Simulation of River Flow using GIS Data

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Master of Technology in Computer Science and Engineering

By

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Declaration

This is to certify that

i) The thesis comprises my original work towards the degree of Master of Technology in Computer Science and Engineering at Nirma University and has not been submitted elsewhere for a degree.

ii) Due acknowledgement has been made in the text to all other material used.

Amit R Patel

Certificate

This is to certify that the Major Project entitled ***"Simulation of River Flow using GIS Data."*** submitted by ***Amit R Patel (08MCE010)***, towards the partial fulfillment of the requirements for the degree of Master of Technology in Computer Science and Engineering of Nirma University of Science and Technology, Ahmedabad is the record of work carried out by him under my supervision and guidance. In my opinion, the submitted work has reached a level required for being accepted for examination. The results embodied in this major project, to the best of my knowledge, haven't been submitted to any other university or institution for award of any degree or diploma.

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Abstract

The major project titled "Simulation of river flow using GIS data" is mainly for the developing a new algorithm for simulation of river flow using various fundamentals of fluid dynamics. The river flowing through South Gujarat, INDIA has used to test the model. Fluid flow of river has been simulated using various fundamentals of Computational Fluid Dynamics (CFD) and GIS data. The entire work is divided into three major parts. First task is to acquire GIS (Geometric Information System) data which is in the form of cross-section of the river at intervals of 5 kms and compute the flow using physics formulae. Secondly, the discretization of model using finite-difference method and Finally visualization of the result by images which gives some realistic view of an river flow.

River water flow is considered as Gradually Varied Flow (GVF). Manning equations and other fundamental equations are used for modeling the fluid flow of the river. Water discharge at particular cross section is consider as an initial condition for algorithm. The entire algorithm for GVF (open channel) gives variation in height of water surface, width, velocity and area at particular cross-section at desired interval of time.

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Abbreviation

GIS Graphical Information System

NSE Navier-Stokes Equations

CFD Computational Fluid Dynamics

PDE Partial Differential Equation

FEM Finite Element Method

FDM Finite Differentiate Method

SPM Smoothed Particle Method

SPH Smoothed Particle Hydrodynamic

LAL Light Accumulation Lattice

DEM Digital Elevation Model

SPAM Smooth-Particle Applied Mechanic

GVF Gradually Varied Flow

TW Top Width

BW Bottom Width

DST Discrete Sine Transforms

DCT Discrete Cosine Transforms

DFTs Discrete Fourier Transforms

Chapter 1

Introduction

Simulation is the imitation of some real thing, state of affairs, or process. The act of simulating something generally entails representing certain key characteristics or behaviors of a selected physical or abstract system. Fluid simulation is an increasingly popular in computer graphics for generating realistic animations of water, smoke, explosions, and related phenomena. Given some input configuration of fluid and scene geometry, a fluid simulator evolves the motion of the fluid forward in time, making use of the (possibly heavily simplified) Navier-Stokes equations which describe the physics of fluids by Computation Fluid Dynamics (**!**CFD).

1.1 Description

Simulation of river flow project is mainly for developing the simulation algorithm for a river flow. The GIS data used for implementing the fluid physics which describes behavior of the fluid consists of width and height of the river basin at spaced cross sections. The whole work is divided in major three modules.

a. Finding suitable approximation to the fluid physics equations.

b. Discretization.

c. Visualizing the results in real time.

1.1.1 Input data and river fluid Modeling

GIS data are used as input data for fluid simulation. In CFD fluid is represent by different equations. The physics of any fluid can be represent by various equations. There are mainly two methods are available for model the fluid. Physical and non physical. Both physically based and non-physically based water models have been developed in past graphics research Physically-based models are computer formulations of the mathematical descriptions of fluids, such as the oft-mentioned Navier-Stokes Equations, While the physics and mathematics are based on basic principles such as mass, momentum, and energy conservation, the resulting equations describing the fluid motion can he difficult to understand both conceptually and mathematically Numerical solvers of these equations must be crafted with care in order to avoid instabilities and to ensue accurate results It is the attempt to de-emphasize these issues, or to avoid them entirely, that leads some graphics researchers to use non-physically based models. Most of fluid modeling is done using Navier-Stokes Equations (NSE) which describe

- a set of nonlinear partial differential equations that describe the flow of fluids.
- A continuity equation describing mass conservation

$$\frac{\partial \rho}{\partial t} + \quad \triangledown . (\rho u) = 0$$

- A conservation of momentum equation

$$\frac{\partial \rho}{\partial t} + (u.\triangledown)\, u = -\frac{1}{\rho} \triangledown p + F + \frac{\mu}{\rho} \triangledown^2 u$$

- A state equation describing energy conservation

$$\rho \left(\frac{\partial \varepsilon}{\partial t} + u \nabla \varepsilon \right) - \nabla . (K_H \nabla T) + \rho \nabla . u = 0$$

Temperature or energy can not affect the pressure on the fluid particle. so it is also negligible. so only velocity will be consider as moving particle.

1.1.2 Discretization

For Fluid modeling various continuous partial differential equations are used. So it is required to construct a discrete representation of the continuous partial differential equations. There are two established techniques for doing so.

Finite difference schemes, which is popular for their simplicity, use structured grids, and are suited for the Eulerian framework Continuous operations like spatial derivatives are replaced by taking weighted differences of values from neighboring nodes.

Finite Element methods, which can be regarded as a superset of FDMs. offer much more flexibility in handling irregular geometries because they are designed for unstructured meshes Weighted combinations of basis functions (which are localized) determine the state values at any given location Consequently, spatial derivatives are determined by a weighted sum of the basis function gradients.

1.1.3 Rendering

Rendering is method for visualizing the results in real time. It produce realistic view of river and water behavior.

1.2 Scope of Project

The real time fluid simulation has very large scope in the field of Computer Graphics research in engineering field and also for the special effect in movies and video games.

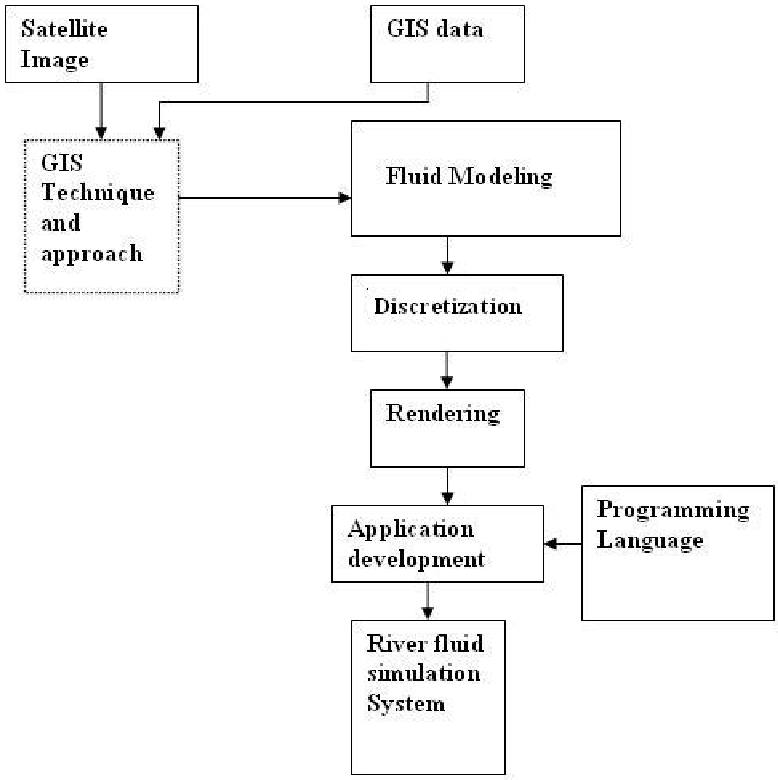

Figure 1.1: Flow model for entire work

1.3 Assumptions

1.3.1 Simulation will be done only for the visible part of Fluid Surface

Here cropped digital image has been used for create a virtual view of TAPI river. Though Simulation is done using this cropped satellite image, it has been done only for the visible part of the river. The area besides of riverbed which cover the land portion does not considered as a part of simulation.

1.3.2 Neglect Moving obstacles

River flow contains various moving objects like wood, some boat and other wrapper or raw materials. Here those all things have been neglected. Only moving water particles are considered as a part of simulation.

1.4 Applications

1.4.1 Study the flooding area

Generally river water flow remains steady in normal time. The water flow does not change very much. But at the time of flooding in river, flow of water become unsteady, it vary at different level. So simulation of river water helps in flooding time to know the water behavior at particular time and distance. So if it is prior known the water level at particular time and distance, some saving actions can be done by alerting the most flooding area. So it is very helpful at the time of flooding in big river.

