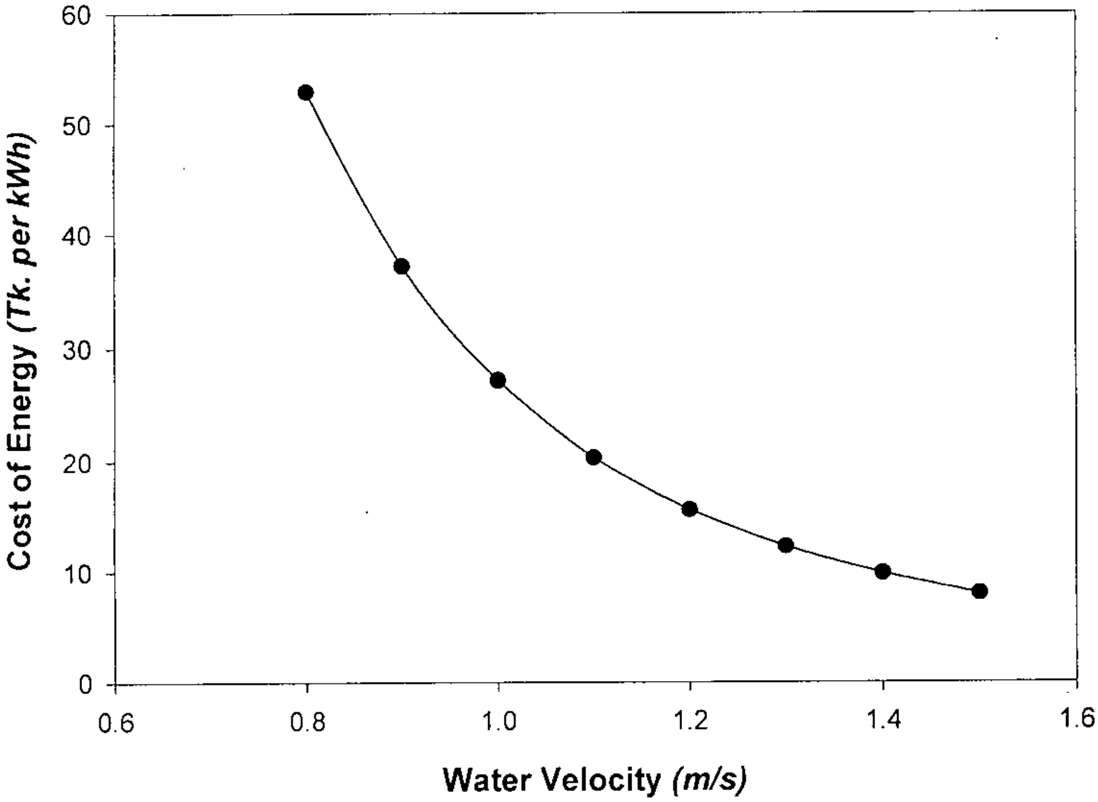


Figure 7.1 Variation of Energy Cost with Water Velocity

The data has been given in appendix H.

Chapter 8 : CONCLUSION

It has been mentioned earlier that the water current turbine can be thought of as an under water windmill which floats on the surface of a river with the rotor completely submerged. It requires neither dams nor diversion of a portion of the water flow. It is teetered in free stream in a river or canal and extracts a portion of the kinetic energy from the moving water. Mooring is from one bank only and so navigation in the river or canal is not affected.

At the end of the thesis the following conclusions can be made:

From the analysis of river current data for different stations at different rivers, it is clear that the rivers in Hill tracts and Sylhet (South East and North East region of Bangladesh) are highly potential for power generation in small scale. Some of the rivers in northwest part of Bangladesh are moderately potential having a river current velocity in a range of 0.5 m/s to 0.8 m/s. The rivers in the southern part of Bangladesh could not be considered in this analysis due to unavailability of data.

From the performance analysis of the model it is evident that the water current turbine is not feasible for very low water velocity. The turbine is suggested for the water velocity of not less than 0.45m/s.

At 0.25m/s the available water power at the turbine rotor with an inclination of 45^0 is 17watt considering the rotor radius is 1m. If C_P is 0.3 the power output will be about 5 watt. But for the same turbine working under the water velocity of 0.45 m/s the available power will be 101watt and the power output will be 30 watt.

Generally speaking, it is desirable to select as high speed a rotor as possible, because the faster the loaded rotor turns the cheaper will be the transmission. Reducing the number of blades or the blade chord length tends to increase the rotational speed, but smooth running and structural considerations set minimums for both these variables.

Finally, the following suggestions can be considered for further investigations:

(i) The river current velocity of other rivers in Bangladesh especially in the southwest part can be studied for selecting the favorable sites for power extraction with the help of this small-scale power-generating turbine.

(ii) Automatic variable pitch reaction turbine can be studied for further improvement of the water current turbine.

(iii) Performance of low cost blade profile (circular arc profile) can also be studied. Because this type of blade shows that their performance is as close as to that of other airfoil shaped wind turbine blades.

(iv) Blades having twist angle can be investigated for the improvement of performance of the turbine.

(v) The design of the pontoon may be given an aerodynamic shape, which will reduce the drag loss.

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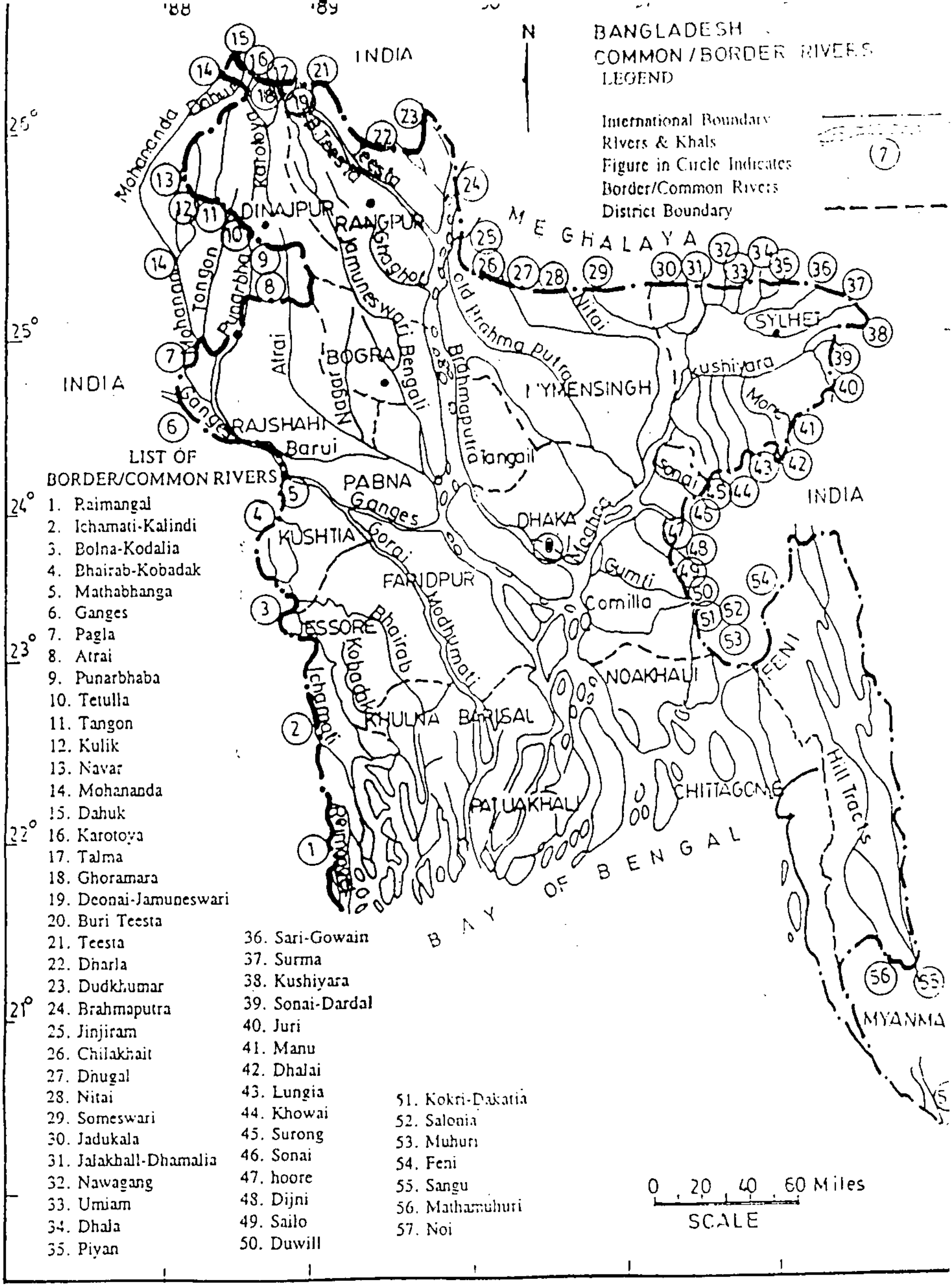
Appendix A


BANGLADESH
COMMON / BORDER RIVERS
LEGEND
International Boundary
Rivers & Khals
Figure in Circle Indicates
Border/Common Rivers
District Boundary
N
INDIA
MEGHALAYA
INDIA
INDIA
MYANMA
BAY OF BENGAL
DINAJPUR
RANGPUR
BOGRA
RAJSHAHI
PABNA
MYMENSINGH
SYLHET
KUSHTIA
FARIDPUR
DHAKA
Comilla
JESSORE
KHULNA
BARISAL
NOAKHALI
PATUAKHALI
CHITTAGONG
Tangail
Hill Tracts
Mohananda
Dahuk
Karotoya
Teesta
Tongon
Punarbhaba
Atrai
Nagar
Jamuneswari
Ghaghot
Bengali
Brahmaputra
Old Brahmaputra
Nitai
Kushiyara
Manu
Sonai
Ganges
Barui
Gorai
Meghna
Gumti
Bhairab
Kobadak
Madhumati
Ichamati
Raimangal
Feni
25°
25°
24°
23°
22°
21°
LIST OF BORDER/COMMON RIVERS
1. Raimangal
2. Ichamati-Kalindi
3. Bolna-Kodalia
4. Bhairab-Kobadak
5. Mathabhanga
6. Ganges
7. Pagla
8. Atrai
9. Punarbhaba
10. Tetulla
11. Tangon
12. Kulik
13. Navar
14. Mohananda
15. Dahuk
16. Karotoya
17. Talma
18. Ghoramara
19. Deonai-Jamuneswari
20. Buri Teesta
21. Teesta
22. Dharla
23. Dudkhumar
24. Brahmaputra
25. Jinjiram
26. Chilakhait
27. Dhugal
28. Nitai
29. Someswari
30. Jadukala
31. Jalakhall-Dhamalia
32. Nawagang
33. Umiam
34. Dhala
35. Piyan
36. Sari-Gowain
37. Surma
38. Kushiyara
39. Sonai-Dardal
40. Juri
41. Manu
42. Dhalai
43. Lungia
44. Khowai
45. Surong
46. Sonai
47. hoore
48. Dijni
49. Sailo
50. Duwill
51. Kokri-Dakatia
52. Salonia
53. Muhuri
54. Feni
55. Sangu
56. Mathamuhuri
57. Noi
0 20 40 60 Miles
SCALE

