GIS-Based Automated Flood Forecast Modelling Application Using Climatic Data in Daduru Oya River Basin

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Declaration

I declare that this thesis is my own work and has not been submitted in any form for another degree or diploma at any university or other institution of tertiary education. Information derived from the published or unpublished work of others has been acknowledged in the text and a list of references is given.

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	Date:
Mr. B. H. Sudhantha	………………………
	Date:

Dedication

To my loving parents for being the guiding light that illuminate the path of knowledge throughout my life.

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Abstract

Flood is the most common and deadliest form of disaster that affects lives and properties all around the world. Predicting natural disasters is very complex due to lack of proper methods and resources in countries like Sri Lanka. But if there is an efficient prediction system it helps to save not only lives but the environment and infrastructure too. Therefore, the aim of this study is to pave the pathway to build an efficient and effective flood prediction system through analysing available flood modelling techniques and their applications to find their strengths and weaknesses. Then the result of the study could be used to put the foundation for the main requirement of building the system to predict natural disasters. To achieve this the GIS technology, Big data analytic and IoT with machine learning techniques, two-dimensional hydrodynamic flood models, statistical models, rainfall-runoff models, Fuzzy-neuro approach and data mining and data analysis applications were analysed by a thorough review of available recent literature.

A generic model was developed to take any DEM data and a pour point feature class layer for the specific DEM to generate outputs based on other variable that could input to the model. It gave model calibration capability as well as significant time saving on tasks. Use of special tools like 'Parse Path' tool, gave the capability to name outputs easily and quickly. And it also made saving so efficient because it automatically saves all the results to the file path of the DEM. Due to these factors, when it starts raining in upper catchment area, could forecast due inundation area in minutes.

Including the GIS technology could improve the data quality and availability while incorporating different data sources for more in-depth analysis could give more accurate predictions. Using GIS based hydrological model, a suitable system to implement in Sri Lanka could be developed.

Abbreviations

2D – Two Dimensional

3D – Three Dimensional

AI - Artificial Intelligence

ANN - Artificial Neural Networks

API - Application Programming Interface

AWS - Automatic Weather Stations

CDMA - Code Division Multiple Access

CEB - Ceylon Electricity Board

CNN - Convolutional Neural Network

CRML - Convolution Regression based on Machine Learning

DDMCU - District Disaster Management Coordinating Units

DEM – Digital Elevation Model

DMC - Disaster Management Centre

DSTA - Dynamic Spatiotemporal Attention

ELM - Extreme Learning Machine

GIS – Geographical Information Systems

GUH - Geomorphologic Unit Hydrograph

GWO - Grey Wolf Optimizer

HEC-HMS - Hydrologic Engineering Centre’s-Hydrologic Modelling System

HEC-RAS – Hydrologic Engineering Centre’s-River Analysis System

HMM – Hidden Markov Model

ID – Irrigation Department

KNN - K-Nearest Neighbour

LSTM - Long Short-Term Memory

MAE - Mean Absolute Error

MAPE - Mean Absolute Percentage Error

MASL - Mahaweli Authority Sri Lanka

ML – Machine Learning

MWOA - Mutated Whale Optimization Algorithm

NBRO - National Building Research Organisation

NCDM - National Council for Disaster Management

RH - Relative Humidity

RMSE - Root Mean Square Error

RNN - Recurrent Neural Networks

SVM – Support Vector Machine

SWAT - Soil and Water Assessment Tool

UH – Unit Hydrograph

WMO – World Meteorological Organisation

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Chapter 1

Introduction

1.1 Background and Motivation

1.1.1 The vision behind the ancient

The long-lasting Sri Lankan civilization is mainly due to the environmentally friendly water management system which supported the agrarian civilization for many centuries in the country. Ancient civilizations were located on the banks of major rivers. The scientific concepts of the integrated management of water resources are the basis of the Sri Lankan hydraulic civilization. Substantial accomplishments in the fields of irrigation, drinking water supply, public health, sustainable planning, and ecological protection were unique [1].

Disaster Risk Reduction (DRR) is evident in Sri Lanka from ancient times with a recorded history of village tank(reservoir) cascade system that was with an eco-friendly and efficient management approach keeping with the Buddhist philosophy. Around 2100 years ago Sri Lankan engineers invented the ‘Sluice’ with a mechanism to dissipate hydraulic energy and control water flow, which enabled them to build very large reservoirs. These systems were disrupted during the European colonial period and natural systems and human life's equilibrium, as well as community resilience, were gradually degraded. The potential for disaster has increased because of modern challenges such as population growth, resource shortages, conflicts, and development-related changes to land use and landscape conditions, particularly with the influence of such human-induced disaster factors [1][2].

1.1.2 Background

Flood is the most common and disastrous form of disaster that affects lives, infrastructure, properties, and environment all around the world which is amounting to around 520 million people a year affecting on average. Floods are a common aspect of people's lives all over the world. For centuries, humans have become accustomed to floods of different extent and rate of recurrences. In many places of the world, floods are anticipated and appreciated since they replenish the soil by providing nutrients that inseminate the flood plains. But, if the flood is unexpected due to sudden heavy rain, damage to a dam, or human activities it will damage the environment as well as causing loss of lives, livelihoods, and infrastructure. The challenge is to keep the positive effects on the environment while keeping out or minimize the negative effects on people due to floods [3].

The increase of flood risk in most of the areas around the world is due to factors such as the increase of human population and variability of climatic changes. Increased population affected to increase of property values and people tend to build their livelihood in flood-prone areas they previously avoided because of the diminishing land area available. Unplanned growth and developments increase flood risk substantially. Government policymakers should consider these factors when they make decisions while making the climatic changes in the centre of all decision-making activities and they should keep in mind the changing risk profile. There is always uncertainty involved with these models and the decision-makers need to understand that [3].