1.4.2 Game and animation movie

Current days games and animated movies become very popular. So there are very good contribution of simulation of ware in games and movies.

1.5 Thesis Organization

The rest of the thesis is organized as follows.

Chapter 2, *The Literature Survey and important observation* describes the various methods for fluid simulation, proposed in different research papers.

Chapter 3, *Fluid Introduction and Open Channel overview* contains introduction part of fluid and properties of fluid. This chapter also gives the brief idea about open channel flow like river.

Chapter 4, *Input Data and Fluid Modeling*, presents model for river water using cross sectional data in gradually varied flow equations.

Chapter 5, *Proposed Algorithm* describe the new developed algorithm for fluid simulation.

Chapter 6, *Implementation and result discussion* gives the code for proposed module and tools to be used.

Chapter 7, *Conclusion* contains concluding remarks for work done.

Chapter 2

Literature Survey and important observation

Literature Survey includes the study and analysis of proposed methods from the different research papers. There are several competing techniques for water simulation with a variety of trade-offs. The different methods originated in CFD community, and have steadily been adopted by graphics practitioners over the past decades.

2.1 Fluid Modeling

Fluid modeling is a method for finding suitable approximation to the fluid physics equations. Following are the different equations for fluid modeling.
Kass and Miller has considered water surface as a height field and the motion is uniform through a vertical column [1]. So the motion of the water in terms of a grid of points on a height-field. $z = h(x)$ be the height of the water surface and $z = b(x)$ be the height of the ground, if $d(x) = h(x) - b(x)$ is the water depth and $u(x)$ is the horizontal velocity of a vertical column of water, the shallow water equations [2] that

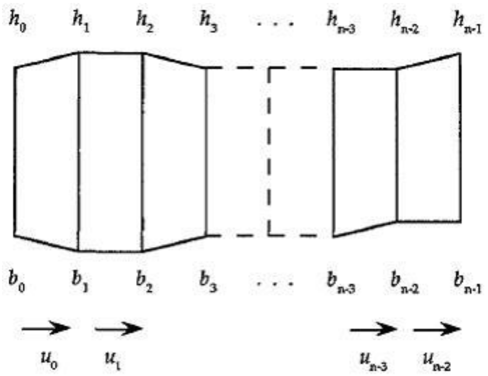

Figure 2.1: Discrete two-dimensional height-field representation of the water surface h, the ground bottom b, and the horizontal water velocity u.

follow from the above assumptions can be written as follows:

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + g\frac{\partial h}{\partial x} = 0 \tag{2.1}$$

$$\frac{\partial d}{\partial t} + \frac{\partial}{\partial x}ud = 0 \tag{2.2}$$

by simplifying these equation we get.

$$\frac{\partial u}{\partial t} + g\frac{\partial h}{\partial x} = 0 \tag{2.3}$$

$$\frac{\partial h}{\partial t} + d\frac{\partial u}{\partial x} = 0 \tag{2.4}$$

Differentiate equation 2.3 with respect to x, then differentiate equation 2.4 with respect to t and finally substitute for the cross-derivatives, we end up with

$$\frac{\partial^2 h}{\partial t^2} = gd\frac{\partial^2 h}{\partial x^2} \tag{2.5}$$

The Navier-Stokes equations of motion for a compressible fluid are written in the following SPAM formulation:
The **Continuity equation** describes the density change [3] in a fluid For incompressible flows such as water, $D\rho/Dt = 0$ For compressible flows, the SPAM description for the change in density is

$$\frac{\mathrm{d}\rho_i}{\mathrm{d}t} = \sum m_j(u_i - u_j)\nabla W_{ij} \tag{2.6}$$

The **Momentum equation**[3] describes the accelerations that particles of mass undergo Accelerations are calculated by the following equation :

$$\frac{\mathrm{d}u_i}{\mathrm{d}t} = \sum m_j(\frac{\sigma_i}{\rho_i^2} + \frac{\sigma_i}{\rho_j^2})\nabla W_{ij} + g \tag{2.7}$$

A Digital Elevation Model DEM data is a digital representation of ground surface topography or terrain. DEM data is significant for environmental studies especially hydrological areas. Used Smoothed Particle Hydrodynamics SPH [4] is a Lagrangian approach in the CFD arena, where the flow is modeled as a collection of particles that move under the influence of hydrodynamics and gravitational force.

$$A_s(r) = \sum m_j\frac{A_j}{\rho_j}W(r - r_j, h) \tag{2.8}$$

The scalar A is interpolated at location r by a weighted sum of contributions from the particles where j iterates over all particles in the scene, m_j is the mass of particle j. r_j the position, ρ_j the density and A_j the field quantity at r_j. The $W(r, h)$ is called smoothing kernel with core radius h.

E R Benjamin used Discrete Sine/Cosine Transforms for real time water simulation[5]. For mass conservation domain is replicated, with neighboring instances being mirror images. Thus, if some amount of fluid would try to leak out of our domain, an equal and opposing force from a neighboring instance would prevent this, leading to a net velocity directed along the boundary.
The fourier transforms for $2n$ elements of complex field U is replaced by a combination of Discrete Sine Transform DST and Discrete Cosine Transform DCT transforms as :

$$U' = (U_x^{scc}, U_y^{csc}, U_z^{ccs}) \tag{2.9}$$

The superscripts indicate which transform is chosen for which dimension. As an example, the first component of the velocity field will be transformed with a DST in the x-dimension, and with DCT transforms in the y- and z-dimensions. The computational complexity and memory requirements of this transform are equivalent to the original triplet of Discrete Fourier Transforms DFTs.
Density Dissipation [5] is updating the density distribution is given by

$$\frac{\partial \rho}{\partial t} = -u.\nabla \rho + vG(\rho, \rho*) \tag{2.10}$$

For **Surface tension** density defined over the entire volume, which is intended to be 0 outside the volume, and $\rho > 0$ inside the volume. Apart from the signed distance metric required for a true level set, ρ and Φ serve the same purpose in surface tension computations. Thus, compute the surface curvature [5] k by:

$$k = \nabla.(\nabla \rho) = \frac{\partial^2 \rho}{\partial x^2} + \frac{\partial^2 \rho}{\partial y^2} + \frac{\partial^2 \rho}{\partial z^2} \tag{2.11}$$

E B Quitzi yue and Fabrice Neyrect consider hydrographic network for river is stored as a directed graph [6], expressing the connections between rivers and channels.

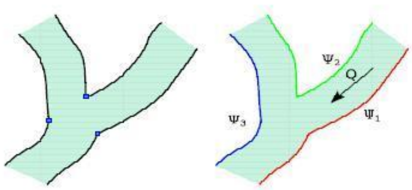

Figure 2.2: The stream function, ψ constant along all connected boundary.

This graph is mapped on the terrain. Volumetric flow rates for each branch of the graph can be included as part of the original data set, or we can reconstruct an approximate version using the vertical cross-sections of each branch.
velocities can be expressed as the curl of a stream function,ψ **[3]**

$$V = \nabla.\psi \tag{2.12}$$

Continuous Function :

$$\psi\left(P\right) = \frac{\sum_i W\left(d_i\right)\psi\left(i\right)}{\sum_i W\left(d_i\right)} \tag{2.13}$$

For each edge i connected to the first edge, the second rule gives us the value for its **flow rate**[6]:

$$Q_i = \frac{\sum_i W_i}{\sum_i W_j} Q_0 \tag{2.14}$$

where W_i is the cross section of the channel i. Because there are relative cross-sections, the **Conservation of mass** [6] is a direct consequence :

$$\sum Q_i = \frac{\sum_i W_i}{\sum_i W_j} Q_0 \tag{2.15}$$

2.2 Discretization methods for different Partial Differential Equations PDE

The **finite-difference technique** where the continuous functions are represented by a collection of samples. The finite-difference technique used for height-field representation [1].

$$\frac{\partial^2 h}{\partial t^2} = -g\frac{d_{i-1} - d_i}{2\Delta x^2}(h_i - h_{i-1}) + g\frac{d_i - d_{i+1}}{2\Delta x^2}(h_{i+1} - h_i) \tag{2.16}$$

Other is **Smooth-Particle Applied Mechanics** SPAM [3] where the state values are derived from a weighted combination of neighboring interpolation points. Spatial derivatives are similarly calculated using the weighting function. Due to its free-form nature, the SPAM technique easily allows both Eulerian and Lagrangian calculations to be performed In Lagrangian framework, the interpolation points represent particles of mass In an Eulerian framework, the interpolation points are just locations in the domain, as in Finite Difference Method FDMs.