Appendix B

Rivers of Bangladesh showing location and length*

Sl. No.	*Rivers*	*Location*	*Length (km)*
1	Algi	Barisal	9.7
2	Alipur-Daratana-Ghasiakhali	Khulna	74.0
3	Amua	Barisal	0.0
4	Anderson Khal	Comilla	4.8
5	Atrai	Faridpur, Barisal	160.9
6	Bahia	Sylhet	69.2
7	Baliatali	Barisal	22.5
8	Balu	Dhaka	45.1
9	Banar	Mymensingh, Dhkaka	162.5
10	Bangali	Rangpur, Bogra	93.3
11	Bamoshi	Mymensingh, Dhkaka	238.1
12	Baral	Pabna, Rajshahi	146.4
13	Barisal Buriswar	Khulna, Barisal	157.7
14	Bogabati	Jessore	72.4
15	Betna-Kholpetua	Jessore, Khulna	191.5
16	Bhadra	Jessore, Khulna	193.1
17	Bhairab (lower)	Jessore, Khulna	159.3
18	Bhairab (upper)	Kushtia	88.5
19	Bhattakhal	Sylhet	38.6
20	Bhogai-Kangsa	Mymensingh	225.3
21	Bishkhali	Barisal	96.5
22	Bogkhali	Chittagong	57.9
23	Brhamaputra-Jamuna	Rangpur, Pabna, & Mymensingh	276.7
24	Buriganga	Dhaka	43.4
25	Burikhora-Chiki	Rangpur	38.6
26	Burungail Khal	Dhaka	0.0
27	Chandana-Arkandi	Faridpur	77.2
28	Chellakhali	Mymensingh	38.6
29	Chitra	Kustia, Jessore	170.6
30	Dahuk	Dinajpur	12.9
31	Dakatia	Comilla, Noakhali	207.6
32	Dauki (spill from Piyan)	Sylhet	12.9
33	Daurchar Kajal	Barisal	53.1
34	Dhalai	Sylhet	40.2
35	Dhaleswari	Mymensingh, Dhaka	160.9

36	Dhanu-Boulai-Ghorautra	Mymensingh, Sylhet	234.9
37	Dharla	Rangpur	72.4
38	Dhepa	Dinajpur	45.1
39	Dhonogoda	Comilla	45.1
40	Dhulia	Barisal	16.1
41	Dhurang	Chittagong	49.9
42	Doani-Charalkata-Jamuneweswari-Karatoa	Rangpur, Bogra, & Pabna	450.5
43	Dudhkumar	Rangpur	41.8
44	Fakirni-Barnai	Rajshahi	74.0
45	Feni	Chittagong, Noakhali	82.1
46	Ganges	Rajshahi, Pabna, Faridpur, & Dhaka	374.9
47	Gazikhali	Dhaka	38.6
48	Ghagat	Rangpur	236.5
49	Ghior	Dhaka	51.5
50	Ghoramara	Dinajpur	12.9
51	Godai (spill from Musakhan)	Rajshahi	29.0
52	Golkhali Khal	Barisal	17.7
53	Gopaldi	Barisal	24.1
54	Gorai-Modhumati-Baleswar	Kustia, Faridpur, Jessore, Khulna, & Barisal	371.7
55	Gumti-Burinadi	Comilla	133.5
56	Halda	Chittagong	104.6
57	Hatia (Bay of Bengal)	Chittagong	90.1
58	Hawra	Comilla	12.9
59	Ichamati (Tributary of Karnafuli)	Chittagong	33.8
60	Ichamati (Western Boundary) Ichamati (Spill from Ganges)	Khulna, Pabna	38.6
61	Ichamoti (out fall of Bangali)	Bogra	53.1
62	Jadukata	Sylhet	19.3
63	Jamuna	Dinajpur, Bogra, & Rajshahi	207.6
64	Jangalia-Kauakhali	Barisal	35.4
65	Jhenai	Mymensingh	120.7
66	Juri	Sylhet	16.1
67	Kacha	Barisal	33.8
68	Kakua	Barisal	29.0

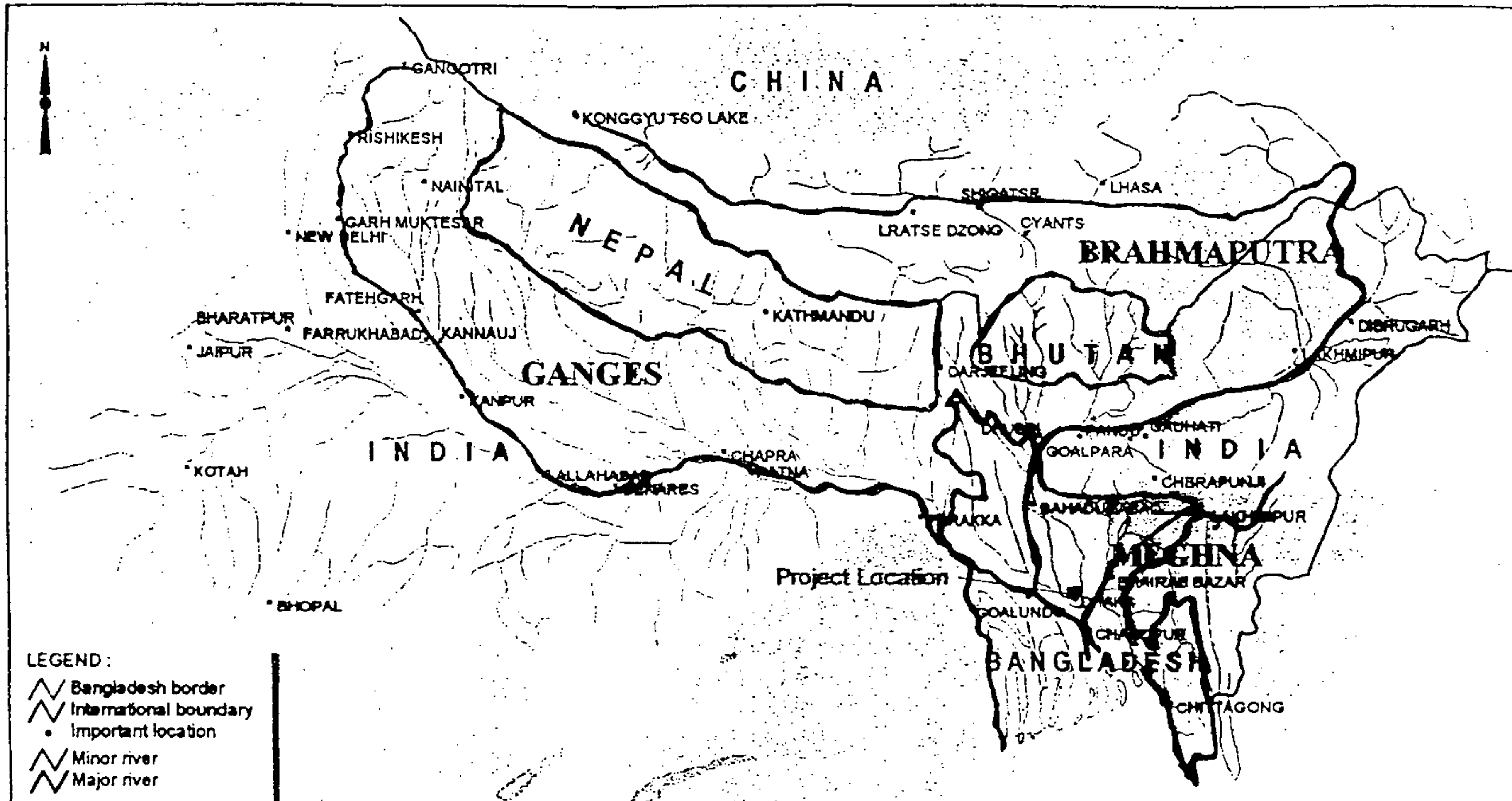
69	Kalagachia Don	Barisal	8.0
70	Kalaia	Barisal	11.3
71	Kaliganga-Botchua	Dhaka	35.4
72	Karangi	Sylhet	41.8
73	Karatoa-Atrai-Gurgumanai-Hurasagar	Dinajpur, Rajshahi, & Pabna	596.9
74	Karkhana	Barisal	25.7
75	Karnafuli	Chittagong, Chittagong Hill Tracts	123.9
76	Karnapara Khal	Dhaka	6.4
77	Katakhali	Rangpur	27.4
78	Khagdon	Barisal	24.1
79	Khajanchi Nadi (spill from Surma)	Sylhet	32.2
80	Kharuvaj	Rangpur	24.1
81	Khukhuria	Dinajpur	61.1
82	Khowai	Sylhet	57.9
83	Kobadakh	Jessore, Khulna	259.0
84	Korom	Dinajpur	19.3
85	Kumar	Faridpur	162.5
86	Kumar	Jessosre, Khulna	144.8
87	Kushiyara	Sylhet	228.5
88	Kutubdia Channel	Chittagong	32.2
89	Lakhya	Dhaka	72.4
90	Little-feri-Dakatia	Noakhali, Comilla	194.7
91	Lohalia	Barisal	67.6
92	Lohaganj	Mymensingh	77.2
93	Lower Kumer	Faridpur	22.5
94	Lungla	Sylhet	45.1
95	Madaripur Beel Route	Faridpur	51.5
96	Madhapur Khal (spill from Surma)	Sylhet	8.0
97	Manu	Sylhet	70.8
98	Mahasingh	Sylhet	32.2
99	Mogra	Mymensingh	128.7
100	Moheshkhali channel	Chittagong	37.0
101	Matamuhuri	Chittagong	122.3
102	Mahtabhanga	Kushtia, Rajshahi	156.1
103	Mohananda	Rajshahi	90.1
104	Muhuri	Noakhali	67.6