Sri Lanka is a tropical Island having a land area of 65 610 km^2 and is closer to the southeast tip of India in the Indian Ocean with a population of just over 21 million [4]. According to statistics flood is becoming more frequent than drought events and other natural disasters [5] and people, housing, agriculture, irrigation, roads, and livestock are affected by that. For example, from the 3rd to the 23rd of December 2019, the late arrival of the north-eastern monsoon following a lengthy inter-monsoon period in Sri Lanka produced floods and landslides in thirteen districts. “64, 608 people (18, 840 families) have been affected, with two persons reported dead, 62 houses fully damaged and 1, 463 houses partially damaged. 17, 766 people (5, 255 families) have been evacuated to the 133 locations set up to assist people displaced” [6]. Therefore, it is clear that taking effective mitigation measures to floods is very essential to preserve life, property, economy and environment [7]. Figure 1.1 shows families affected in May 2018 flood in Sri Lanka.

Figure 1.1: Families affected in May 2018 Flood in Sri Lanka [44].

Table 1.1 depicts number of houses damaged or destroyed due to various disasters in year 2015, 2016 and 2017 in Sri Lanka.

Table 1.1: Number of houses damaged/ destroyed due to various disasters in Sri Lanka [5].

Disaster	2015		2016		2017	
	Completely damaged	Partially damaged	Completely damaged	Partially damaged	Completely damaged	Partially damaged
Landslides/ slope failure	48	232	274	2370	325	1569
Floods	423	5112	385	2549	1411	11946
Lightning	1	31	6	25	2	40
High winds/ cyclones	122	1007	71	1965	860	33290
Total	594	6382	736	6909	2598	46845

Table 1.2 illustrates damage in year 2017 due to various disasters in Sri Lanka.

Table 1.2: Damage in 2017 due to disasters in Sri Lanka [5].

2017						
Disaster	**Deaths & Disappear**	**Injured**	**Affected Population**	**Affected Families 2016**	**Completely Damaged Houses**	**Partially Damaged Houses**
Flood	210.00	124.00	676,809.00	174,186.00	1,411.00	11,946.00
Drought	-	-	2,440,290.00	667,939.00	-	-
Cyclone	19.00	87.00	129,122.00	36,277.00	860.00	33,290.00
Landslide	158.00	18.00	137,721.00	34,866.00	325.00	1,569.00
Fire	4.00	7.00	357.00	83.00	19.00	24.00
Others	118.00	112.00	2,049.00	485.00	64.00	78.00
Total	**509.00**	**348.00**	**3,386,348.00**	**913,836.00**	**2,679.00**	**46,907.00**

The number of deaths and disappearances in year 2017 due to various disasters in Sri Lanka is illustrated in figure 1.2.

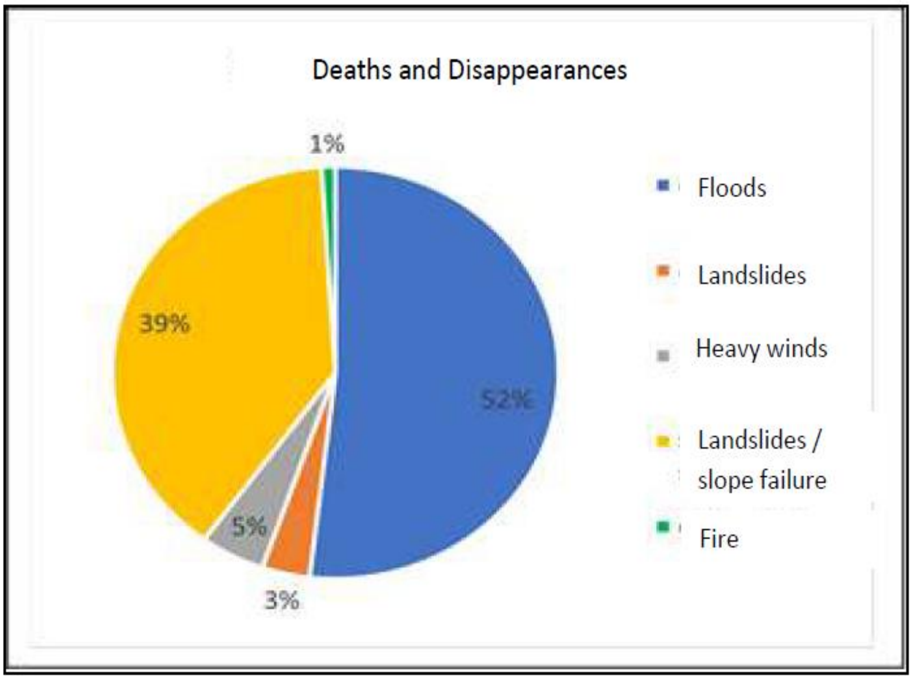

Figure 1.2: The number of deaths and disappearances due to disasters in year 2017 in Sri Lanka [5].

Figure 1.3 depicts annual time series distribution for people affected due to disasters without Tsunami from 1974 to 2008 in Sri Lanka.