2.3 Rendering

For visualizing the results in real time A fully recursive ray-tracer was implemented to capture the interaction between light and water It was capable of modeling scattered light and caustics.

Illumination [3] is used to produce realistic images of water such as caustic effects and light scattering. Instead, the underwater light-field distribution was sampled on

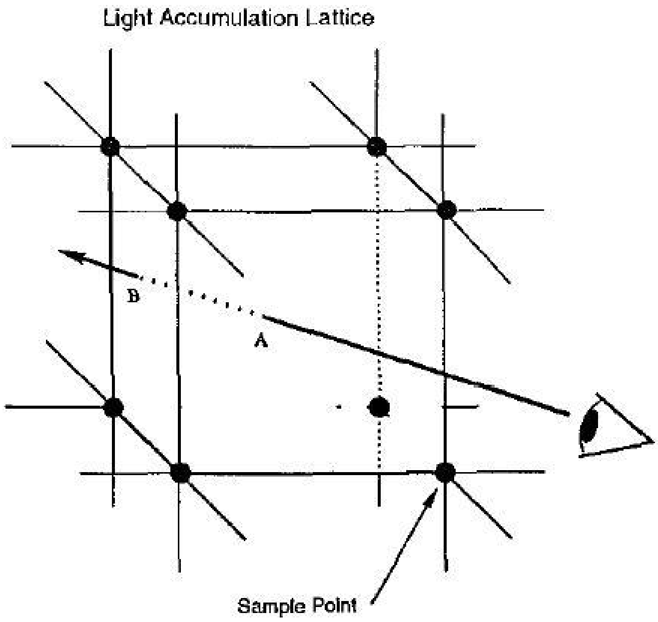

Figure 2.3: A viewing ray entering a Light Accumulation Lattice cell at point A and exiting and point B

a uniform lattice into a data structure called a Light Accumulation Lattice LAL [3] figure 2.3 vectors detailing the direction and the energy per unit area flowing through the sample points were stored on the lattices nodes Because a sample point could lie in multiple light volumes, vectors were stored using linked lists Thus, the light field anywhere in the volume can be linearly interpolated from the sample points in the LAL Ambient light from the sky was stored as a downward pointing vector in all of the sample points that lay it, For water all values were corrected for transmission attenuation and for expansion and compression of the light volume, the light grows brighter as the light is focused into a smaller area due to the increased energy density. It Calculate the amount of light scattered towards the viewer's eye by the water.

Rendering with caustic shading [1] in which rendering several different effects must be taken into account. Firstly, rays of light which are incident on a water surface are refracted by that surface. This results in uneven illumination of the terrain under

the water. This effect is illustrated in Fig. 2.2 in which the ray from the light source is shown being deflected by the water surface.
There are two approximations used by kass and Miller.

a. The first is the flat bottom approximation which is illustrated in Figure 2.4.

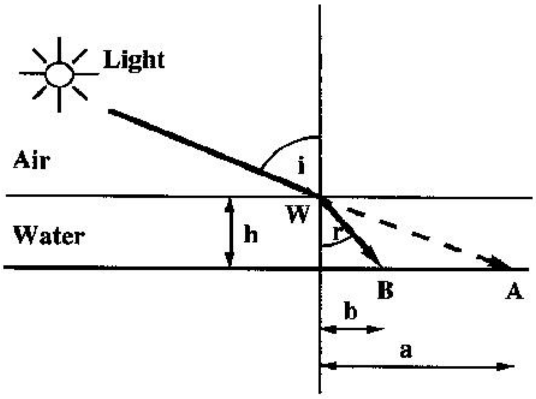

Figure 2.4: Illumination Refraction for Uneven Terrain

If the terrain is locally flat, then the destination of the ray may be computed using simple trigonometry

$$b = h \tan i \tag{2.17}$$

So, instead of tracing a ray from W towards the terrain to find the intersection point B, a simple expression suffices.

b. The second simplification is the flat water approximation. The point A is considered as the destination of a ray as if it was un deflected by any water. The height of the water above A is then used to compute an approximate position for a ray intersection with the water surface.

$$a = h/ \tan i \tag{2.18}$$

c. This value of a gives an estimate of the position of W. The refracted ray is computed from the water depth and normal at W using Snell's law. The refracted ray is then used to compute the position of B. The net result of this process is that a sample moves from A to B.

Implemented a visualization that is based on the physical laws of reflection and refraction [1]. To find the color in a fragment, start by finding a normal to the water surface at that point by looking up the horizontal and vertical neighbors in a height-map-texture and constructing a tangent and bi-normal from these.

Rendering by Texture reconstruction[6] in which surface pixel on screen is recovered by at least one sprite (independent graphic object controlled by its own bit plane) The blending is applied to physical parameters such as vertical displacements, obtained from the reference textures. These blended parameters are then used to compute derived quantities such as reflection and refraction terms, in order to compute a realistic fluid appearance.

2.4 Estimation of velocity fields between two images

The velocity estimation relies on the following hypothesis: The brightness of the points does not change between successive frames [7](at least when the time step between successive images is small enough). Let Ω denote the rectangular domain where the images are defined. The motion between the instants $t0$ and $t1$ where the images are I_0 and I_1 is then the vector field (u, v) such that for every point $(x, y) \in \Omega$,

$$I_1(x + u(x, y), y + v(x, y)) = I_0(x, y) \tag{2.19}$$

The identification of the velocity field, by having a look at the difference between the second image I_1 and the first image I_0 transported by the velocity.

Chapter 3

Fluid introduction and Open Channel overview

Fluid having particles which easily move and change their relative position without a separation of the mass, and which easily yield to pressure; capable of flowing; liquid or gaseous. Fluid can refer to either a liquid or a gas. A gas fills its container completely, whereas a liquid has a distinct "free surface" whose shape does not depend on its container. (Often, in computer graphics to visualize a liquid, you render only its surface-for example, ripples on a pond or a stream of water.) Liquids and gasses both obey the same basic fluid formulae and share similar properties.

3.1 Characteristics of Fluids

A fluid is a subset of the states of matter, consisting of liquids, gases and plasmas. This is because they have common properties that are distinct from solids. A fluid does not have a specific shape as does a solid. Instead, fluids take the shape of their containers. They also will flow or pour when under the influence of a force such as gravity.

3.1.1 Natural shape

Fluids exist at higher temperatures and thus their particles have greater kinetic energy. The shape of a fluid adapts to its environment or container.

Liquids : A liquid in space will form the natural shape of a sphere. This is because the attraction between its atoms or molecules is greater than the forces from their kinetic energy moving outward. A sphere is a shape with the smallest surface area for a given volume of material.

A liquid sphere or drop of liquidsuch as waterthat is falling toward the Earth through the atmosphere will be a slightly flattened sphere, due to the air resistance. If we spill some water on the floor, it will splash and spread out on the floor. Liquids like thin oil will spread out even more than water on the floor.

3.1.2 Flowing

The major feature of a fluid is that it flows when acted upon by some force. This makes a fluid different than a solid, which may be distorted by a force but will not start to flow. Typically, the force is that of gravity, but other forces can also apply.

3.2 Properties of fluid

Properties to the fluid that characterize how the fluid interacts with itself. The most common and important properties a fluid can have include these:

Pressure : Pressure refers to normal forces that apply to fluid parcels as well as the forces that fluid applies to its container and other solid objects embedded in the fluid as shown in figure 3.1(a).

Viscosity : Fluids also have shear forces, which act across the fluid, distorting it. Viscosity is the extent to which fluid resists that distortion, as Figure 3.1(b) shows. Thick fluids (like syrup) have high viscosity; thin fluids (like water) have low viscosity.

Density : Density expresses how much matter is in each small volume of space in the fluid.

Temperature : Temperature refers to how much heat resides in a fluid parcel. Temperature itself does not directly affect how the fluid moves, but it can affect pressure and density, which in turn affect motion.