105	Muradia Don	Barisal	20.9
106	Mushakhan	Rajshahi	32.2
107	Nabaganga	Kushtia, Jessore	231.7
108	Naf	Chittagong	64.4
109	Nagar	Rajshahi, Bogra	127.1
110	Nangoora	Pabna	53.1
111	Nilokhi	Barisal	61.1
112	Nitai	Mymensingh	35.4
113	Noakhali Khal	Noakhali	51.5
114	Old Brahmaputra	Mymensingh	276.7
115	Pancha Korolia	Barisal	25.7
116	Pandah Nehalganj	Barisal	45.1
117	Pathraj	Dinajpur	61.1
118	Patuakhali river	Barisal	12.9
119	Piyan	Sylhet	54.7
120	Punarbhaba	Dinajpur, Rajshahi	160.9
121	Rahmatkhali Khal	Noakhali	38.6
122	Ramnagar-Kanakhdia	Barisal	20.9
123	Rupsa-Pasur	Khulna	141.6
124	Sadakhal (Kushiara Surma spill)	Sylhet	9.7
125	Sangu	Chittagong, Chittagong Hill Tracts	173.8
126	Sari-Gowain	Sylhet	67.6
127	Sarupkhati	Barisal	38.6
128	Satkhira Khal-Maricap Sakalia-Guntia Kali-Galagasia	Khulna	64.4
129	Selonia	Noakhali	45.1
130	Sipsa	Khulna	101.4
131	Siva-Barnai-Gurnai	Rajshahi	141.6
132	Someswari	Mymensingh	112.6
133	Sonai	Sylhet	24.1
134	Sonai-Bardal	Sylhet	48.3
135	Srimanta	Barisal	32.2
136	Surjamani Khal	Barisal	6.4
137	Surma-Meghna	Barisal, Comilla, & Sylhet	669.3
138	Sutang	Sylhet	56.3
139	Talma	Dinajpur	32.2
140	Tangon	Dinajpur	135.2

141	Tentulia	Barisal	83.7
142	Teesta	Rangpur	112.6
143	Tiakhali-Dhankhali Don	Barisal	51.5
144	Titas	Comilla	54.7
145	Tongi Khal	Dhaka	16.1
146	Torki	Barisal	27.4
147	Turag	Dhaka	70.8

* Source: Department of Water Resource Engineering, Bangladesh University of Engineering and Technology, Dhaka-1000, Bangladesh.

Appendix C



The Ganges, The Brahmaputra and The Meghna River Basin

Appendix D

The Ganges at Hardinge Bridge							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
1996	Jan						
	Feb						
	Mar						
	Apr	0.0945	4.945	0.0717	4.69	0.0831	0.1764
	May	0.1821	7.09	0.0949	5.22	0.1385	0.2327
	Jun	0.2841	5.81	0.1794	6.73	0.23175	0.5440
	Jul	2.0392	13.395	0.7683	9.84	1.40375	2.8243
	Aug	2.6557	13.93	1.3385	11.43	1.9971	3.3292
	Sep	3.1378	14.49	0.9413	10.39	2.03955	3.8353
	Oct	1.4784	12.11	0.6675	10.01	1.07295	2.0168
	Nov	0.6294	9.9	0.3829	8.48	0.50615	0.9339
	Dec	0.3723	8.41	0.2577	7.59	0.315	0.5733

The Ganges at Hardinge Bridge							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
1997	Jan	0.2638	7.21	0.1566	6.46	0.2102	0.3975
	Feb	0.1754	6.46	0.0822	5.86	0.1288	0.2869
	Mar	0.1089	5.80	0.0261	5.19	0.0675	0.1735
	Apr	0.17	6.01	0.0474	5.11	0.1087	0.2371
	May	0.1148	5.80	0.0828	5.65	0.0988	0.1990
	Jun	0.3394	8.105	0.1080	5.885	0.2237	0.6274
	Jul						
	Aug						
	Sep						
	Oct						
	Nov	0.6184	8.95	0.4893	8.395	0.55385	0.9277
	Dec	0.7937	9.82	0.4064	8.08	0.60005	0.9584

The Ganges at Hardinge Bridge							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
1998	Jan	0.5621	8.635	0.3402	7.04	0.45115	0.6997
	Feb	0.3993	6.52	0.2236	5.82	0.31145	0.4629
	Mar	0.2274	5.735	0.1870	5.365	0.2072	0.3003
	Apr	0.2849	6.040	0.2019	5.515	0.2434	0.3738
	May	0.3344	7.343	0.2817	6.193	0.30805	0.4028
	Jun	0.5607	9.62	0.3428	7.488	0.45175	0.8018
	Jul	2.6638	13.74	0.9381	10.88	1.80095	3.0253
	Aug	3.2980	14.8	2.5546	13.395	2.9263	3.6485
	Sep	3.3240	15.19	1.3392	12.26	2.3316	3.7220
	Oct	1.4276	12.535	0.9677	11.455	1.19765	2.01683
	Nov	1.0144	11.73	0.5109	9.365	0.76265	1.4305
	Dec	0.4688	8.87	0.2708	7.465	0.3698	0.7884

The Ganges at Hardinge Bridge							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
1999	Jan	0.2698	7.29	0.2304	6.94	0.2501	0.3351
	Feb	0.2281	6.875	0.1614	5.9	0.19475	0.2634
	Mar	0.1649	5.855	0.1219	5.31	0.1434	0.2175
	Apr	0.1521	5.22	0.1104	5.115	0.13125	0.1952
	May	0.2446	6.795	0.1234	5.69	0.184	0.2962
	Jun	0.6882	10.175	0.2549	6.875	0.47155	0.8948
	Jul	1.6849	12.66	1.0449	11.605	1.3649	2.344
	Aug	2.9427	14.085	2.2159	13.535	2.5793	3.7610
	Sep	3.2864	14.385	2.8026	13.54	3.0445	3.7873
	Oct	2.224	13.075	1.2431	11.92	1.73355	2.9144
	Nov	0.9775	11.245	0.3901	8.66	0.6838	1.1527
	Dec						

The Gorai River at Gorai Bridge							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
1997	Jan						
	Feb						
	Mar						
	Apr						
	May						
	Jun	0.4272	5.985	0.403	5.990	0.4151	0.5914
	Jul						
	Aug						
	Sep						
	Oct						
	Nov	0.9293	6.525	0.8987	6.70	0.914	1.4114
	Dec	1.0767	6.605	0.6780	6.27	0.87735	1.2370

The Gorai River at Gorai Bridge							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
1998	Jan	0.6655	6.17	0.4392	5.475	0.55235	1.0625
	Feb	0.6293	5.0			0.6293	
	Mar						
	Apr						
	May						
	Jun	0.5158	7.16	0.4534	6.82	0.4846	0.7696
	Jul	1.4805	11.615	0.8388	8.185	1.15965	2.2446
	Aug	1.4820	13.15	1.2414	11.87	1.3617	2.3152
	Sep	1.5555	13.43	0.7136	9.94	1.13455	2.1386
	Oct	0.9334	9.125	0.6706	8.485	0.802	1.5320
	Nov	1.4988	7.11	0.9587	8.755	1.22875	2.1217
	Dec	1.5305	6.48	0.9223	4.85	1.2264	2.0125

The Gorai River at Gorai Bridge							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
1999	Jan	0.9988	5.88	0.887	5.66	0.9429	1.2699
	Feb	0.2330	5.29	0.1608	5.445	0.1969	0.4050
	Mar	0.2046	4.63	0.2031	4.77	0.20385	0.3307
	Apr	0.2000	4.58	0.1934	4.45	0.1967	0.3089
	May	0.2757	5.06	0.2148	4.81	0.24525	0.4749
	Jun	1.2025	9.085	0.4880	6.235	0.84525	1.6849
	Jul	1.5815	11.100	1.3528	11.13	1.46715	2.1086
	Aug	1.6178	12.305	1.3456	11.35	1.4817	2.3620
	Sep	1.8367	12.445	1.4507	11.85	1.6437	2.3096
	Oct	1.0441	10.74	0.8828	9.92	0.96345	1.6456
	Nov	0.7544	9.054	0.6719	7.59	0.71315	1.1738
	Dec	1.0816	6.82	0.7531	6.285	0.91735	1.2262

The Gorai River at Gorai Bridge							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
2000	Jan	0.8074	5.885	0.7881	5.455	0.79775	1.0864
	Feb	0.7240	5.34	0.6874	5.03	0.7057	0.9991
	Mar	0.5377	4.88	0.5099	4.61	0.5238	0.6625
	Apr						
	May						
	Jun						
	Jul						
	Aug						
	Sep						
	Oct						
	Nov						
	Dec						

The Atrai River at Singra							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
1997	Jan						
	Feb						
	Mar						
	Apr						
	May						
	Jun						
	Jul	0.549	12.52			0.549	0.988
	Aug	0.521	11.98	0.402	11.39	0.4615	0.941
	Sep	0.583	11.99	0.509	11.93	0.546	0.941
	Oct	0.403	11.14	0.366	11.85	0.3845	0.824
	Nov	0.280	10.58	0.197	9.95	0.2385	0.471
	Dec	0.093	9.06	0.076	8.79	0.0845	0.189

The Atrai River at Singra							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
1998	Jan						
	Feb						
	Mar						
	Apr						
	May						
	Jun						
	Jul	0.940	12.935	0.432	12.060	0.686	1.159
	Aug	0.952	12.74	0.911	12.93	0.9315	1.159
	Sep	0.814	12.82	0.810	12.78	0.812	1.159
	Oct	0.570	11.81	0.278	11.22	0.424	0.928
	Nov	0.370	11.080	0.282	10.57	0.326	0.697
	Dec	0.200	10.10	0.094	9.47	0.147	0.466

The Atrai River at Singra							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
1999	Jan						
	Feb						
	Mar						
	Apr						
	May						
	Jun	0.0247	8.965			0.0247	0.0458
	Jul	0.8513	12.715	0.2007	10.92	0.526	1.2515
	Aug	0.7125	12.425	0.5537	11.89	0.6331	0.8357
	Sep	0.7383	12.84	0.7123	12.83	0.7253	1.0505
	Oct						
	Nov						
	Dec						

The Mohananda River at Chapainawabgonj							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
1997	Jan						
	Feb						
	Mar						
	Apr						
	May						
	Jun						
	Jul	0.206	20.15			0.206	0.283
	Aug	0.226	20.75	0.21	18.99	0.218	0.354
	Sep	0.429	19.96	0.268	19.64	0.3485	0.706
	Oct	0.207	16.85	0.167	15.17	0.187	0.354
	Nov						
	Dec						

The Mohananda River at Chapainawabgonj							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
1998	Jan						
	Feb						
	Mar						
	Apr						
	May						
	Jun						
	Jul	0.425	20.6	0.137	16.95	0.281	0.812
	Aug	0.338	21.075	0.265	21.795	0.3015	0.604
	Sep	0.657	22.07	0.099	22.62	0.378	1.112
	Oct	0.411	18.3	0.383	18.425	0.397	0.697
	Nov	0.190	15.37	0.189	16.24	0.1895	0.35
	Dec	0.138	14.6	0.093	13.99	0.1155	0.281