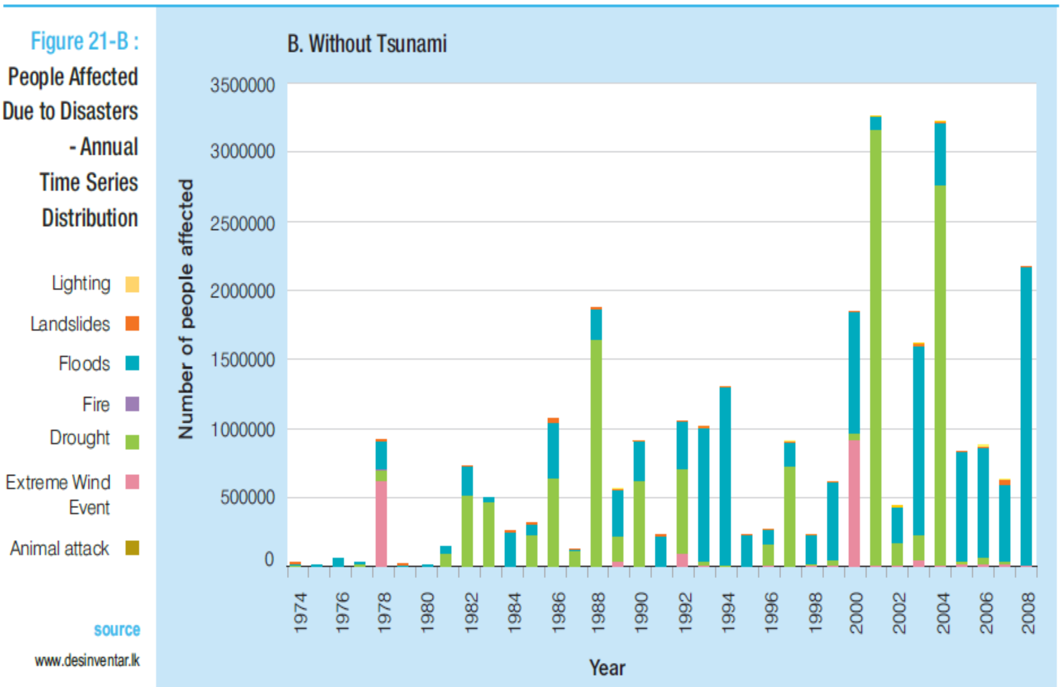

Figure 1.3: People affected due to disasters in Sri Lanka – annual time series distribution [48].

In table 1.3, amount of money allocated for disaster mitigation projects after taking into consideration the damages caused by the flood disaster in year 2012 to 2017 in Sri Lanka is displayed.

Table 1.3: Amount of money allocated for disaster mitigation projects after taking into consideration the damages caused by the flood disaster [5].

Disaster	District	Allocation (Rs. Millions)					
Flood		2012	2013	2014	2015	2016	2017
	Kaluthara	-	3.00	7.00	10.00	24.00	-
	Galle	1.00	10.00	8.00	6.50	9.50	9.17
	Matara	-	1.00	-	0.69	-	-
	Hambantota	2.00	96.00	121.00	14.60	-	13.04
	Puttlam	-	2.00	17.00	17.60	35.17	17.67
	Ratnapura	3.00	3.00	1.00	2.60	52.81	29.13
	Kurunegala	-	13.00	9.00	-	127.56	105.73
	Nuwara Eliya	-	3.00	4.00	1.90	12.98	21.67
	Matale	-	10.00	1.00	10.10	42.00	-
	Kilinochchi	6.00	1.00	23.00	-	7.80	24.07
	Mulathive	-	7.00	-	-	23.50	-
	Kegalle	-	13.00	1.00	8.80	16.30	11.21

Relief expenditure from year 2007 to 2011 for various disasters in Sri Lanka is given in table 1.4.

Table 1.4: Relief expenditure: 2007-2011 [2].

Year	Cyclone	Drought	Flood	Landslides	Others	Total (Rs.)
2007	17,662,054	19,921,772	159,111,089	22,586,775	24.263.218	219,281,690
2008	11,675,820	15,286,758	210,339,335	20,502,716	59,138,606	316,943,235
2009	4,387,936	27,655,774	202,680,398	4,928,667	56,516,573	296,169,348
2010	8,678,239	16,308,306	244,091,220	3,252,698	8,782,287	281,112,750
2011	20,997,295	12,263,596	589,835,798	34,397,743	15,889,434	673,383,866
Total	**63,401,344**	**91,436,206**	**1,406,057,840**	**85,668,599**	**140,326,900**	**1,786,890,889**

Source: National Disaster Relief Services Centre

1.1.3 Motivation for the research

Sri Lanka is an agricultural country and due to that, time and quantity variation in rainfall could have a direct impact on the Gross National Product of the country. Since Sri Lanka is situated in a tropical location near the equator, there could be high variability of weather conditions causing unexpected heavy rain, floods, landslides, high wind, and lightning.

Frequent floods and landslides are causing extensive damage to infrastructure and threaten development. Advanced knowledge of these disasters will assist early prevention and control mechanisms as well as future preparedness. It is crucial to make effective and efficient decisions and planning to prevent future disasters.

Therefore, it was decided to create a tool that can assist in achieving this goal to contribute to the Sri Lankan economy and welfare of people in the hope of developing it further to make it applicable to any country in the world in water resources management.

1.2 Research Problem

Riverine floods, urban floods, and reservoir-induced floods are the three types of floods in Sri Lanka [8]. Predicting natural disasters is very complex due to the lack of proper methods and resources in countries like Sri Lanka. But if there is an efficient prediction system it helps to save not only lives but the environment and infrastructure too.

The present situation in Sri Lanka is that there is no proper integration tool to predict natural disasters from water [5]. There is an abundance of data available in isolation, but it is difficult in analysis to use those related data because they are with different authorities in different formats, and no integration among them. It will give more accurate results if integrated. Could save lot of time by making a model that can use again and again with minimal changes that could be done easily.

1.2.1 Research questions

1) What are the GIS-based flood modelling techniques available and what are their applications?
2) What are the advantages and disadvantages of each method?
3) What are the research gaps?
4) What will be the data needed to solve the identified gap?
5) What are the relevant characteristics of the data?
6) What are the strategies to design and implement the system?
7) How to evaluate the accuracy of the model?
8) What kind of improvements will be beneficial in the future?

In table 1.5, SWOT analysis is done assuming Sri Lanka is the internal boundary of the analysis and natural and external factors that cannot be controlled by Sri Lanka internally as the external boundary.

Table 1.5: SWOT analysis.

STRENGTHS • Network covering the whole island provides the basis for track information regarding disasters. • Flood warning system installed in one major river basin. • Formal communication between officials. • Flood Protection Ordinance No. 20 of 1931 was implemented by Irrigation Department. • The Town and Country Planning Ordinance of 1946 contains provisions for zoning land for planned land-use schemes, thus providing important measures against threats of disasters like floods and landslides due to unplanned development activities. • Sri Lanka Disaster Management Act no. 13 of 2005 was enacted to provide the legal basis for disaster risk reduction instrumentation.	WEAKNESSES • No sufficient information to predict floods in Daduru Oya river basins. • The low priority for data collection and non-uniform data collection. • Documents are posted between officials which is a very slow process. • Delays in entering data into registers. • The same data are repeated in several reports. • Delays in receiving reports. • Lack of data analyzing capabilities using geographical maps. • In general, risk management pre-warning systems are insufficient. • Absence of a single authority to issue warnings. • Takes a long time to make decisions due to lack of integration among different authorities. • Inadequately managed relief work. • Lack of dependable communication network during disasters. • Inadequacy of public awareness and education mechanisms. • Lack of coordination in research and implementation of results.
OPPORTUNITIES • Already established data collection systems. • Institutional arrangement for risk management evolving. • New ongoing research in universities with new technology such as Remote Sensing & GIS, AI, Big data analytics, ML, etc.	THREATS • Lack of Satellite information. • Rainfall intensity increasing irregularly. • Difficult to forecast due to variable weather conditions. • Time duration is law due to the steep slope.