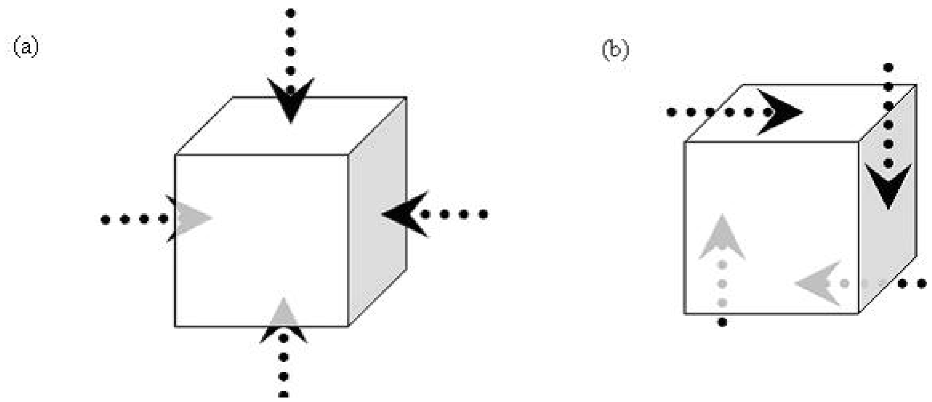

Figure 3.1: Components of stress: (a) normal (pressure) and (b) shear

3.3 Open Channel Flow

River water flow is considered as an open channel flow. An open channel is a natural or artificial water way in which a liquid here water flow with a free surface. Flow in an open channel differs from a pressure flow in a closed body in as much as the former has a free surface which introduced an extra boundary condition that the pressure on the free surface is subjected to ambient or atmospheric pressure.

3.3.1 Types of Open Channel

The different types of flow that can occur in an open channel can be classified according to the changes in velocity and depth of flow with respect to space and time.

- **Steady, Uniform Flow :** If the flow condition do not change with time and distance then this called steady, uniform flow.

- **Steady, Non Uniform Flow :** If the flow condition do not change with time ,but its changed alone the length of the channel then it is called steady, non uniform flow.

  Steady non uniform flow can be either gradually varied or rapidly varied depending on the total length of the channel involved for a given change in depth and velocity.

- **Unsteady, Uniform Flow :** Here flow conditions change with time ,but do not change along the length of distance. This kind of flow is occurs very rarely.

- **Unsteady, Non Uniform Flow :** Here flow conditions change with time and channel distance. When temporal changes in flow characteristics take place, an open channel flow can be gradually varied unsteady flow or a racially varied unsteady flow.

3.3.2 Gradually Varied Flow GVF

A GVF is defined as a steady flow whose depth varies gradually along the length of the river channel. GVF occur in the vicinity of controls such as dams, sluice gates, channel transition and changes in bed slope. In all such problems prediction of the flow profile for given flow conditions assumes importance.
The theory of Gradually Varied Flow is base upon the following assumptions.

a. The uniform flow formula can be used to evaluate head loss in Gradually Varied Flow and roughness coefficients applicable to uniform flow are valid even for non-uniform flow.

b. The channel slope is small.

c. The channel is prismatic.

d. The stream lines are practically parallel and curvature effects are negligible.

e. Velocity distribution coefficients are constant and most cases may be taken as unity.

The differential equation for GVF is derived from the energy equation. The total head over at any cross section is

$$H = z + ycos^2\theta + \alpha V^2/2g \tag{3.1}$$

Choosing channel bottom as the x -axis and differentiating the preceding equation with respect to x, we get

$$\frac{\mathrm{d}H}{\mathrm{d}x} = \frac{\mathrm{d}z}{\mathrm{d}x} + \left(\frac{\mathrm{d}y}{\mathrm{d}x}\right) cos^2\theta + \frac{\mathrm{d}}{\mathrm{d}y}.\left(\alpha\frac{V^2}{2g}\right)\left(\frac{\mathrm{d}y}{\mathrm{d}x}\right) \tag{3.2}$$

Solving dy/dx and substituting $cos\theta \simeq 1$, $\alpha \simeq 1$, $dz/dx = -S_0$ and $dH/dx = -S_f$, we get

$$\frac{\mathrm{d}y}{\mathrm{d}x} = \frac{S_0 - S_f}{1 + \frac{\mathrm{d}}{\mathrm{d}y}\left(\frac{V^2}{2g}\right)} \tag{3.3}$$

Equation 3.3 is the general differential equation for gradually varied flow.

Chapter 4

Input data and Fluid modeling

4.1 Input data

4.2 GIS inroduction

A geographic information system (GIS), or geographical information system, is any system that captures, stores, analyzes, manages, and presents data that are linked to location. In the simplest terms, GIS is the merging of cartography and database technology. GIS systems are used in cartography, remote sensing, land surveying, photogrammetry, geography, urban planning, emergency management, navigation, and localized search engines [8].

4.2.1 Cross Section data

Cross-sectional data or cross section in statistics and econometrics is a type of one-dimensional data set. Cross-sectional data refers to data collected by observing many subjects (such as individuals, firms or countries/regions) at the same point of time, or without regard to differences in time. Analysis of cross-sectional data usually consists of comparing the differences among the subjects.

Here input data is provided from the GIS database. TAPI river, which is located at south Gujarat area of INDIA. The cross-section data of this TAPI river is available from the GIS lab, Civil department of Nirma Institute of Technology. Cross sections of river are to be taken at different distance intervals which contains the information of water physics like width(m), height(m), area(m^2), velocity(m/s) , wetted perimeter(m), discharge(m^3/s) and other necessary property of river at particular time step. Here discharge is the amount of water which is going out from particular cross section area of river. Figure 4.1 and figure 4.2 shows the top and front view of river cross section. Both images are useful to understand the various properties of river cross section. Figure 4.3 shows the sample cross section data of TAPI river distance between Ukai to Kakarapar.

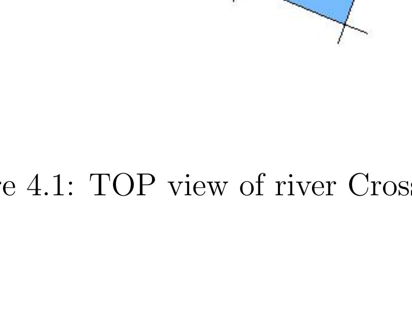

Figure 4.1: TOP view of river Cross Section

4.2.2 Digital Image

Digital Image of TAPI river from Ukai to Kakarapar is available from GIS lab of Civil Department, Nirma Institute of Technology, Ahmedabad. Digital image is shown in figure 4.4.

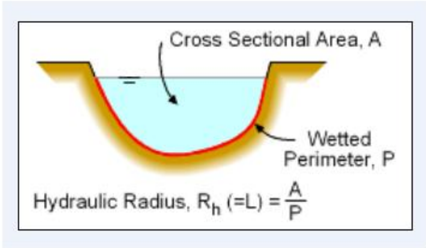

Figure 4.2: FRONT view River Cross Section

4.3 Fluid Modeling

There are several competing techniques for liquid simulation with a variety of trade-offs. As the process of fluid simulation is divided in major three parts as below.These methods originated in the computational fluid dynamics(CFD) community, and have steadily been adopted by graphics practitioners over the past decade. The key difference in the graphics setting is that the results need only be plausible. That is, if a human observer is unable to identify by inspection whether a given animation is physically correct, the results are sufficient, whereas in physics, engineering, or mathematics, more rigorous error metrics are necessary.
Most of fluid modeling is done using Navier-Stokes Equations (NSE) [9] [10] which describe

- a set of nonlinear partial differential equations that describe the flow of fluids.
- A continuity equation describing mass conservation

$$\frac{\partial \rho}{\partial t} + \quad \bigtriangledown . \left(\rho u\right) = 0$$

- A conservation of momentum equation

$$\frac{\partial \rho}{\partial t} + \left(u . \bigtriangledown\right) u = -\frac{1}{\rho} \bigtriangledown p + F + \frac{\mu}{\rho} \bigtriangledown^2 u$$