The Mohananda River at Chapainawabgonj							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
1999	Jan						
	Feb						
	Mar						
	Apr						
	May						
	Jun	0.1940	14.39	0.1932	13.27	0.1936	0.3230
	Jul	0.6781	19.93	0.2689	17.93	0.4735	0.9466
	Aug	0.7246	21.425	0.6550	20.330	0.6898	1.0090
	Sep	0.7636	22.38	0.7319	21.48	0.74775	1.1129
	Oct						
	Nov						
	Dec						

The Atrai River at Nowhata							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
1997	Jan						
	Feb						
	Mar						
	Apr						
	May						
	Jun						
	Jul	0.463	14.2			0.463	0.66
	Aug	0.436	14.00	0.42	14.05	0.428	0.824
	Sep	0.525	14.71	0.47	14.71	0.4975	0.706
	Oct	0.471	13.51	0.393	14.11	0.432	0.706
	Nov						
	Dec						

The Atrai River at Nowhata							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
1998	Jan						
	Feb						
	Mar						
	Apr						
	May						
	Jun						
	Jul	0.437	14.75			0.437	0.627
	Aug	0.366	14.165	0.333	14.65	0.3495	0.604
	Sep	0.377	14.88	0.344	14.91	0.3605	0.697
	Oct	0.306	14.51	0.251	13.94	0.2785	0.697
	Nov	0.273	14.11	0.085	13.01	0.179	0.512
	Dec						

The Atrai River at Nowhata							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
1999	Jan						
	Feb						
	Mar						
	Apr						
	May						
	Jun						
	Jul	0.2384	14.5	0.1965	14.56	0.21745	0.4546
	Aug	0.2314	14.165	0.1567	13.85	0.19405	0.4200
	Sep	0.2285	14.69	0.2201	14.54	0.2243	0.4477
	Oct						
	Nov						
	Dec						

The Mohananda River at Rohanpur							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
1997	Jan						
	Feb						
	Mar						
	Apr						
	May						
	Jun						
	Jul	0.424	21.06			0.424	0.589
	Aug	0.49	21.210	0.449	20.380	0.4695	0.706
	Sep	0.501	20.31	0.464	20.76	0.4825	0.941
	Oct	0.282	17.69	0.236	14.6	0.259	0.354
	Nov	0.2	15.14	0.156	14.76	0.178	0.330
	Dec						

The Mohananda River at Rohanpur							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
1998	Jan						
	Feb						
	Mar						
	Apr						
	May						
	Jun						
	Jul	0.434	21.05	0.279	16.945	0.3565	0.697
	Aug	0.612	23.580	0.311	22.35	0.4615	0.812
	Sep	0.651	24.3	0.54	21.79	0.5955	0.928
	Oct	0.667	19.84	0.51	19.35	0.5885	0.858
	Nov	0.304	16.88	0.185	15.92	0.2445	0.512
	Dec	0.125	15.17	0.077	14.58	0.101	0.235

The Mohananda River at Rohanpur							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
1999	Jan						
	Feb						
	Mar						
	Apr						
	May						
	Jun	0.0736	14.29	0.00	14.21	0.0368	0.1151
	Jul	0.2790	20.80	0.1788	18.14	0.2289	0.4546
	Aug	0.3363	22.080	0.2822	20.72	0.30925	0.5239
	Sep	0.3553	22.715	0.2727	22.25	0.314	0.4893
	Oct						
	Nov						
	Dec						

The Bengali River at Shimulbari							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
1997	Jan						
	Feb						
	Mar						
	Apr	0.095	13.165	0.085	13.040	0.09	0.142
	May	0.074	13.040	0.068	13.015	0.071	0.128
	Jun	0.566	15.0	0.114	13.24	0.34	0.675
	Jul	0.985	16.72	0.745	16.085	0.865	1.18
	Aug	0.581	15.885	0.394	14.96	0.4875	0.759
	Sep	0.937	16.485	0.91	16.345	0.9235	1.138
	Oct	0.572	15.785	0.239	14.505	0.4055	0.787
	Nov	0.183	14.10	0.155	13.81	0.169	0.24
	Dec	0.154	13.73	0.131	13.765	0.1425	0.184

The Bengali River at Shimulbari							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
1998	Jan	0.071	13.72	0.055	13.755	0.063	0.100
	Feb	0.117	13.548	0.081	13.267	0.099	0.184
	Mar						
	Apr						
	May						
	Jun						
	Jul						
	Aug						
	Sep						
	Oct						
	Nov						
	Dec						

The Bengali River at Shimulbari							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
1999	Jan						
	Feb						
	Mar						
	Apr						
	May						
	Jun						
	Jul	1.007	17.745	0.997	17.275	1.002	1.264
	Aug	0.984	17.28	0.914	16.32	0.949	1.222
	Sep	0.891	16.86			0.891	1.096
	Oct	0.969	17.69	0.540	15.565	0.7545	1.236
	Nov	0.468	15.165	0.194	13.85	0.331	0.661
	Dec						

The Bengali river at Khanpur							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
1997	Jan						
	Feb						
	Mar						
	Apr						
	May						
	Jun	0.439	8.7			0.439	0.563
	Jul	0.656	11.985	0.183	9.765	0.4195	0.857
	Aug	0.474	11.00	0.448	10.675	0.461	0.59
	Sep	0.668	11.875	0.613	11.39	0.6405	0.829
	Oct	0.485	10.885	0.178	9.2	0.3315	0.59
	Nov	0.252	8.67	0.171	8.59	0.2115	0.338
	Dec	0.198	8.63	0.164	8.55	0.181	0.240

The Bengali river at Khanpur							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
1998	Jan	0.198	8.62	0.154	8.51	0.176	0.240
	Feb	0.134	8.17	0.076	7.65	0.105	0.254
	Mar						
	Apr						
	May						
	Jun						
	Jul						
	Aug						
	Sep						
	Oct						
	Nov						
	Dec						

The Bengali river at Khanpur							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
1999	Jan						
	Feb						
	Mar						
	Apr						
	May						
	Jun						
	Jul	0.846	14.17	0.810	13.42	0.828	1.250
	Aug	0.789	13.365	0.622	11.99	0.7055	1.18
	Sep	0.752	13.555			0.752	1.222
	Oct	0.669	12.29	0.447	11.31	0.558	1.236
	Nov	0.333	10.415	0.192	8.905	0.2625	0.493
	Dec						

The Nagar River at Bogra							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
1997	Jan						
	Feb						
	Mar						
	Apr						
	May						
	Jun	0.041	11.38				0.072
	Jul	0.466	13.75	0.031	11.355	0.2485	0.618
	Aug	0.465	13.66	0.207	11.92	0.336	0.618
	Sep	0.512	14.085	0.328	12.72	0.42	0.675
	Oct	0.318	12.175	0.299	11.747	0.3085	0.45
	Nov	0.147	11.550	0.11	11.467	0.1285	0.226
	Dec	0.142	11.51	0.123	11.49	0.1325	0.226

The Nagar River at Bogra							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
1998	Jan	0.157	11.65	0.153	11.63	0.155	0.240
	Feb	0.086	11.493	0.01	11.165	0.048	0.142
	Mar						
	Apr						
	May						
	Jun						
	Jul						
	Aug						
	Sep						
	Oct						
	Nov						
	Dec						

The Nagar River at Bogra							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
1999	Jan						
	Feb						
	Mar						
	Apr						
	May						
	Jun						
	Jul	0.531	14.03	0.512	13.88	0.5215	0.787
	Aug	0.456	14.885	0.413	13.15	0.4345	0.634
	Sep	0.558	14.245	0.427	15.455	0.4925	0.787
	Oct	0.533	14.085	0.446	13.670	0.4895	0.787
	Nov						
	Dec						

The Bengali River at Mohimagonj							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
1997	Jan						
	Feb						
	Mar						
	Apr	0.312	13.736	0.297	13.686	0.3045	0.408
	May	0.284	13.671	0.282	13.656	0.283	0.38
	Jun	0.573	14.916	0.514	14.021	0.5435	0.681
	Jul	1.001	18.038	0.22	15.761	0.6105	1.166
	Aug	0.302	16.201	0.218	15.816	0.26	0.422
	Sep	0.4	17.256	0.363	18.911	0.3815	0.493
	Oct	0.293	16.186	0.185	15.091	0.239	0.408
	Nov	0.541	14.771	0.42	14.611	0.4805	0.675
	Dec	0.380	14.501	0.316	14.441	0.348	0.450

The Bengali River at Mohimagonj							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
1998	Jan	0.272	14.396	0.256	13.346	0.264	0.338
	Feb	0.120	14.216	0.077	14.046	0.0985	0.226
	Mar						
	Apr						
	May						
	Jun						
	Jul						
	Aug						
	Sep						
	Oct						
	Nov						
	Dec						

The Bengali River at Mohimagonj							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
1999	Jan						
	Feb						
	Mar						
	Apr						
	May						
	Jun						
	Jul	0.977	18.201	0.706	17.951	0.8415	1.194
	Aug	0.670	17.769	0.459	16.639	0.5645	0.885
	Sep	1.00	18.619	0.504	17.056	0.752	1.208
	Oct	0.924	18.096	0.462	16.466	0.693	1.152
	Nov	0.388	15.81	0.221	14.756	0.3045	0.493
	Dec						

The Tulshiganga River at Sonamukhi							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
1997	Jan						
	Feb						
	Mar						
	Apr						
	May						
	Jun	0.082	11.62	0.07	11.26	0.076	0.128
	Jul	0.746	15.55	0.258	13.025	0.502	0.885
	Aug	0.257	13.125	0.091	11.73	0.174	0.338
	Sep	0.424	14.99	0.401	14.455	0.4125	0.675
	Oct	0.242	13.075	0.1	12.225	0.171	0.324
	Nov	0.068	11.575	0.023	10.980	0.0455	0.086
	Dec	0.39	10.97	0.35	10.96	0.37	0.44

The Tulshiganga River at Sonamukhi							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
1998	Jan	0.019	10.95	0.013	10.935	0.016	0.044
	Feb	0.013	10.91	0.010	10.735	0.0115	0.029
	Mar						
	Apr						
	May						
	Jun						
	Jul						
	Aug						
	Sep						
	Oct						
	Nov						
	Dec						