1.3 Scope of the Research

This research attempts to create a tool to integrate data related to flood and use it to predict future flood events more accurately with data in the Daduru Oya river basin and any other river basin in Sri Lanka. However, it does not attempt to:

- Apply to other natural disasters or to apply to the whole world.

1.4 Aim and Objectives of the Study

1.4.1 Aim of the project

The project aims to integrate data from different sources into one platform using ArcGIS and create a tool using python language with ArcGIS so that it will be more efficient and effective, and accurate in modelling, analysing, predicting, and managing floods.

1.4.2 Objectives of the project

- Review about flooding and flood prediction.
- Gather data about the Flooding conditions in the Daduru Oya basin area and prevailing mitigation methods.
- Analyse different flood management strategies and select the best method for the scenario.
- Collect data from different weather stations related to the Daduru Oya basin from different sources.
- Design a method to quantify, rate, and integrate the above factors to get more complete and precise outcomes.
- Analyse existing pluviometric and hydrometric data. (Rainfall, groundwater characteristics, flow characteristics of surface waters, etc.)
- Analyse river basin characteristics. (Land use, soil, topography, etc.)
- Do water level modelling based on weather conditions.
- Forecast floods based on weather and geographical conditions.
- Analyse the strategies to integrate the model in a real-time forecasting system.
- Evaluate the accuracy of the models.
- Propose future improvements.

1.4.3 Significance of the study

- Minimizing flood-prone areas will reduce the risk of life and property, infrastructure destruction, production losses, and long-term economic loses.
- In the long run, it will cause to increase the financial strength of the urban council.
- Investors can be attracted to the country.
- The flood insurance premium will be decreased for the citizens and businesses.
- Will increase the standard of living in the area.

1.5 Limitations of the Project

Due to time and resource constraints, the research will be conducted only for the river basin areas in Sri Lanka, and information technology, and geographical information systems technology will be used to aid the entire process.

1.6 Thesis Structure

Chapter 1 - Introduction, begins with an illustrative discussion of vision behind the ancient and the background of the project followed by motivation for the research. Then a clear statement of research problem with research questions that have been answered throughout the project and a comprehensive SWOT analysis. It flows into scope of the research, aim and objectives, significance of the research to the society and limitations. In Chapter 2 – Literature review, a thorough review of literature was carried out to cover aspects such as, why the study is important, theoretical aspects of the research area, available technology and tools and finally current flood management techniques in Sri Lanka. Chapter 3 – Methodology, introduce the area of study, users of the project, inputs and outputs and data collection. Then it explains the selection of models and tools for analysis followed by the technology adopted. Chapter 4 – Implementation illustrates the model developed for flood forecasting and then a comprehensive discussion of underlying theory with step-by-step explanation of the model building process. Chapter 5 – Evaluation, evaluates research outcomes with Irrigation department flood inundation map comparison and finally in Chapter 6 – Conclusion and Future Work followed by references and Appendix A, B, C, D, E and F with model outcomes, reclassification table, code and PRISMA statement.

Chapter 2

Literature Review

2.1 Introduction

The aim of this chapter is to pave the pathway to build an efficient and effective flood prediction system through understanding theory behind the selected domain, analysing available flood modelling techniques and their applications, to find their strengths and weaknesses. Then the result of the study could be used to put the foundation for the main requirement of building the system to predict natural disasters as given under aims and objectives in previous chapter. To achieve this, related theories were analysed and technologies such as the big data analytic and IoT with machine learning techniques, two-dimensional hydrodynamic flood models, statistical models, rainfall-runoff models, Fuzzy-neuro approach and data mining and data analysis applications were also analysed by a thorough review of available recent literature. Then current flood management activities in Sri Lanka are reviewed.

It was developed a search strategy to discover applicable literature. This search tactic was tailored to databases: IEEE Explore, ACM, and ScienceDirect and the search terms used were the following: Flood, Modelling, Techniques, Forecasting, Prediction, and GIS based. The selection criteria were based on the PRISMA statement [9] and it could refer from Appendix - F. The search mainly focused on mapping existing literature on GIS based flood modelling techniques in the fields of Computer Science, Earth and Planetary Sciences, and Environmental Science. The search then narrowed to the subject areas of geographic information systems, remote sensing, data analysis, and data mining fields. The search span was from year 2010-2020 and include journal articles, review articles, research articles, book chapters, and conference abstracts. All articles before 2010 were excluded from the search except few articles that were published before 2010 according to the importance, and presentation slides from important sources also selected. Only open access articles in English language were selected. A total of 3459 research articles were excluded and 51 records were extracted.

2.2 Importance of Water and Water Management

For the healthy functioning of the planet's ecosystem and for sustainable human development, water is a necessity. The hydrologic cycle is illustrated in figure 2.1. Accessible fresh water makes up less than one percent of all the water on the Earth, in the form of rivers, lakes, ponds, and wetlands. Even though nearly 70 percent of the world is covered by water, when the fresh water that is trapped in glaciers, icebergs, and groundwater is included in the total amount of fresh water it is still comprises less than 3% of Earth's water and the rest is saline, and ocean based. Only 0.007 percent of the planet's water is available to fuel and feed its 6.8 billion inhabitants [10].