- A state equation describing energy conservation

A	B	C	D	E	F	G	H	I	J	K	L	M	N
PILLAR NO.	CO-ORDINATES		INBETWEEN DISTANCE OF PILLAR	TOP R.L. OF PILLAR IN MT.	G.L. IN MT.	VELOCITY IN M/SEC.	Area m2	Perimeter	New Area m^2	Q(m3/s)	Discharge in Lakhe Cusace	R	Slope S
RD1	49855.999	50019.101		14.801	13.762	0	0						
	0	0	674.409	0	0	0.082	24868.31	943.975	9947.322	815.6804	0.28805834	10.5377	1.65717E-07
LD1	49833.902	50693.148		14.802	13.763	0	0	0	0	0	0	0	0
	0	0		0	0	0	0	0	0	0	0	0	0
RD2	49788.847	49910.916		14.803	13.764	0	0	0	0	0	0	0	0
	0	0	787.5550	0	0	0.084	24676.6	963.303	9870.639	829.13366	0.29280937	10.24666	1.80449E-07
LD2	49725.44	50695.914		14.804	13.765	0	0	0	0	0	0	0	0
	0	0		0	0	0	0	0	0	0	0	0	0
RD3	49699.212	49884.667		14.805	13.766	0	0	0	0	0	0	0	0
	0	0	815.7750	0	0	0.086	25519.17	958.472	10207.67	877.85934	0.3100169	10.64994	1.79747E-07
LD3	49617.918	50696.381		14.806	13.767	0	0	0	0	0	0	0	0
	0	0		0	0	0	0	0	0	0	0	0	0
RD4	49588.227	49856.234		14.78	13.768	0	0	0	0	0	0	0	0
	0	0	842.8330	0	0	0.088	23867.64	958.472	9547.056	840.14093	0.2966966	9.960704	2.05582E-07
LD4	49507.171	50695.16		14.781	13.769	0	0	0	0	0	0	0	0
	0	0		0	0	0	0	0	0	0	0	0	0
RD5	49500.477	49838.985		14.782	13.77	0	0	0	0	0	0	0	0
	0	0	858.1260	0	0	0.088	24444.31	963.59	9777.726	860.43985	0.30386519	10.14718	2.0061E-07
LD5	49397.226	50690.877		14.783	13.771	0	0	0	0	0	0	0	0
	0	0		0	0	0	0	0	0	0	0	0	0
RD6	49404.309	49851.561		14.784	13.772	0	0	0	0	0	0	0	0
	0	0	843.353	0	0	0.093	22802.19	955.343	9120.875	848.24139	0.29955729	9.547226	2.42824E-07
LD6	49294.212	50687.697		14.785	13.773	0	0	0	0	0	0	0	0

Figure 4.3: Cross-section data from Ukai to kakarapar

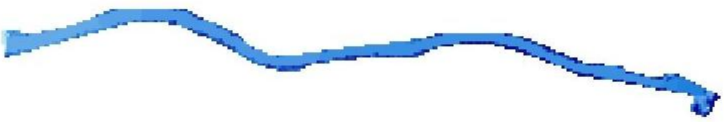

Figure 4.4: Digital image of TAPI river from Ukai to Kakarapar

$$\rho\left(\frac{\partial \varepsilon}{\partial t} + u\nabla\varepsilon\right) - \nabla.\left(K_H \nabla T\right) + \rho\nabla.u = 0$$

Temperature or energy can not affect the pressure on the fluid particle. so it is also negligible. so only velocity will be consider as moving particle. So velocity can be defined by the Shallow water equation using two or three dimension grid of height is,

$$\frac{\partial^2 h}{\partial t^2} = gd\frac{\partial^2 h}{\partial x^2}$$

which is the wave equation with wave velocity $\sqrt{gd}$

Though available input data are in the form of cross-section data, Manning formula is best suited for create model of river.

4.3.1 Manning formula

The Manning Equation is the most commonly used equation to analyze open channel flows. The channel can be any shape - circular, rectangular, triangular, etc. The Manning Equation was developed for uniform steady state flow.

$$V = k/nR_h^{2/3}.S^{1/2} \tag{4.1}$$

where:
V is the cross-sectional average velocity (ft/s, m/s),
k is a conversion constant equal to 1.486 for U.S. customary units or 1.0 for SI units,
n is the Gauckler-Manning coefficient (independent of units) : for Major Rivers n= 0.035,
R_h is the hydraulic radius (ft, m) : R_h=A/P,
A= Area of Cross-section,P= Perimiter
S is the slope of the water surface or the linear hydraulic head loss (ft/ft, m/m) (S = Height / L),

Gauckler-Manning coefficient

The GaucklerManning coefficient, often denoted as n, is an empirically derived coefficient, which is dependent on many factors, including surface roughness and sinuosity. When field inspection is not possible, the best method to determine n is to use photographs of river channels where n has been determined using GaucklerManning's formula. For major river the value of Gauckler-Manning coefficient n is 0.035. It is independent of unit.

Hydraulic radius

The hydraulic radius is a measure of a channel flow efficiency. Flow speed along the channel depends on its cross-sectional shape (among other factors), and the hydraulic radius is a characterisation of the channel that intends to capture such efficiency. Hydraulic radius is defined as the ratio of the channel's cross-sectional area of the flow to its wetted perimeter:

$$R_h = A/P \tag{4.2}$$

where:
R_h is the hydraulic radius (m),
A is the cross sectional area of flow (m2),
P is wetted perimeter (m).

The greater the hydraulic radius, the greater the efficiency of the channel and the less likely the river is to flood. The highest values occur when channels are deep, narrow, and semi-circular in shape.

The hydraulic radius is not half the hydraulic diameter as the name may suggest. It is a function of the shape of the pipe, channel, or river in which the water is flowing. In wide rectangular channels, the hydraulic radius is approximated by the flow depth. The measure of a channel's efficiency (its ability to move water) is used by water engineers to assess the channel's capacity. The hydraulic radius of a channel is defined as the ratio of its cross-sectional area to its wetted perimeter. Wetted Perimeter is that portion of the cross-section that is in contact with the liquid as shown in figure 3.2.

Important note for Manning formula

a. It ignores viscosity effects and hence is leat dependable at low Reynolds number.

b. Roughness coefficient n ia assumed to remain constant at all velocities.

c. It describe only the mean velocity.

d. Boundary Shear is assumed constant along the perimeter.

4.3.2 Discharge formula

$$Q = A.V \tag{4.3}$$

In hydrology, discharge is the volume rate of water flow, including any suspended solids (i.e. sediment), dissolved chemical species ($i.e.CaCO3_(aq)$) and/or biologic material (i.e. diatoms), which is transported through a given cross-sectional area. Frequently, other terms synonymous with discharge are used to describe the volumetric flow rate of water and are typically discipline dependent. For example, a fluvial hydrologist studying natural river systems may define discharge as stream flow, whereas an engineer operating a reservoir system might define discharge as outflow, which is contrasted with inflow.
Here discharge is considered as a amount of water going out from a particular cross section area of river means outflow . Solving for Q then allows an estimate of the volumetric flow rate (discharge) without knowing the limiting or actual flow velocity.

4.3.3 Fundamental equations for GVF

GVF is a plot of water depth versus distance along the channel as the water depth gradually achieves normal depth. The method involves the continuity equation and energy slope equations. Here calculation initially computes open channel properties

depth, height, velocity, area, Froude number, etc. A GVF profile is also known as a water depth profile, backwater calculation, and non-uniform flow computation. Fundamental flow equations are first presented, followed by equations for computing the depth Y. Then, using the input value of Y, the GVF profile type is determined and the GVF profile is computed using the Improved Euler method. Manning's equation for Yn and the equation for the friction slope Sf are empirical; they are shown in the form that uses meters and seconds for units. Units for all other equations can be from any consistent set of units.
The following equations are always valid for open channels.

$$Q = A.V \tag{4.4}$$

where:
Q is the Volumetric flow rate(m),
A is the cross sectional area of flow (m2),
V is velocity (m/s)

$$TW = BW + Y(Z_1 + Z_2) \tag{4.5}$$

where:
TW is the top width of water (m),
BW is the bottom width of water (m),
Y is depth of water (m).
Z_1, Z_2 is One channel side slope (horizontal to vertical ratio) [m/m].

$$A = Y(TW + BW)/2 \tag{4.6}$$

$$P = B + Y(\sqrt{(}1 + Z_1^2) + \sqrt{(}1 + Z_2^2)) \tag{4.7}$$

where:
P is the wetted perimeter (m)

4.4 GRID overview

River channel is considered in a grid form where the different variables are stored at different locations. On the grid, the horizontal velocities are stored at vertical edges, in two dimensions first, illustrated in figure 4.5. The pressure in grid cell (i, j) is sampled at the center of the cell, indicated by p_{ij} . The velocity is split into its two Cartesian components. The horizontal u component is sampled at the centers of the vertical cell faces, for example indicated by $u_{i+1/2,j}$ for the horizontal velocity between cells (i, j) and (i+1, j). The vertical v component is sampled at the centers of the horizontal cell faces, for example indicated by $v_{i,j+1/2}$ for the vertical velocity between cells (i, j) and (i, j +1). Note that for grid cell (i, j) we have sampled the normal component of the velocity at the center of each of its faces: this will very naturally allow us to estimate the amount of fluid flowing into and out of the cell.