The Tulshiganga River at Sonamukhi							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
1999	Jan						
	Feb						
	Mar						
	Apr						
	May						
	Jun						
	Jul	0.672	16.26	0.526	15.25	0.599	0.899
	Aug	0.399	14.355	0.231	13.193	0.315	0.633
	Sep	0.744	16.72	0.303	13.605	0.5235	0.970
	Oct	0.568	15.512	0.147	12.76	0.3575	0.801
	Nov	0.112	11.985	0.067	11.375	0.0895	0.212
	Dec						

The Atrai River at Chakharihorpur							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
1997	Jan						
	Feb						
	Mar						
	Apr	0.84	16.515	0.089	16.610	0.4645	0.15
	May	0.083	16.555	0.081	16.522	0.082	0.131
	Jun	0.313	17.62	0.081	16.51	0.197	0.445
	Jul	0.780	19.035	0.718	18.785	0.749	0.989
	Aug	0.906	19.94	0.461	17.47	0.6835	1.088
	Sep	0.68	18.70	0.582	18.21	0.631	0.858
	Oct	0.462	17.52	0.397	17.065	0.4295	0.616
	Nov	0.401	16.935	0.376	16.845	0.3885	0.531
	Dec	0.322	16.79	0.314	16.775	0.318	0.445

The Atrai River at Chakharihorpur							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
1998	Jan	0.282	16.7	0.269	16.675	0.2755	0.399
	Feb	0.235	16.645	0.226	16.545	0.2305	0.354
	Mar	0.152	16.47	0.114	16.305	0.133	0.249
	Apr						
	May						
	Jun						
	Jul						
	Aug						
	Sep						
	Oct						
	Nov						
	Dec						

The Atrai River at Chakharihorpur							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
1999	Jan						
	Feb						
	Mar						
	Apr						
	May						
	Jun						
	Jul	0.486	20.68	0.452	19.85	0.469	0.616
	Aug	0.465	20.51	0.395	18.835	0.43	0.596
	Sep	0.501	21.45	0.437	18.435	0.469	0.662
	Oct	0.444	19.675	0.422	19.245	0.433	0.662
	Nov	0.403	18.205	0.391	17.965	0.397	0.596
	Dec						

The Tulshiganga River at Naogaon							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
1997	Jan						
	Feb						
	Mar						
	Apr						
	May						
	Jun						
	Jul	0.475	13.75			0.475	0.629
	Aug	0.471	13.51	0.292	12.45	0.3815	0.629
	Sep	0.881	14.43	0.45	13.3	0.6655	1.088
	Oct	0.453	13.24	0.272	11.64	0.3625	0.596
	Nov	0.158	10.71	0.123	10.79	0.1405	0.236
	Dec	0.00	10.45	0.00	10.5	0.00	

The Tulshiganga River at Naogaon							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
1999	Jan						
	Feb						
	Mar						
	Apr						
	May						
	Jun						
	Jul	0.4675	14.04	0.466	14.81	0.46675	0.642
	Aug	0.423	13.48	0.414	13.42	0.4185	0.596
	Sep	0.443	13.7			0.443	0.596
	Oct	0.434	13.98	0.391	13.275	0.4125	0.583
	Nov	0.368	12.31	0.319	11.605	0.3435	0.531
	Dec						

The Atrai River at Mohadevpur							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
1997	Jan						
	Feb						
	Mar						
	Apr	0.096	13.35	0.069	13.22	0.0825	0.157
	May	0.084	13.36	0.083	13.45	0.0835	0.137
	Jun	0.223	14.85	0.084	13.39	0.1535	0.334
	Jul	0.884	17.46	0.319	15.21	0.6015	1.153
	Aug	0.387	15.510	0.289	15.1	0.338	0.581
	Sep	0.884	16.47	0.862	16.19	0.873	1.488
	Oct	0.319	14.23	0.27	13.98	0.2945	0.445
	Nov	0.252	13.92	0.243	13.86	0.2475	0.380
	Dec	0.236	13.81	0.231	13.79	0.2335	0.367

The Atrai River at Mohadevpur							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
1998	Jan	0.222	13.74	0.206	13.69	0.214	0.354
	Feb	0.157	13.63	0.145	13.55	0.151	0.268
	Mar	0.119	13.46	0.113	13.35	0.116	0.236
	Apr						
	May						
	Jun						
	Jul						
	Aug						
	Sep						
	Oct						
	Nov						
	Dec						

The Atrai River at Mohadevpur							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
1999	Jan						
	Feb						
	Mar						
	Apr						
	May						
	Jun						
	Jul	0.923	18.285	0.278	15.94	0.6005	1.299
	Aug	0.318	16.715	0.271	15.165	0.2945	0.489
	Sep	0.925	18.315	0.263	15.105	0.594	1.219
	Oct	0.267	15.075	0.257	15.045	0.262	0.380
	Nov	0.238	14.17	0.227	14.33	0.2325	0.354
	Dec						

The Atrai River at Atrai							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
1997	Jan						
	Feb						
	Mar						
	Apr						
	May						
	Jun	0.186	8.92	0.00	8.46	0.093	0.275
	Jul	0.780	13.445	0.502	11.425	0.641	0.989
	Aug	0.530	12.035	0.527	11.98	0.5285	0.694
	Sep	0.762	12.53	0.755	12.49	0.7585	0.957
	Oct	0.525	12.045	0.493	11.370	0.509	0.694
	Nov	0.243	10.445	0.230	9.93	0.2365	0.367
	Dec	0.219	9.53	0.195	9.08	0.207	0.314

The Atrai River at Atrai							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
1999	Jan						
	Feb						
	Mar						
	Apr						
	May						
	Jun						
	Jul	0.503	13.515			0.503	0.681
	Aug	0.428	13.275	0.313	12.315	0.3705	0.629
	Sep	0.476	13.445	0.332	12.665	0.404	0.662
	Oct	0.495	13.69	0.422	12.7	0.4585	0.714
	Nov	0.381	11.265	0.365	11.985	0.373	0.531
	Dec						

The Atrai River at Noldangar Hat							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
1997	Jan						
	Feb						
	Mar						
	Apr						
	May						
	Jun						
	Jul	0.626	13.265	0.387	10.63	0.5065	0.793
	Aug	0.49	12.645	0.486	12.66	0.488	0.694
	Sep	0.605	13.15	0.601	13.04	0.603	0.793
	Oct	0.508	12.73	0.391	12.165	0.4495	0.694
	Nov	0.392	11.48	0.308	10.7	0.35	0.531
	Dec	0.232	9.755	0.144	8.865	0.188	0.354

The Bogkhali River at Ramu							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
	Jan						
	Feb						
	Mar						
	Apr						
1997	May	0.649	3.105	0.48	2.49	0.5645	0.782
	Jun	0.922	3.995	0.797	3.31	0.8595	1.155
	Jul	1.185	5.97	0.863	4.39	1.024	1.613
	Aug	0.899	4.35	0.76	3.48	0.8295	1.191
	Sep	0.976	3.78	0.767	3.145	0.8715	1.305
	Oct	1.018	4.07	0.700	2.9	0.859	1.442
	Nov	0.523	2.875	0.523	2.78	0.523	0.585
	Dec	0.471	2.72	0.47	2.74	0.4705	0.561

Ramu The Bogkhali River at Ramu							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
	Jan	0.459	2.715	0.453	2.64	0.456	0.539
	Feb	0.393	2.45	0.389	2.63	0.391	0.483
	Mar	0.409	2.45	0.387	2.53	0.398	0.483
	Apr	0.566	2.64	0.405	2.45	0.4855	0.671
1998	May						
	Jun	0.486	4.66	0.72	3.55	0.603	1.098
	Jul	1.398	5.05	1.169	3.765	1.2835	1.737
	Aug	1.596	6.14	1.15	3.91	1.373	2.11
	Sep	0.891	4.1	0.731	3.165	0.811	1.098
	Oct	0.794	3.61	0.655	3.145	0.7245	0.947
	Nov	0.742	3.32	0.592	3.05	0.667	0.915
	Dec	0.685	2.90	0.65	2.94	0.6675	0.743

The Sangu River at Bandarban							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
1999	Jan	0.409	4.7	0.409	4.65	0.409	0.458
	Feb	0.403	4.62	0.397	4.57	0.4	0.434
	Mar						
	Apr	0.365	4.39	0.339	4.41	0.352	0.408
	May						
	Jun	1.229	14.30	0.704	6.68	0.9665	1.425
	Jul	1.128	9.40	0.789	7.165	0.9585	1.277
	Aug	0.817	8.13	0.723	6.70	0.77	0.947
	Sep	0.837	6.97	0.744	6.81	0.7905	0.996
	Oct	0.742	6.68	0.705	6.10	0.7235	0.903
	Nov	0.679	6.00	0.674	5.85	0.6765	0.801
	Dec	0.675	5.765	0.673	5.47	0.674	0.787

The Sangu River at Bandarban							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
2000	Jan	0.585	5.25	0.541	4.61	0.563	0.666
	Feb	0.550	4.45	0.537	4.56	0.5435	0.650
	Mar	0.530	4.52	0.514	4.43	0.522	0.633
	Apr						
	May						
	Jun						
	Jul						
	Aug	0.854	7.23	0.793	6.915	0.8235	0.966
	Sep	0.758	6.54	0.707	6.06	0.7325	0.897
	Oct						
	Nov						
	Dec						

The Piyan River at Jaflong							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
1997	Jan						
	Feb						
	Mar						
	Apr						
	May						
	Jun						
	Jul						
	Aug	0.923	10.76	0.71	9.53	0.8165	1.406
	Sep	0.918	10.79	0.643	9.88	0.7805	1.473
	Oct	0.434	9.41	0.265	8.50	0.3495	0.77
	Nov	0.396	8.49	0.382	8.39	0.389	0.77
	Dec	0.345	13.28	0.342	14.267	0.3435	0.536

The Piyan River at Jaflong							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
1998	Jan	0.318	8.29	0.313	8.32	0.3155	0.502
	Feb	0.338	8.26	0.332	8.31	0.335	0.502
	Mar	0.361	8.43	0.351	8.56	0.356	0.589
	Apr	0.329	8.61	0.327	8.35	0.328	0.468
	May	1.117	11.64	0.308	8.37	0.7125	1.74
	Jun	0.965	11.18	0.863	10.62	0.914	1.406
	Jul	1.212	11.74	1.131	11.63	1.1715	1.673
	Aug	0.880	10.56	0.867	10.78	0.8735	1.305
	Sep	0.920	10.835	0.760	9.1	0.84	1.473
	Oct	0.653	8.745	0.402	8.555	0.5275	0.924
	Nov	0.557	8.4	0.407	8.55	0.482	0.803
	Dec	0.608	8.33	0.597	8.38	0.6025	0.951