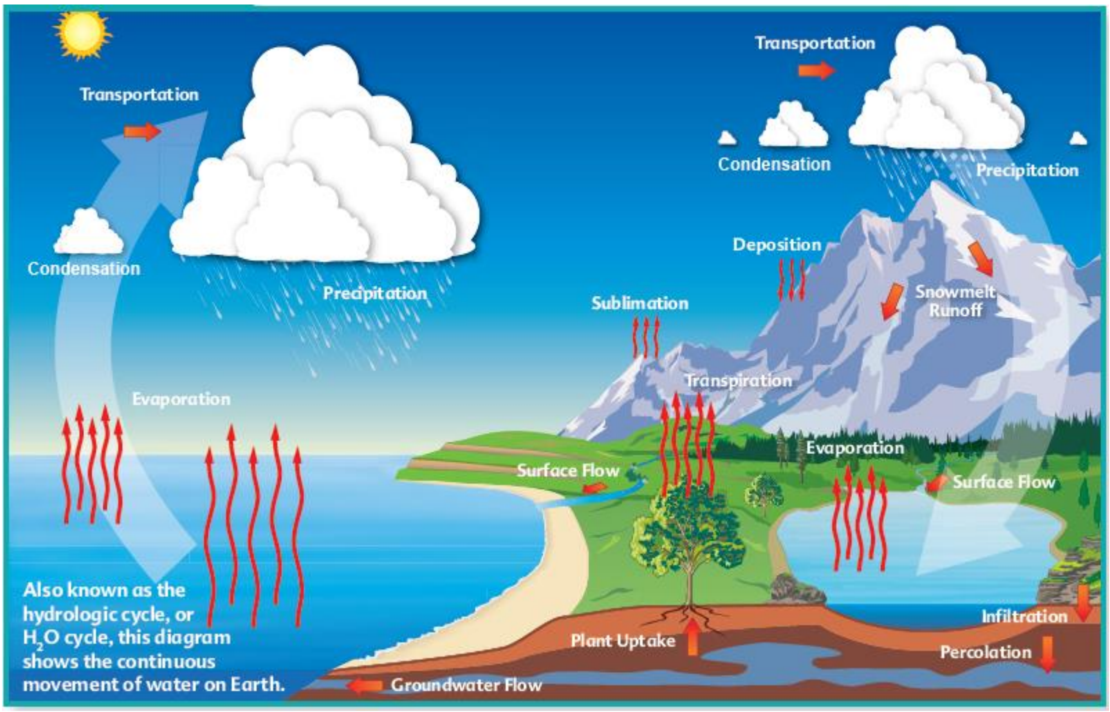

Figure 2.1: The Hydrologic Cycle [10].

Water resources are vital to civilization because they support our way of life as well as the environs on which we rely. Though, there may be insufficient or excessive water, and what is available may not be situated where we require it, or it may be too contaminated or costly. Population expansion, land-use fluctuations, urbanization, and movement from countryside to city regions, as well as global climate change, are all contributing to a rising global water issue. All these issues highlight the need for prudent water resource development and management (figure 2.2). Water supply and wastewater disposal facilities, flood runoff collection and management, and habitat maintenance are all examples of relevant water resources engineering applications [10].

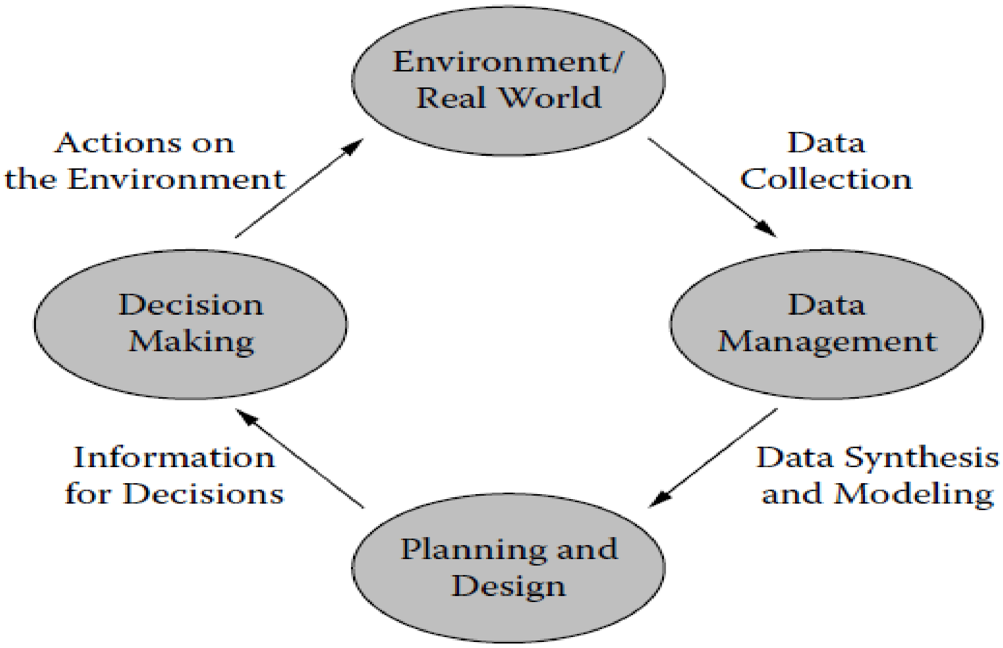

Figure 2.2: Water resources engineering [10].

The ability to balance the supply and demand of water of acceptable quality for various populations and consumers is critical to human survival. Our houses, industries, towns, farms, and leisure places all require water, and the effective operation of natural and human water delivery systems is critical to their performance (i.e., sustainability). To maintain modern lifestyles and avoid shortages (droughts), surpluses (floods), and resource deficiency, a lot of time, energy, and effort has gone into learning more about the spatial and temporal trends and characteristics of individual hydrological systems so that we can predict, control, and adjust system activity [11].

2.3 Flood Disaster

2.3.1 Definitions of flood

There are several definitions available from a variety of domestic and global sources. The World Meteorological Organization (WMO)/UNESCO International Glossary of Hydrology (WMO No. 385, 1992) defines terminology in many languages. The term 'flood' is defined as follows in the Glossary:

(1) A short increase in the water level in a stream to a peak, after which the water level falls more slowly.