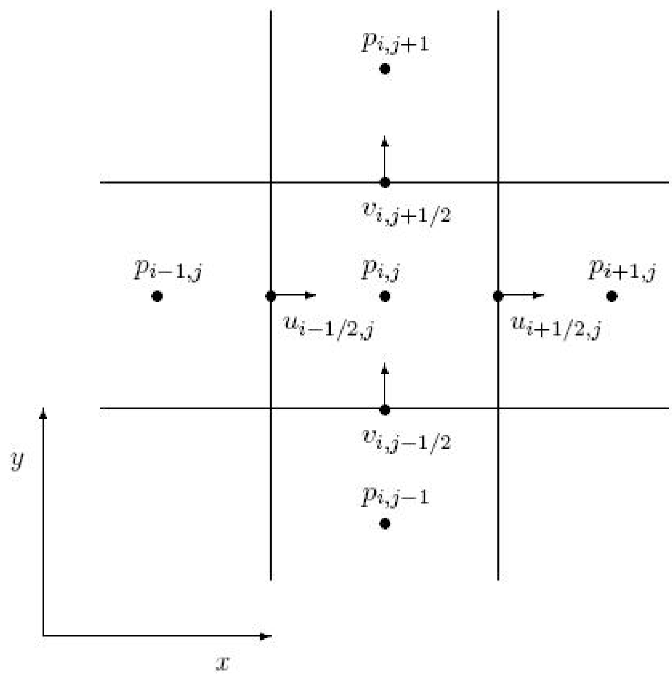

Figure 4.5: The two-dimensional grid

In three dimensions, the grid is set up the same way, with pressure at the grid cell

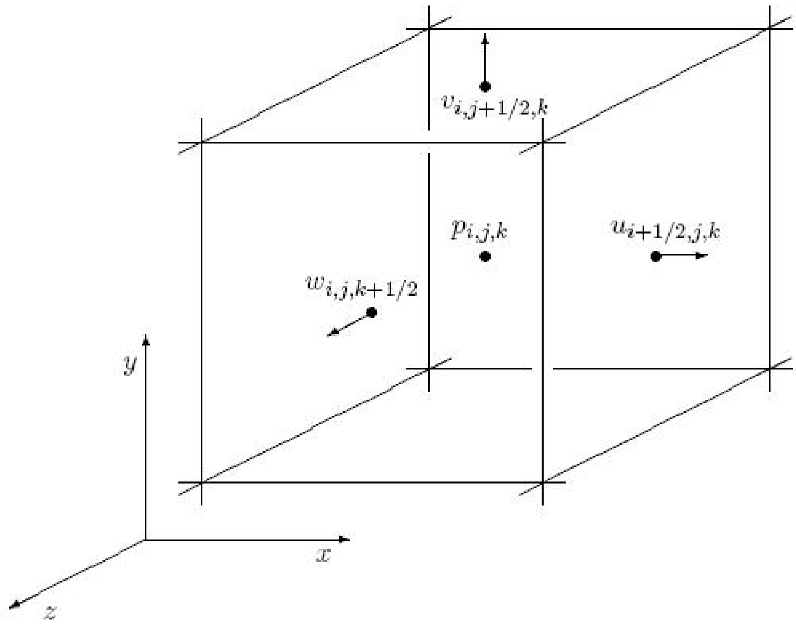

Figure 4.6: The Three-dimensional grid

centers and the three different components of velocity split up so that we have the normal component of velocity sampled at the center of each cell face as shown in figure 4.6

4.5 Numerical simulation for 2D and 3D

Here the water simulation is represented by different partial differential equations (PDEs). so for descretization of these PDEs there are various numerical methods are available. in my simulation i am going to refer the **finite difference method**, in which functions are represented by their values at certain grid points and derivatives are approximated through differences in these values.

4.5.1 Finite Difference Method (FDM)

- Popular for simplicity use structured grid.

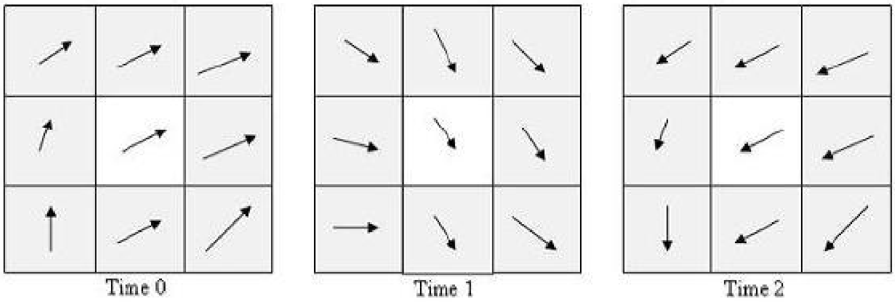

Figure 4.7: Eulerian acceleration: velocity at a fixed location changes over time.

- Suited for Eulerian Framework which describe the behavior of the fluid at any fixed location at the modeling space shown in figure 4.7.

The staggered MAC grid is perfectly suited for handling pressure and incompressibility, In two dimensions these averages are:

$$\vec{u}_{ij} = (\tfrac{u_{i-1/2j}+u_{i+1/2j}}{2}, \tfrac{v_{ij-1/2}+v_{ij+1/2}}{2})$$

In three dimensions the formulas are similar:

$$\vec{u}_{i,j,k} = (\tfrac{u_{i-1/2,j,k}+u_{i+1/2,j,k}}{2}, \tfrac{v_{i,j-1/2,k}+v_{i,j+1/2,k}}{2}, \tfrac{w_{i,j,k-1/2}+w_{i,j,k+1/2}}{2})$$

Chapter 5

Proposed Algorithm

This chapter present an algorithm developed for modeling water flow.

5.1 Proposed algorithm for GVF

A GVF computation involves starting at a known depth Y and making successive water depth computations at distance intervals. To compute GVF profile (graph), the improved Euler method is used. Here discharge at different cross sections and initial depth of water at each cross section is easily computed from the GIS data. Entire algorithm is as follows.

5.2 Description of Algorithm

1. Starting with the known depth as Y and discharge Q at different cross section. Here Discharge is the amount of water going out from particular cross section.
2. As there is a change in flow rate, so if the new water discharge is more than previous one then the water level will be high and according to that the top width TW_i, area A_i will be increase. The velocity will be also increase and decrease based on variation in all basic equations value.
3. This step compute the friction slope. S_f friction slope is the rate at which energy

1. Take Discharge and initial depth at time $t = starttime$.

2. Compute the top width, perimeter and area using the fundamental equations defined above.

3. Compute friction slope
   $Sf_i = \frac{(nQ_i)^2 P_i^{\frac{4}{3}}}{A_i^{\frac{10}{3}}}$

4. Find hight difference by

   $\left(\frac{\mathrm{d}Y}{\mathrm{d}X}\right)_i = \frac{S_0 - S_f}{cos\theta - \frac{TW_i Q^2}{gA_i^3}}$
   Where $\theta = tan^{-1}S0$

5.Compute
   $Y_{i+1} = Y_i + \sum_{n=1}^{i} \frac{\frac{\mathrm{d}Y}{\mathrm{d}X}_i}{i}$

6. Assign $Y = Y_{i+1}$

7. Repeat step 2 to 6 for $t = endtime$ by incrementing i and t.

is lost due to channel resistance. 4. So for find the new height Y_i first need to find the current variation in height dy_i.

5. Then finally adding the variation in total height in final step, algorithm gives the variation in height.

6. In step 6 this new height Y_i is assign to the Y and recursively executing steps from 2 to 6 we got all variation for time tn.

Chapter 6

Implementation and Result discussion

6.1 Implementation Overview

Using available cross section data of river distance between Ukai to Kakarapar and solving the equation for gradually varied flow (GVF) calculated the variations in width, height, area and velocity of water at different time at different cross sections of river. Implementation for the same thing has been done in MATLAB. The property variations are implemented for 159.49 kilometers area of TAPI river.

Though input cross section data is in the form of excel sheet file. The excel file contains different necessary values at each cell. In my implementation i have considered two dimension array for all value like Area, Velocity, Discharge, Height, Perimeter and other values given in input file. The pseudo code for entire work done can be describe as follows.

Table 6.1: Pseudo code for GVF

```
Retrieve all values from input data
 Read input values using xlsread("file path", range)
 call  CrossSectionDistance()
for time t =1 to n
          call EquationCalc()
          if t==1
             Arrayname(time,i)=initialarray(i);
          else
             Y(time,i)=Y1(time-1,i)
             calculate A(time,i), Q(time,i), V(time,i),
             TW(time,i) and Y(time,i).
          end
end
call plotgraph()
```

6.2 Result Discussion

So the output graph shows how velocity, area, height and width are vary at different cross section for four time step. Here all these variations depends on the discharge values. Discharge in lacks cusec, is amount of water which is going out from that particular cross section area of river. If discharge value at any current time is greater than at previous time then there is increase in water level. So height will be increase and according to the change in height value width, area and velocity will be change. Figure 6.1 shows the graph for discharge vs. distance. So from figure 6.1, 6.2 and 6.3 we can see that if there is a variation in flow rate then there are corresponding changes in top width and height variation.