The Piyan River at Jaflong							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
1999	Jan	0.499	8.27	0.418	8.25	0.4585	0.763
	Feb	0.466	8.2	0.452	8.23	0.459	0.683
	Mar	0.481	8.20	0.421	8.22	0.451	0.629
	Apr	0.417	8.21	0.39	8.27	0.4035	0.67
	May	0.699	9.105			0.699	1.245
	Jun						
	Jul	1.143	10.67	0.838	12.225	0.9905	1.539
	Aug	0.899	10.64	0.692	10.02	0.7955	1.245
	Sep	0.752	9.195	0.675	9.950	0.7135	1.272
	Oct	0.986	8.665	0.702	8.940	0.844	1.499
	Nov	0.954	8.545	0.539	8.23	0.7465	1.439
	Dec	0.418	8.23	0.382	8.19	0.4	0.576

The Piyan River at Jaflong							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
2000	Jan	0.429	8.16	0.419	8.07	0.424	0.6
	Feb	0.626	7.96	0.417	8.04	0.5215	0.585
	Mar	0.434	7.975	0.413	8.030	0.4235	0.583
	Apr						
	May	1.125	11.585	0.317	8.445	0.721	1.727
	Jun	0.926	10.96	0.845	12.115	0.8855	1.459
	Jul						
	Aug						
	Sep						
	Oct						
	Nov						
	Dec						

The River Kushiyara at Sheola							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
1997	Jan						
	Feb						
	Mar						
	Apr						
	May						
	Jun						
	Jul						
	Aug	0.997	11.95	0.991	11.92	0.994	1.284
	Sep	1.12	12.475	1.079	12.385	1.0995	1.4
	Oct	1.235	13.38	0.635	9.39	0.935	1.602
	Nov	0.532	7.085	0.456	6.45	0.494	0.693
	Dec	0.472	6.09	0.386	5.335	0.429	0.614

The River Kushiyara at Sheola							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
1998	Jan	0.359	5.175	0.331	4.99	0.345	0.527
	Feb	0.322	4.73	0.316	4.555	0.319	0.484
	Mar	1.034	10.69	0.29	4.74	0.662	1.349
	Apr	0.512	7.355	0.468	7.705	0.49	0.756
	May	0.811	9.96	0.441	6.55	0.626	1.073
	Jun	1.515	13.915	1.148	12.765	1.3315	1.972
	Jul	1.498	14.03	1.140	12.88	1.319	1.924
	Aug	1.435	13.695	1.408	12.955	1.4215	1.786
	Sep	1.465	13.295	1.196	11.185	1.3305	1.813
	Oct	0.642	8.88	0.292	7.12	0.467	1.308
	Nov	0.473	6.215	0.412	7.25	0.4425	0.865
	Dec	0.307	5.485	0.274	4.970	0.2905	0.623

The River Kushiyara at Sheola							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
1999	Jan	0.328	4.67	0.271	4.58	0.2995	0.527
	Feb	0.301	4.43	0.230	4.20	0.2655	0.499
	Mar	0.257	4.01	0.241	3.96	0.249	0.392
	Apr	0.384	5.19	0.372	4.355	0.378	0.543
	May	0.693	9.21	0.274	3.885	0.4835	0.844
	Jun						
	Jul	1.34	13.65	1.314	12.89	1.327	1.807
	Aug	1.385	13.215	1.229	12.765	1.307	1.762
	Sep	1.301	13.1	1.085	12.26	1.193	1.694
	Oct	1.109	12.29	1.047	11.915	1.078	1.341
	Nov	0.791	7.99	0.718	6.78	0.7545	1.018
	Dec	0.561	6.105	0.397	5.695	0.479	0.829

The River Kushiyara at Sheola							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
2000	Jan	0.402	4.91	0.321	5.060	0.3615	0.588
	Feb	0.399	5.26	0.293	4.48	0.346	0.558
	Mar	0.608	7.777	0.306	4.35	0.457	0.762
	Apr	0.391	5.98	0.360	5.78	0.3755	0.581
	May	1.483	13.225	0.689	9.745	1.086	1.852
	Jun	1.060	12.625	1.023	12.585	1.0415	1.446
	Jul						
	Aug						
	Sep						
	Oct						
	Nov						
	Dec						

The Bogkhali River at Ramu							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
1999	Jan	0.543	2.87	0.542	2.85	0.5425	0.655
	Feb	0.504	2.78	0.474	2.65	0.489	0.587
	Mar						
	Apr	0.369	3.41	0.326	2.61	0.3475	0.503
	May						
	Jun	0.896	5.965	0.629	3.67	0.7625	1.619
	Jul	1.016	3.93	0.765	3.61	0.8905	1.242
	Aug	1.177	4.41	0.968	3.785	1.0725	1.429
	Sep	0.945	3.69	0.832	3.4	0.8885	1.181
	Oct	0.597	3.55	0.521	3.00	0.559	0.698
	Nov	0.552	2.41	0.539	2.67	0.5455	0.605
	Dec	0.612	2.57	0.56	2.42	0.586	0.698

The Bogkhali River at Ramu							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
2000	Jan	0.587	2.49	0.547	2.43	0.567	0.664
	Feb	0.518	2.55	0.509	2.54	0.5135	0.633
	Mar	0.589	2.63	0.533	2.59	0.561	0.699
	Apr						
	May						
	Jun						
	Jul						
	Aug	0.859	4.05	0.714	3.78	0.7865	1.086
	Sep	0.9	4.12	0.788	3.71	0.844	1.18
	Oct						
	Nov						
	Dec						

The Matamuhuri River at Lama							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
	Jan						
	Feb						
	Mar						
	Apr						
1997	May	0.712	6.59	0.516	6.06	0.614	0.884
	Jun	0.901	7.99	0.725	7.07	0.813	1.305
	Jul	1.265	9.8	0.829	7.74	1.047	1.829
	Aug	1.072	7.76	1.070	7.65	1.071	1.442
	Sep	1.381	8.31	0.924	7.43	1.1525	1.829
	Oct	0.689	6.54	0.628	6.08	0.6585	0.809
	Nov	0.598	6.03	0.59	5.93	0.594	0.67
	Dec	0.574	5.85	0.527	5.63	0.5505	0.67

The Matamuhuri River at Lama							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
	Jan	0.646	5.58	0.634	5.59	0.64	0.742
	Feb	0.646	6.14	0.64	5.56	0.643	0.762
	Mar	0.683	6.08	0.636	6.12	0.6595	0.784
	Apr	0.763	6.245	0.656	6.07	0.7095	0.833
1998	May						
	Jun	0.956	7.05	0.776	6.43	0.866	1.394
	Jul	1.673	12.655	0.972	8.755	1.3225	2.116
	Aug	1.533	9.65	1.048	8.09	1.2905	1.832
	Sep	1.124	9.09	0.947	7.86	1.0355	1.445
	Oct	0.994	7.645	0.939	7.39	0.9665	1.428
	Nov	0.8	7.29	0.668	7.38	0.734	1.055
	Dec	0.619	7.28	0.612	7.30	0.6155	0.743

The Matamuhuri River at Lama							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
1999	Jan	0.543	7.23	0.519	7.21	0.531	0.688
	Feb	0.515	7.21	0.504	7.21	0.5095	0.672
	Mar						
	Apr	0.341	7.15	0.339	7.16	0.34	0.467
	May						
	Jun	0.915	8.63	0.508	6.965	0.7115	1.127
	Jul	0.879	7.60	0.872	7.50	0.8755	1.086
	Aug	0.959	7.86	0.759	6.98	0.859	1.293
	Sep	0.833	7.51	0.761	7.33	0.797	0.937
	Oct	0.695	7.15	0.672	6.87	0.6835	0.877
	Nov	0.645	7.00	0.599	6.88	0.624	0.777
	Dec	0.651	6.86	0.607	6.81	0.629	0.787

The Matamuhuri River at Lama							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
2000	Jan	0.546	6.84	0.535	6.84	0.5405	0.605
	Feb	0.499	6.83	0.498	6.83	0.4985	0.605
	Mar	0.593	6.84	0.589	6.85	0.591	0.664
	Apr						
	May						
	Jun						
	Jul						
	Aug	1.002	7.72	0.846	7.27	0.964	1.292
	Sep	0.872	7.37	0.657	6.95	0.7645	1.180
	Oct						
	Nov						
	Dec						

The Halda River at Panchapukuria							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
1997	Jan						
	Feb						
	Mar	0.503	4.14	0.427	4.01	0.465	0.83
	Apr						
	May						
	Jun						
	Jul	1.127	7.34	0.92	5.77	1.0235	1.522
	Aug	1.086	7.09	1.068	6.60	1.077	1.522
	Sep	1.092	6.91	0.928	6.03	1.01	1.523
	Oct	0.693	4.96	0.665	4.74	0.679	1.049
	Nov	0.654	4.71	0.606	4.61	0.63	1.049
	Dec	0.59	4.83	0.557	4.50	0.5735	0.83

The Halda River at Panchapukuria							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
1998	Jan	0.667	4.65	0.466	4.46	0.5665	0.862
	Feb	0.562	4.38	0.399	4.27	0.4805	0.717
	Mar	0.614	4.59	0.412	4.28	0.513	0.669
	Apr	0.701	4.85	0.389	4.83	0.545	0.868
	May	0.847	5.21	0.628	4.61	0.7375	0.944
	Jun	0.835	5.42	0.806	5.76	0.8205	0.946
	Jul	1.310	8.73	1.015	6.68	1.1625	1.666
	Aug	1.192	8.47	1.088	6.83	1.14	1.534
	Sep	1.1	7.12	0.663	5.51	0.8815	1.776
	Oct	0.54	4.67			0.54	0.609
	Nov	0.665	5.6	0.517	4.64	0.591	0.894
	Dec	0.517	4.67	0.507	4.59	0.512	0.624

The Halda River at Panchapukuria							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
1999	Jan	0.507	4.52	0.499	4.45	0.503	0.628
	Feb	0.471	4.39	0.463	4.33	0.467	0.541
	Mar						
	Apr	0.462	4.33	0.451	4.2	0.4565	0.529
	May						
	Jun	0.978	6.54	0.514	4.98	0.746	1.098
	Jul	1.361	9.93	0.614	5.4	0.9875	1.612
	Aug	1.069	6.84	0.592	5.29	0.8305	1.175
	Sep	0.638	5.49	0.595	5.15	0.6165	0.746
	Oct	0.626	5.42	0.606	5.20	0.616	0.733
	Nov	0.609	4.96	0.604	4.84	0.6065	0.705
	Dec	0.61	4.82	0.605	4.87	0.6075	0.732