(2) An elevated flow rate, as determined by the stage height or release.

(3) The turn of the tide. [12]

Teeming the water of the typical bounds of a stream or other body of water, or build-up of water by drainage over regions that are not ordinarily underwater is described as 'flooding', which refers to the impacts of a flood rather than the flood itself [12].

River floods, coastal floods, pluvial and groundwater floods, and manmade system failures can all cause flooding in human settlements. Overflows are generally the consequence of a complicated set of causes issued by a mixture of climatic and hydrological extremities, such as heavy rainfall, and increasing river flows. Inundating, on the other hand, is a common occurrence as a result of human activities such as uncontrolled expansion and development in floodplains or as a result of a dam or embankment failing [3].

2.3.2 Flood types

2.3.2.1 Flash floods

Flash floods are usually linked to short-duration strong convection storms that fall over a narrow region. Flash flooding may occur in nearly any region with steep slopes, although it is most prevalent in mountainous areas where strong thunderstorms occur often. Flash floods are frequently caused by heavy rainfall that lasts only a short period. This sort of flooding frequently sweeps away buildings, roads, and bridges across small streams, posing a serious threat to communities and transportation in these isolated locations [12].

2.3.2.2 Fluvial (riverine) floods

Fluvial flooding may occur in a variety of river and watershed systems. Flows surpassing the volume of stream channels and spill out over natural banks or constructed dams produce overflows in river valleys, which usually happen on flood plains or wash lands. Flash floods, which occur in narrow, steep, and restricted valleys and are characterized by their rapid formation following rainfall and high flow velocities, are typically more destructive. They are extremely hazardous to human life because of their speed [12].

2.3.2.3 Single event floods

The most frequent type of flooding occurs when significant rains fall in a drainage basin for hours to days, resulting in catastrophic flooding. Torrential rains are usually linked with cyclonic disturbances, mid-latitude depressions, and storms, as well as well-defined synoptic-scale frontal systems [12].

2.3.2.4 Multiple event floods

These are the outcome of severe rainfall and a series of meteorological disturbances that follow one other closely. The channel of a succession of low-pressure zones or depressions from the Bay of Bengal, which follows a similar course is the reason for frequent floods in the Indo-Gangetic plains and central Indian regions. Over western Europe, several event floods can affect vast basins in mid-latitude locations in the winter, when sequences of active depressions occur [12].

2.3.2.5 Seasonal floods

As a result of heavy seasonal rainfall these floods occur regularly. Monsoonal climatic zones are generally the worst hit, and catastrophic circumstances occur when ‘normal’ flooding is substituted by protracted or high-runoff floods. Inundating is typically a basin-wide occurrence that might continue for many weeks. Various separate peak events can occur throughout a flood season in vigorous monsoon conditions. Seasonal floods occur due to extreme water levels in lakes in the upper sections of a river basin, such as Lake Victoria and the River Nile. Wet circumstances in the top section of a watershed, which has a dissimilar climatic system than the lower, impacted portions, might cause another form of a seasonal flood. Rivers like the Nile and Yangtze are good examples [12].

2.3.2.6 Coastal floods

The most common causes of this sort of flooding are rainstorm surges and strong winds that coincide with high tides. The surge is caused by a rise in sea levels caused by low air pressure. The piling up of water is magnified in some configurations, such as big estuaries or limited marine regions, by a combination of seabed shallowing and return flow retardation. When hurricanes (cyclones) hit, major deltas like the Mississippi and Ganges are susceptible to this sort of flooding. Because of specific paths of winter depressions, the southern North Sea in western Europe is another vulnerable location. If the surge happens at the mouth of a river that streams into the sea, the surge will impede the river's flow, causing in acute inundating along and close to the shore. Tsunamis caused by sub-seabed earthquakes are a highly specialized source of significant coastal flooding on occasion [12].

2.3.2.7 Estuarine floods

Inlet regions of the coastline where a concentrated seaward flow of fresh water in a river meets the coastal tide are Estuaries. During high tides, the collaboration between the seaward flow of river water and the landward flow of salty water can result in a water build-up or inland-moving tidal bore. The funnel form of many estuaries frequently increases high water levels in the linked river's higher, narrower sections. These sorts of floods are particularly common in deltaic sections of rivers near coastlines, such as the Ganges Mouths. In terms of flooded depth and area, they are more common and less severe than floods produced by storm surges [12].

2.3.2.8 Urban floods

Severe precipitation within towns and cities causes fast overflow from paved and built-up areas, surpassing the volume of storm drainage systems, resulting in urban flooding. Ponds arise in low-lying regions of cities not just because of high rainfall rates, but also as a result of drainage blockages produced by material clogging drainage culverts and outlets, frequently owing to a lack of maintenance. Embankments and pumped drainage systems safeguard several major cities in delta areas, including New Orleans, Dhaka, and Bangkok. When rainfall rates surpass pumping capacity, storm runoff accumulates quickly, causing widespread flooding [12].

2.3.2.9 Snowmelt floods

The spring thaw creates meltwater flow in upland and high-latitude locations where large amounts of snow accumulate during the winter. If temperatures rise quickly, the pace of melting may accelerate, resulting in floods that can spread to lower sections of river systems. Meltwater floods will be more severe if the melting is followed by intense rain, and they will be made worse if the subsurface stays frozen. Even though a seasonal phenomenon in which significant snowfields exist in headwaters, resulting in favourable flooding in downriver zones, catastrophic impacts can happen on minor scales, particularly in locations vulnerable to fluctuations in cold and warmer wet winter weather [12].

2.3.2.10 Ice- and debris-jam floods

Ice floes can build in rivers in places where seasonal melting is rapid, producing impediments and obstructing flows, creating river levels to increase upriver of the ice jam. A flood wave, like that generated by a dam breach, might flow downstream if the “ice jam” is suddenly released. Landslips and debris floods can be caused by both meltwater and strong rains in steep regions. Major constrictions can form as these migrate downstream. Severe floods can occur if these structures collapse or are compromised. Both of these events are extremely difficult to forecast [12].