Table 6.1, 6.2, 6.3 and 6.4 shows the value of discharge or Flow rate(Q), Velocity(V), Area(A), Top width of river water surface(TW) and height or depth of water level from surface to the bottom land (Y) at different time $t1$, $t2$, $t3$ and $t4$.

Table 6.2: Pseudo code for create Virtual view of river

```
Read input image.
   InputImage=imread('image file path')
read water texture image
   InputTexture=imread('image file path')
for i = 1 to m
   for j = 1 to n
         comment :Store water texture in temporary array
         TempTexture(i,j)=InputTexture(i,j)
   end
end
for i = 1 to m
   for j = 1 to n
         comment :Apply texture in input image
         FinalTexture(i,j)=TempTexture(i,j)
   end
end
comment :Convert vector in matric form.
   X1=vec2mat(X,3);
   Y1=vec2mat(Y,3);
   Z1=vec2mat(FinalTexture,3);
grid on;
figure;
surfc(X1,Y1,Z1);
shading interp;
view(-30,70);
```

Table 6.3: Pseudo code for create Virtual view of river with height

```
Retrieve all values from input data
 Read input values using xlsread("file path", range)
 call  CrossSectionDistance()
for time t =1 to n
        call EquationCalc()
        if t==1
           Arrayname(time,i)=initialarray(i);
        else
           Y(time,i)=Y1(time-1,i)
           calculate A(time,i), Q(time,i), V(time,i),
           TW(time,i) and Y(time,i).
call plotgraph()
commentCreate virtual river model with new height values.
call plot_3d_height()
 Read input image.
   InputImage=imread('image file path')
        comment : Assign new height value at each pixel
for i = 1 to m
   for j = 1 to n
        InputImage(i,j)=Y(i,j)
   end
end
comment :Convert vector in matric form.
   X1=vec2mat(length,3);
   Y1=vec2mat(width,3);
   Z1=vec2mat(InputImage,3);
grid on;
figure;
surfc(X1,Y1,Z1);
shading interp;
view(-30,70);
        end
end
```

Table 6.4: Fluid properties values at time t=1

Cross section./ Fluid Property	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**
Q1	0.5190	0.3649	0.0735	0.5931	0.1171	0.2492	0.4280	0.6106
A1	0.7340	0.5614	0.5296	0.3649	0.6802	0.5492	0.1464	0.3116
TW1	0.6493	0.6023	0.5493	0.5421	0.5629	0.5643	0.5796	0.6108
V1	0.0980	0.1000	0.1080	0.1080	0.0800	0.0800	0.0800	0.0900
Y1	0.5200	0.6250	0.4900	0.7050	0.5750	0.5150	0.6850	0.5450

Table 6.5: Fluid properties values at time t=2

Cross section./ Fluid Property	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**
Q2	0.5614	0.5190	0.3649	0.0735	0.5931	0.1171	0.2492	0.4280
A2	0.3694	0.4042	0.3521	0.4710	0.3176	0.3117	0.4667	0.4009
TW2	0.7101	0.6458	0.7175	0.6684	0.5509	0.6035	0.6800	0.7338
V2	0.1520	0.1286	0.1038	0.1559	0.1872	0.3769	0.5351	0.1070
Y2	1.0407	1.2517	1.0058	1.5124	1.1501	1.0419	1.3742	1.0909

Table 6.6: Fluid properties values at time t=3

Cross section./ Fluid Property	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**
Q3	0.7340	0.5614	0.5190	0.3649	0.0735	0.5931	0.1171	0.2492
A3	0.7382	0.8076	0.7214	1.0085	0.6323	0.6280	0.9332	0.7997
TW3	0.7091	0.6445	0.7165	0.6667	0.5498	0.6025	0.6786	0.7328
V3	0.9947	0.6958	0.7203	0.3619	0.1162	0.9449	0.1256	0.3118
Y3	0.9232	1.1478	0.9528	1.3104	2.7860	0.9095	1.4323	0.9915

Table 6.7: Fluid properties values at time t=4

Cross section./ Fluid Property	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**
Q4	0.7749	0.7340	0.5614	0.5190	0.3649	0.0735	0.5931	0.1171
A4	0.6553	0.7406	0.6837	0.8742	1.5230	0.5488	0.9721	0.7273
TW4	0.7093	0.6447	0.7166	0.6672	0.5465	0.6028	0.6785	0.7330
V4	1.1832	0.9919	0.8221	0.5937	0.2397	0.1340	0.6103	0.1612
Y4	1.0337	1.2466	1.0535	1.4151	1.4976	1.2172	1.3648	1.1588

Case 1:

From table 6.1 consider the value of cross section 24 at time $t = 1$. Here value of Discharge $Q1 = 0.5190$, Area $A1 = 0.7340$, top width $TW1 = 0.6493$, Velocity $V1 = 0.0980$ and height $Y1 = 0.5200$. Now after one time step means time $t = 2$ variation in same properties described by table 6.2. New discharge value will be $Q2 = 0.5614$ which is greater than $Q1$. As we know $Q = A * V$ change in Q reflect corresponding change in value of velocity as well as area also. So here $A2 = 0.3694$ and $V2 = 0.1520$. So $A2 * V2 = 0.3694 * 0.1520 = 0.5614$. Now new height will be $Y2 = 1.0407$ which is greater than $Y1$. Same way we can find all these values at different n times.

Case 2:

From table 6.3 consider the value of cross section 30 at time $t = 3$. Here value of Discharge $Q3 = 0.5931$, Area $A3 = 0.6280$, top width $TW3 = 0.6025$, Velocity $V1 = 0.99449$ and height $Y3 = 0.9095$. Now after one time step means time $t = 4$ variation in same properties described by table 6.4. New discharge value at cross section 30 will be $Q4 = 0.0735$ which is smaller than $Q3$. As there is a change in Q there will be corresponding change in value of velocity as well as area also. So here $A4 = 0.5488$ and $V2 = 0.1340$. So $A4 * V4 = 0.5488 * 0.1340 = 0.07352$. Now new height is $Y4 = 1.2172$ which is greater than $Y3$.

It is not possible every time that if current discharge value is greater than previous one then height will increase. The increase or decrease the height value depends on geometry of bottom land as well as some big obstacles in between the river.

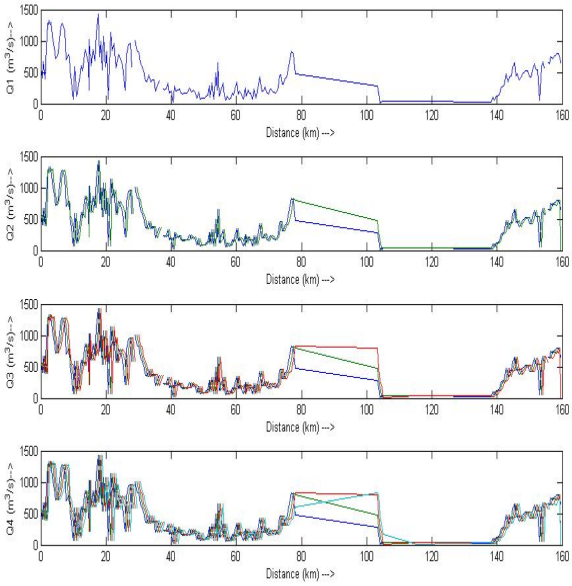

Figure 6.1: Flow rate at time t1(first), t2(second), t3(third), t4(fourth)

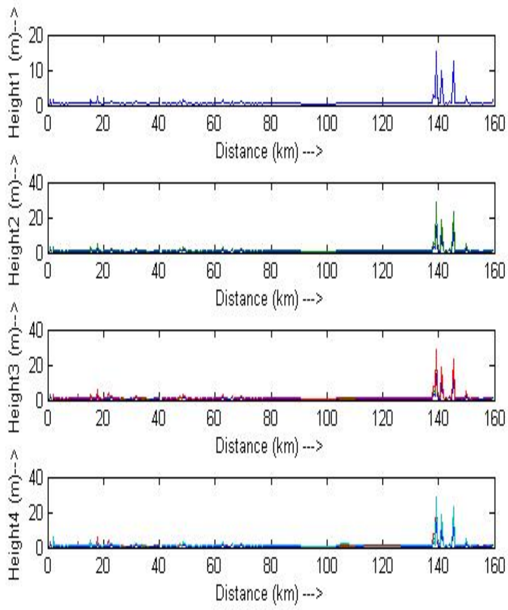

Figure 6.2: Height at time t1(first), t2(second), t3(third), t4(fourth)

Available input digital image is shown in figure 4.4. Figure 6.6 shows the texture image which contains the texture of water. Though input image has not any water texture, applying water texture shown in figure 6.6 on available digital image result got is shown by figure 6.7. Now this image need to be convert in three dimension (3D) as shown in figure 6.8. Finally figure 6.9 represent the 3D virtual model for Ukai to kankrapar area of TAPI river with variation in depth of water at each cross section.