The Halda River at Panchapukuria							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
2000	Jan	0.594	4.76	0.592	4.74	0.593	0.688
	Feb	0.592	4.62	0.591	4.55	0.5915	0.666
	Mar	0.627	4.66	0.568	4.58	0.5975	0.733
	Apr						
	May						
	Jun						
	Jul						
	Aug	1.135	7.50	0.695	5.62	0.915	1.282
	Sep	0.657	5.14	0.649	5.07	0.653	0.765
	Oct						
	Nov						
	Dec						

The Sangu River at Bandarban							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
1997	Jan						
	Feb						
	Mar	0.529	4.88	0.499	4.81	0.514	0.801
	Apr						
	May						
	Jun						
	Jul	1.247	8.63			0.6235	1.522
	Aug	1.11	7.56	0.825	6.52	0.9675	1.429
	Sep	1.047	7.52	0.812	6.21	0.9295	1.315
	Oct	1.151	7.65	0.724	5.25	0.9375	1.522
	Nov	0.691	5.04	0.664	5.26	0.6775	0.848
	Dec	0.633	5.19	0.558	4.87	0.5955	0.862

The Sangu River at Bandarban							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
1998	Jan	0.612	4.83	0.474	4.81	0.543	0.788
	Feb	0.618	7.835	0.595	8.248	0.6065	0.771
	Mar	0.545	4.81	0.504	4.77	0.5245	0.624
	Apr	0.495	4.79	0.464	4.70	0.4795	0.624
	May	1.383	9.39	0.498	4.73	0.9405	1.667
	Jun	1.076	6.89	0.675	5.36	0.8755	1.326
	Jul	1.309	8.30	1.270	8.26	1.2895	1.534
	Aug	1.12	7.12	1.084	9.2	1.102	1.534
	Sep	0.935	7.11	0.816	8.8	0.8755	1.026
	Oct	0.618	6.63	0.455	5.4	0.5365	0.719
	Nov	0.426	5.05	0.421	5.015	0.4235	0.502
	Dec	0.416	4.83	0.415	4.75	0.4155	0.459

The River Brammaputra at Bahadurabad							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
1996	Jan						
	Feb						
	Mar						
	Apr						
	May						
	Jun	0.936	18.015	0.682	16.81	0.81	1.92
	Jul	1.731	19.930	1.168	19.24	1.45	2.77
	Aug	1.248	19.110	1.159	18.61	1.20	2.42
	Sep	1.188	18.995	0.907	17.41	1.05	2.33
	Oct						
	Nov						
	Dec						

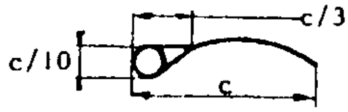
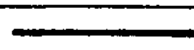
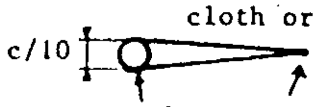
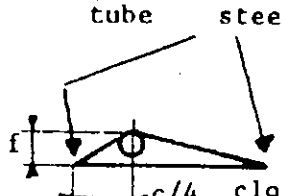
The River Brammaputra at Bahadurabad							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
1997	Jan						
	Feb						
	Mar						
	Apr						
	May						
	Jun						
	Jul						
	Aug						
	Sep						
	Oct	0.768	14.145	0.682	14.27	0.73	1.38
	Nov	0.754	15.305	0.693	14.455	0.72	1.58
	Dec						

The River Brammaputra at Bahadurabad							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
1998	Jan	0.696	13.16	0.587	13.28	0.64	1.23
	Feb	0.649	13.035	0.577	12.96	0.61	1.15
	Mar	0.793	14.315	0.645	13.00	0.72	1.52
	Apr	0.806	14.67	0.685	14.72	0.75	1.63
	May	0.994	17.55	0.806	15.105	0.90	1.94
	Jun	1.442	19.3	1.341	19.10	1.39	2.7
	Jul	1.855	11.905	1.494	19.49	1.67	3.34
	Aug	1.696	20.065	1.498	19.485	1.60	3.26
	Sep	1.710	20.28	0.904	17.68	1.31	3.29
	Oct	0.961	17.095	0.784	16.35	0.87	2.54
	Nov	0.753	14.895	0.725	14.825	0.74	1.61
	Dec	0.725	14.825	0.602	13.96	0.66	1.61

The River Brammaputra at Bahadurabad							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
1999	Jan	0.62	13.67	0.515	13.425	0.57	1.28
	Feb	0.515	13.34	0.238	13.24	0.38	1.07
	Mar	0.524	13.385	0.489	13.09	0.51	1.11
	Apr	0.659	14.205	0.513	13.22	0.59	1.38
	May	0.939	17.06	0.730	15.22	0.83	2.08
	Jun	1.019	17.855	0.847	16.68	0.93	3.20
	Jul	1.49	19.22	1.242	18.875	1.37	3.29
	Aug	1.591	19.70	0.955	18.1	1.27	3.29
	Sep	1.346	19.14	0.882	17.59	1.11	2.85
	Oct	0.92	17.735	0.834	16.995	0.88	2.35
	Nov						
	Dec						

The River Brammaputra at Bahadurabad							
Year	Month	Velocity (Daily mean) and corresponding Water level					Max. Velocity Recorded (m/s) (of the month)
		Max. Mean Velocity (m/s)	W.L (m) PWD	Min. Mean Velocity (m/s)	W.L (m) PWD	Average Mean Velocity (m/s)	
2000	Jan	0.665	14.00	0.546	13.64	0.61	1.14
	Feb	0.552	13.59	0.515	13.325	0.53	1.30
	Mar	0.645	13.71	0.508	13.27	0.58	1.16
	Apr	0.912	15.05	0.593	13.66	0.75	1.776
	May	1.003	17.045	0.813	15.365	0.91	2.678
	Jun						
	Jul						
	Aug						
	Sep						
	Oct						
	Nov						
	Dec						

Appendix E

airfoil name	geometrical description	$(C_d/C_l)_{min}$	α^o	C_l
sail and pole		0.1	5	0.8
flat steel plate		0.1	4	0.4
arched steel plate				
	f/c=0.07	0.02	4	0.9
	f/c=0.1	0.02	3	1.25
arched steel plate with tube on concave side	 d<0.1c f/c=0.07	0.05	5	0.9
	f/c=0.1	0.05	4	1.1
arched steel plate with tube on convex side	 f/c=0.1	0.2	14	1.25
sail wing	cloth or sail  tube steel cable	0.05	2	1.0
sail trouser f/c=0.1 $d_{tube}=0.6f$	 cloth or sail	0.1	4	1.0
NACA 4412		0.01	4	0.8
NACA 23015		0.01	4	0.8

Appendix F

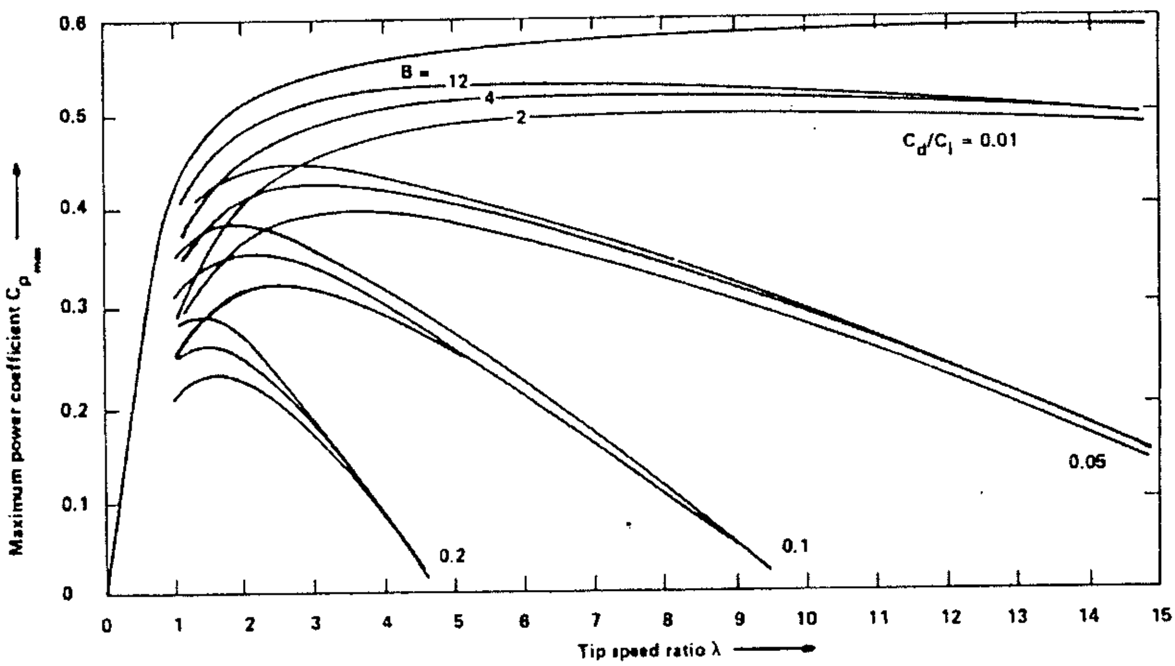


Figure F.1 Influence of Blade Number and Drag/Lift Ratio on the Maximum Attainable Power Coefficient for Each Tip Speed Ratio

Appendix G

Data for Pitch Angle 5^0, Shaft Inclination 45^0, and Water Velocity 0.65 m/s

Spring Gauge (gm)	Applied Load (gm)	Difference, F (gm)	N RPM	Torque, Q N-m	Ω rad/s	Tip Speed Ratio, λ	Power Output, P_0 (watt)	Input Power to the shaft, P_i (watt)	Power Coefficient, C_P	Power Density, (watt/m^2)
0	0	0	175	0	18.317	5.9177	0	13.45	0	0
700	372.5	327.5	154	0.0723	16.119	5.2075	1.165	13.45	0.0866	10.55288
1200	745	455	149	0.1004	15.595	5.0385	1.5661	13.45	0.1164	14.18524
1700	1117.5	582.5	145	0.1286	15.177	4.9032	1.9511	13.45	0.1451	17.6727
2200	1490	710	142	0.1567	14.863	4.8018	2.3289	13.45	0.1731	21.09529
2700	1872.5	827.5	138	0.1826	14.444	4.6665	2.6379	13.45	0.1961	23.89384
3500	2617.5	882.5	136	0.1948	14.235	4.5989	2.7724	13.45	0.2061	25.11265
3900	3000	900	134	0.1986	14.025	4.5312	2.7858	13.45	0.2071	25.23401
4600	3500	1100	130	0.2428	13.607	4.396	3.3033	13.45	0.2456	29.92092
5250	4000	1250	126	0.2759	13.188	4.2607	3.6382	13.45	0.2705	32.95486
5600	4500	1100	122	0.2428	12.769	4.1255	3.1	13.45	0.2305	28.07963
6100	4908	1192	119	0.2631	12.455	4.024	3.2767	13.45	0.2436	29.67988
7200	5408	1792	111	0.3955	11.618	3.7535	4.5948	13.45	0.3416	41.61979
8000	5816	2184	105	0.482	10.99	3.5506	5.2972	13.45	0.3938	47.98227
8400	6316	2084	97	0.4599	10.153	3.2801	4.6696	13.45	0.3472	42.29688