In Sri Lanka, other than snowmelt floods and ice-and debris-jam floods, all other categories of floods may occur from time to time.

2.4 Flood Management Initiatives

Activities related to flood management may be divided into four categories:

1. Efforts to mitigate the flood.
2. Efforts to reduce flood damage vulnerability.
3. Efforts to change the loss load.
4. Coping with the loss. [13]

All these flood-control techniques fall under the following categories: Measures that are structural and non-structural. All actions performed as part of the activity of "Modifying the flood" that is physical are referred to as "Structural measures", while those used as management tools without substantial construction activity are referred to as "Non-structural measures" [13]. Flood prediction and early warning have proven to be an efficient and cost-effective non-structural technique that can be used to limit the damaging consequences of floods, which often affect lives [3].

2.5 Flood Forecasting and Warning

Flood forecasting allows for forewarning of when and to what degree the river will use its flood plain, as well as for how long. A countrywide flood forecasting, and warning system might be created as part of the policy of putting more focus on non-structural solutions. Human suffering can be mitigated to a significant amount with credible advance information/warning about coming floods, loss of human lives, and movable property. People and livestock can be relocated to safer areas. Similarly, important movable properties might be relocated to safer locations outside of the flood zone. During various plan eras, the nation may implement many reservoir systems to harness water resources for agriculture, electricity, and other purposes. Flood control has been attempted to be achieved as one of the objectives of multi-purpose dams by providing flood cushion, recognizing the tremendous possibility of reservoirs in seizing floods, and managing downstream flows for flood control [3][13].

2.5.1 The role of flood forecasting in flood management

Flood prediction is an important element of flood management planning and development. Temporary flood gates or moveable barricades, home protection such as sandbagging, and local evacuation to flood shelters can be successful non-structural solutions for target inhabited flood plain regions [3][12].

The collaboration of water management organizations, local or municipal governments, transportation, and communications operations, and emergency services are necessary in flood managing. These consumers may plan ahead of time and respond appropriately if information from flood forecasting is offered. Flood forecasting may be part of a larger disaster management expertise delegated from the highest levels of government in extreme situations. Flood forecasting's precise role will vary depending on the circumstances required by both the hydro-meteorological and built-up environments [3][12].

2.5.2 Elements of flood forecasting systems

A critical component in building inundation alert method is guaranteeing their resilience so that they can handle a wide variety of possible occurrences. Flooding is a phenomenon with a broad range of magnitude and intensity. As a result, inundation alert procedures must be built to anticipate both uncommon and more damaging occurrences, as well as less dangerous and more regular ones. Nevertheless, during catastrophic occurrences, the ambiguities intrinsic in predicting are probable to be amplified, and such scientific and technical constraints must be recognized [3].

The "United Nations" published its "Global Survey of Early Warning Systems" in 2006, and it highlighted four aspects in environmental threat early warning methods, including inundation predicting:

1) Risk awareness is the systematic evaluation of risks and vulnerabilities, including the plotting of patterns and trends.
2) Monitoring and alerting services: precise and early predicting of dangers via the use of dependable, scientific techniques and technology.

3) Distribution and transmission: unambiguous and timely delivery of alerts to all vulnerable individuals.
4) Reaction ability: nationwide and provincial capabilities that provide information about how to respond appropriately when alerts are sent. [3]

2.5.3 Basic contemplations

To design a suitable flood forecasting service, it is necessary to understand: the hydro-morphological characteristics of the basin topography, geology, and soils, and the degree of structural development; the main physical processes occurring during hydro-meteorological events; and the type of service that is required and that can be achieved technically and economically [3].

Each river basin has its own set of flood features and patterns. In general, five types of basins can be classified based on their temporal and spatial responses to a hydrometeorological incident (Table 2.1) [3]:

Table 2.1: Types of river basins [3].

S N	Types	Size	Response time	Characteristics
a	Urban basins	Very small (a few km^2)	One or two hours	Densely populated and have a high proportion of impermeable surfaces that overwhelm the capacity of the drainage network
b	Upper watersheds and small to medium catchments	Between 10 and 500 km^2	A few hours	Upland areas and with steep slopes that react quickly
c	Medium-sized rivers	Between 500 and 10 000 km^2	Days to weeks (reflects major seasonal meteorological conditions)	Long-distance flow propagation with varying contribution of tributaries
d	The very specific domain of estuaries		Several hours (depending on the length of the fluvial upstream reach)	Combined influence of maritime storm surge, tide effects and upstream incoming flood and strong wind
e	Groundwater-controlled river systems		Long-duration flooding, lasting several weeks in some cases	Long, periodic fluctuations of the water table

By analysing the table, it could be derived that the river basins of Sri Lanka come under the category of medium-sized rivers since their size is between 500 and 10 000 km^2 and other characteristics also match.

Any forecasting service's nature is mostly determined by the sorts of flooding that occur in the basin. Table 2.2 depicts these procedures and demonstrates how a single service may need to support a variety of basin categories [3].

Table 2.2: Physical processes of flooding [3].

Physical influence	Wind	Infiltra-tion	Rainfall intensity	Run off	Propaga-tion	Tide and surge	Water table
Type of basin							
Urban		+	+++	+++	+		
Upper basin		++	++	+++	+		
Long river	+		+	++	+++		+
Estuary	+++				++	+++	
Aquifer	+			+		+	+++

Watersheds in Sri Lanka comes under long river category as derived earlier. Therefore, wind, rainfall intensity, run off, propagation and water table should be considered.

2.5.4 Types of services offered

By balancing the technical feasibility of forecasting flood threats with the economic justification for protecting sensitive persons and infrastructure, it could determine the category and amount of service that can be offered. The varieties of services, from the most basic to the highest level of quality, are briefly given below:

1) Threshold-based flood warning

   Rather than a quantitative projection, this is a qualitative estimate of the rise in river flows or levels. Extrapolations are conducted at regular intervals to adjust the projected or actual flood situations [3].