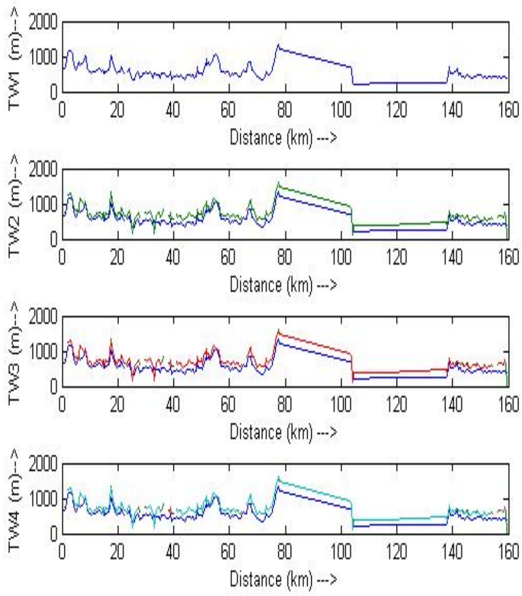

Figure 6.3: Top Width at time t1(first), t2(second), t3(third), t4(fourth)

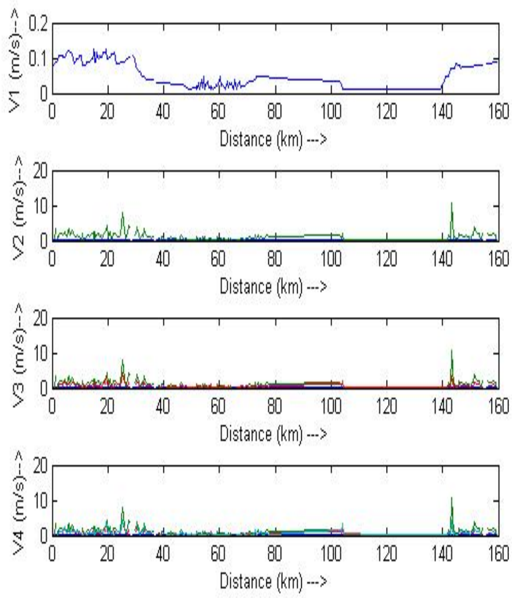

Figure 6.4: Velocity at time t1(first), t2(second), t3(third), t4(fourth)

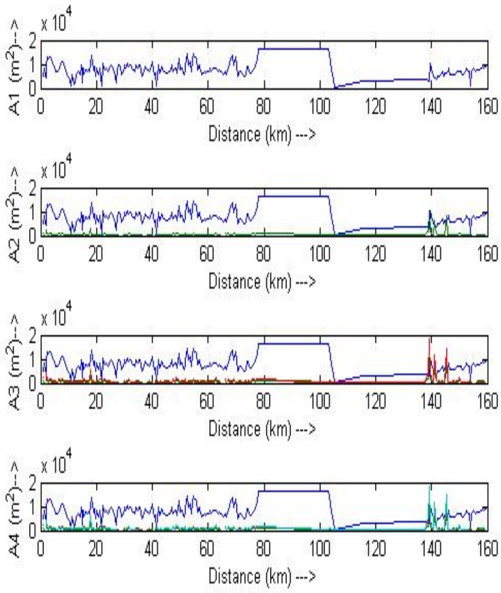

Figure 6.5: Area at time t1(first), t2(second), t3(third), t4(fourth)

Figure 6.6: Water texture image

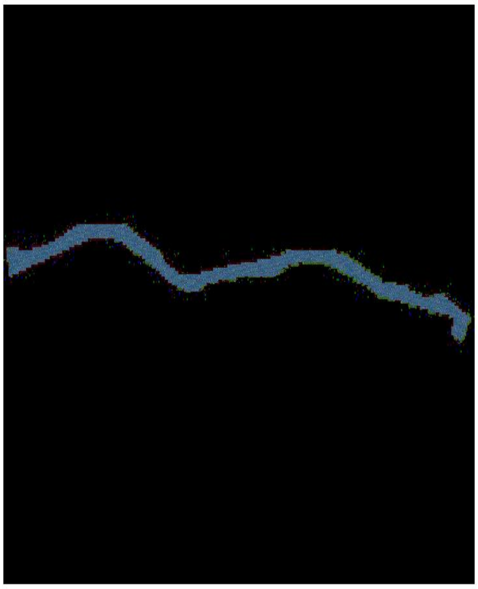

Figure 6.7: Resultant image with water texture

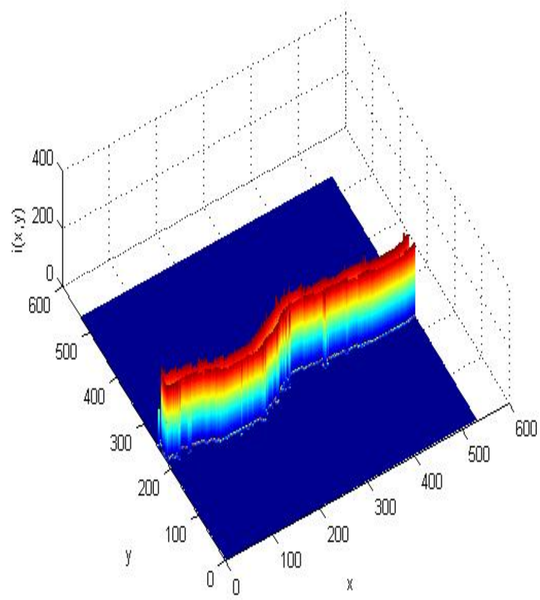

Figure 6.8: 3D virtual model of Ukai to Kakarapar (TAPI river)

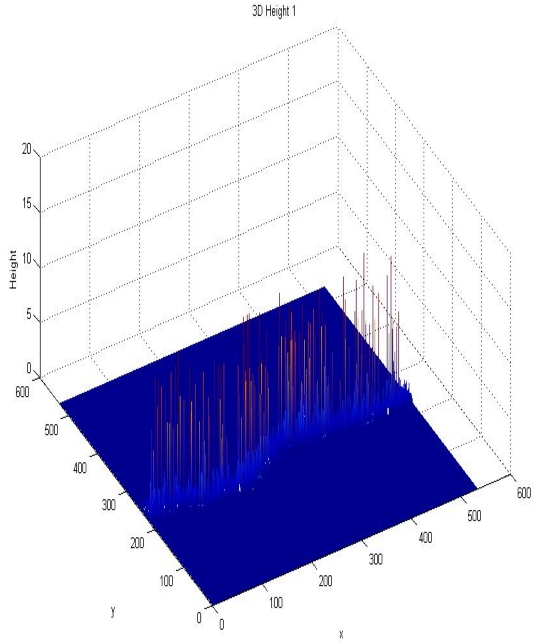

Figure 6.9: 3D virtual model with depth of water distance from Ukai to Kakarapar (TAPI river)

Chapter 7

Conclusion

7.1 Conclusion

By successfully implementing the proposed algorithm the variation in water properties like area, velocity, depth and width can easily computed for TAPI river. When there is a linear flow the velocity, depth of water remain same or the variation is very less. When the area is increase the velocity is decrease and as velocity decrease the flow become linear so depth will decrease. These variation are useful at the time of river flooding or to know the behavior of water flow at particular time at particular distance. so it can be prior known the situation of water flow at particular time and place. So entire work examine the capability of computer techniques to support environmental hazards studies.

The work also show a virtual view (3D model) of TAPI river area from Kakrapar to Ukai. It is also possible to represent virtual model in different views by setting the viewing angle for a three-dimensional plot to the Cartesian coordinates x, y, and z. It can be very useful for study area like geographic information system.

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