Experimental Data for Pitch Angle 5^0, Shaft Inclination 45^0, and Water Velocity 0.43 m/s

Spring Gauge (gm)	Applied Load (gm)	Difference, F (gm)	N RPM	Torque, Q N-m	Ω rad/s	Tip Speed Ratio, λ	Power Output, P_0 (watt)	Input Power to the shaft, P_i (watt)	Power Coefficient, C_P	Power Density, (watt/m^2)
0	0	0	104	0	10.885	3.5168	0	3.8131	0	0
750	372.5	377.5	96	0.0833	10.048	3.2463	0.8371	3.8131	0.2195	6.04544
1300	745	555	87	0.1225	9.1059	2.9419	1.1154	3.8131	0.2925	8.054748
1750	1117.5	632.5	84	0.1396	8.7919	2.8405	1.2273	3.8131	0.3219	8.862975
2400	1490	910	75	0.2008	7.85	2.5361	1.5766	3.8131	0.4135	11.38524
2750	1872.5	877.5	71	0.1937	7.4313	2.4009	1.4392	3.8131	0.3774	10.3931
3550	2617.5	932.5	64	0.2058	6.6986	2.1642	1.3786	3.8131	0.3615	9.955625
4000	3000	1000	55	0.2207	5.7566	1.8598	1.2705	3.8131	0.3332	9.174923
4700	3500	1200	41	0.2648	4.2913	1.3864	1.1365	3.8131	0.2981	8.207385
4900	4000	900	25	0.1986	2.6167	0.8454	0.5197	3.8131	0.1363	3.753377
	4500		stall							

Experimental Data for Pitch Angle 5^0, Shaft Inclination 45^0, and Water Velocity 0.25 m/s

Spring Gauge (gm)	Applied Load (gm)	Difference, F (gm)	N RPM	Torque, Q N-m	Ω rad/s	Tip Speed Ratio, λ	Power Output, P_0 (watt)	Input Power to the shaft, P_i (watt)	Power Coefficient, C_P	Power Density, (watt/m^2)
0	0	0	57	0	5.966	1.9275	0	0.7653	0	0
650	372.5	277.5	45	0.0612	4.71	1.5217	0.2885	0.7653	0.3769	2.612849
1200	745	455	31	0.1004	3.2446	1.0483	0.3258	0.7653	0.4258	2.951291
1500	1117.5	382.5	25	0.0844	2.6167	0.8454	0.2209	0.7653	0.2886	2.000831

Experimental Data for Pitch Angle 0^0, Shaft Inclination 45^0, and Water Velocity 0.65 m/s

Spring Gauge (gm)	Applied Load (gm)	Difference, F (gm)	N RPM	Torque, Q N-m	Ω rad/s	Tip Speed Ratio, λ	Power Output, P_0 (watt)	Input Power to the shaft, P_i (watt)	Power Coefficient, C_P	Power Density, (watt/m^2)
	0	0	160	0	16.75516	5.413206	0	13.45725	0	0
400	372.5	27.5	150	0.00607	15.70796	5.07488	0.095346	13.45725	0.007085	0.863645
1200	745	455	143	0.10043	14.97492	4.838053	1.50393	13.45725	0.111756	13.62255
1500	1117.5	382.5	140	0.084427	14.66077	4.736555	1.237769	13.45725	0.091978	11.21168
2000	1490	510	136	0.11257	14.24189	4.601225	1.603206	13.45725	0.119133	14.52179
2700	1872.5	827.5	130	0.18265	13.61357	4.39823	2.486517	13.45725	0.184772	22.5228
3500	2617.5	882.5	128	0.19479	13.40413	4.330565	2.610988	13.45725	0.194021	23.65025
4000	3000	1000	125	0.220725	13.08997	4.229067	2.889283	13.45725	0.214701	26.17105
4600	3500	1100	123	0.242798	12.88053	4.161402	3.12736	13.45725	0.232392	28.32754
5300	4000	1300	119	0.286943	12.46165	4.026072	3.575777	13.45725	0.265714	32.38929
6000	4500	1500	116	0.331088	12.14749	3.924574	4.021883	13.45725	0.298864	36.4301
6400	4908	1492	113	0.329322	11.83333	3.823077	3.896973	13.45725	0.289582	35.29867
6850	5408	1442	112	0.318285	11.72861	3.789244	3.733047	13.45725	0.2774	33.81383
7200	5816	1384	111	0.305483	11.62389	3.755412	3.550906	13.45725	0.263866	32.16401
7600	6316	1284	109	0.283411	11.41445	3.687746	3.23498	13.45725	0.240389	29.30236

Experimental Data for Pitch Angle 0^0, Shaft Inclination 45^0, and Water Velocity 0.43 m/s

Spring Gauge (gm)	Applied Load (gm)	Difference, F (gm)	N RPM	Torque, Q N-m	Ω rad/s	Tip Speed Ratio, λ	Power Output, P_0 (watt)	Input Power to the shaft, P_i (watt)	Power Coefficient, C_P	Power Density, (watt/m^2)
	0	0	85	0	8.901179	4.377629	0	3.815047	0	0
500	372.5	127.5	76	0.028142	7.958701	3.914115	0.223977	3.815047	0.058709	2.028779
1000	745	255	72	0.056285	7.539822	3.708109	0.424378	3.815047	0.111238	3.844003
1450	1117.5	332.5	66	0.073391	6.911504	3.3991	0.507243	3.815047	0.132958	4.594589
1950	1490	460	64	0.101534	6.702064	3.296097	0.680484	3.815047	0.178368	6.163805
2500	1872.5	627.5	57	0.138505	5.969026	2.935587	0.82674	3.815047	0.216705	7.488583
2750	2617.5	132.5	40	0.029246	4.18879	2.060061	0.122506	3.815047	0.032111	1.109652
	3000		stall							

Experimental Data for Pitch Angle 0^0, Shaft Inclination 45^0, and Water Velocity 0.25 m/s

Spring Gauge (gm)	Applied Load (gm)	Difference, F (gm)	N RPM	Torque, Q N-m	Ω rad/s	Tip Speed Ratio, λ	Power Output, P_0 (watt)	Input Power to the shaft, P_i (watt)	Power Coefficient, C_P	Power Density (watt/m^2)
	0	0	50	0	5.235988	4.39823	0	0.765661	0	0
500	372.5	127.5	37	0.028142	3.874631	3.25469	0.109042	0.765661	0.142415	0.987695
900	745	155	23	0.034212	2.408554	2.023186	0.082402	0.765661	0.107623	0.746398
	1117.5		stall							

Appendix H

Table for Power Output and Cost of Energy while the Water Current Turbine Model is operating at different Water Velocity

Water Velocity (m/s)	Power Output (watt)	Cost of Energy (Tk. per kWh)
0.8	11.02	52.93
0.9	15.7	37.15
1.0	21.5	27.13
1.1	28.7	20.33
1.2	37.2	15.68
1.3	47.3	12.33
1.4	59.1	9.87
1.5	72.7	8.02

Appendix I

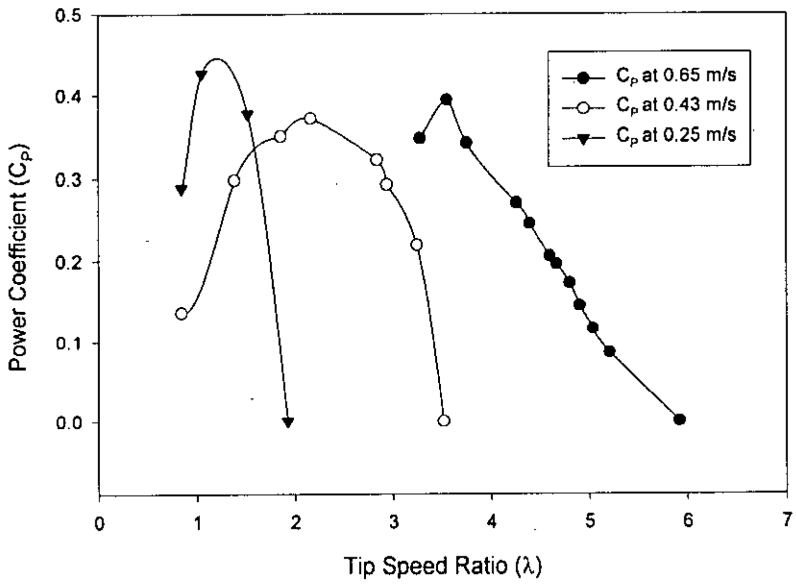


Fig. I.1 Power Coefficient vs. Tip Speed Ratio at Different Water Velocities with Pitch Angle 5°

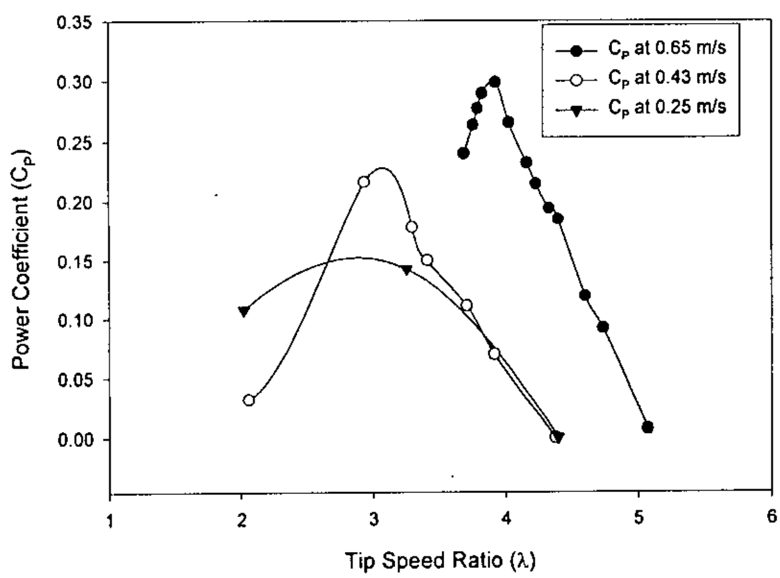


Fig. I.2 Power Coefficient vs. Tip Speed Ratio at Different Water Velocities with Pitch Angle 0°