2) Flood forecasting

   A more decisive service that is based on simulation and modelling technologies. Simple procedures such as statistical curves, level-to-level correlations, or time-of-travel relationships could be used in the simulation. These procedures enable a quantifiable and time-based forecast of water levels, allowing for inundation alerts with an appropriate level of assurance and consistency [3].

3) Vigilance mapping

   An extension of the site-specific alert strategy outlined in 2). Several countries' inundation alert services now provide map-based visualizations as an Internet service (for example, France’s “vigilance map”). The risk levels obtained from observations or models are denoted by a colour code (in the French example, green, yellow, orange, red) representing the gravity of the event [3].

4) Flood prediction

   The most advanced facility and necessitates the use of a hydrological or hydrodynamic level-and-flow model in conjunction with digital depictions of the inundation land surface. The type of the risk region is the determinant of the level of detail and precision of the terrain model. Models like this may forecast floods in extremely specific regions, such as housing areas or important infrastructures like power plants and highway or rail crossings. Creating this technique necessitates a comprehensive understanding of floods linked with previous extreme occurrences [3].

It was decided that the study should be carried out in a manner that it could facilitate Inundation forecasting type of service to be given in foreseeable future.

2.5.5 Required data

Flood prediction and alert necessitates the collection of many technical data sets, which include:

1) Hydrological data
   River level and flow, and especially for predicted spots and high-risk areas.
2) Meteorological data
   Rainfall statistics, weather predictions, and rainfall incident alerts.
3) Topographic data
   physical spatial characterization of runoff-influencing variables that may be necessary for models; and
4) Structural and social data

   Population density, high-risk areas, reservoirs and flood protection, electricity, and transportation infrastructure. [3]

Other than structural and social data, all other data sets will be used in the study.

2.6 Methods of Flood Prediction and Modelling

2.6.1 Why model?

To assist decision-makers in developing water resource options, analysing their implications, and interpreting and selecting viable solutions for implementation, river basin models which are interactive programs that use analytical approaches like simulation and optimization algorithms could be used. Models mimic the behaviour of water resource systems based on a set of rules that control water distribution and infrastructure functioning. Models could also be used to optimize the behaviour of water resource systems based on an objective function and associated restrictions. Models tend to shorten the time required for decision-making in various applications while improving the consistency and quality of those judgments [14].

River basin modelling necessitates, to various degrees depending on the situation at hand, the following activities:

- Data Measurement and Gathering – receiving different data (e.g., water level and temperature, precipitation, air temperature, concentrations, and so on) from stations located across a river basin. Various economic and social statistics are also measured and gathered.
- Data Processing – the storing and processing of data relating to the basin’s processes of interest, including both spatial and time-series data. A relational database is used to store the measured data in this context, a data model is used to organize the data in the database using the “basin” concept, and a geographic information system is used to show the data visually.
- Analytical Tools – models that anticipate basin responses to various climate and development states.
- Decision Formulation and Selection – use of model findings and engagement with users to make water management decisions in the basin; and
- Decision Implementation – distribution of water usage decisions under diverse situations. [14]

A generic framework for the usage of a river basin model is depicted in figure 2.3.

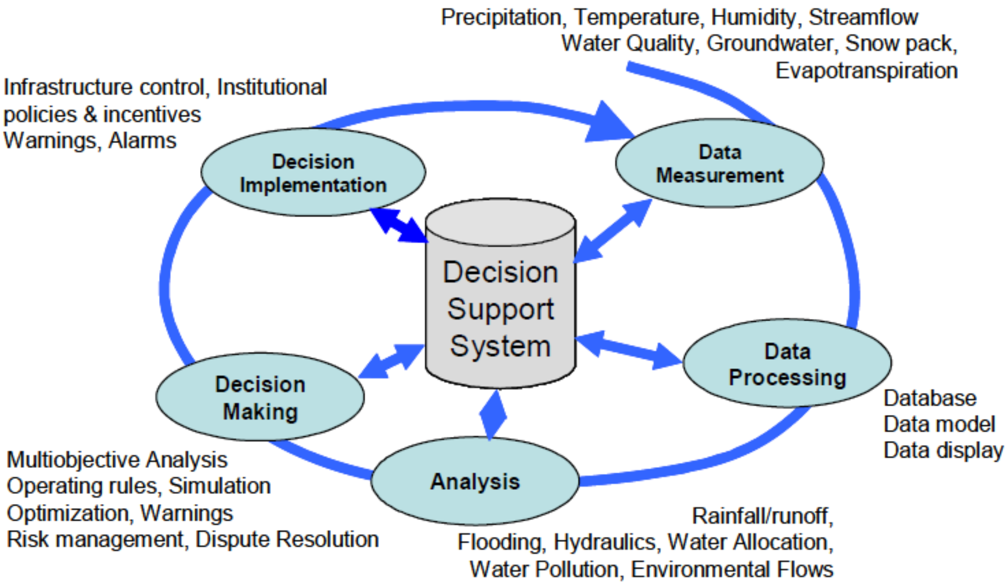

Figure 2.3: A generic framework for the application of a river basin model [13].

Flooding event protection necessitates advanced dimension models and fewer time steps than numerous other water resource management models, such as municipal or agricultural water supply, recreation, water quality, and so on. Inundation drifts typically happen at brief time intervals (hours, days, or weeks), which makes it hard to prototype such occurrences using simple mass balances in multifunctional water resource planning models. Flood overflow due to flood wave distribution in a watershed necessitates two-dimensional modelling rather than one-dimensional modelling. To defend against floods, both structural (e.g., reservoirs, levees, floodproofing) and non-structural (e.g., land use regulations and zoning, inundation alert, and removal strategies) methods are utilized. Upriver reservoir operatives must offer storage space for inundation security and emergency notice to downriver floodplain residents. These operatives must be aware of how much water to discharge and when to release it to limit predicted flood destruction downriver. Overflow storage volume and flood flow discharge rules influence flood flow and peak in a basin. These may be calculated by modelling flood events as they enter basin reservoirs. Flood destruction may be anticipated if the peak flow dissemination and the connections between flood phase and destruction, as well as flood phase and peak flow, are identified [14]. A schematic diagram of the components of a river basin system is illustrated in figure 2.4.

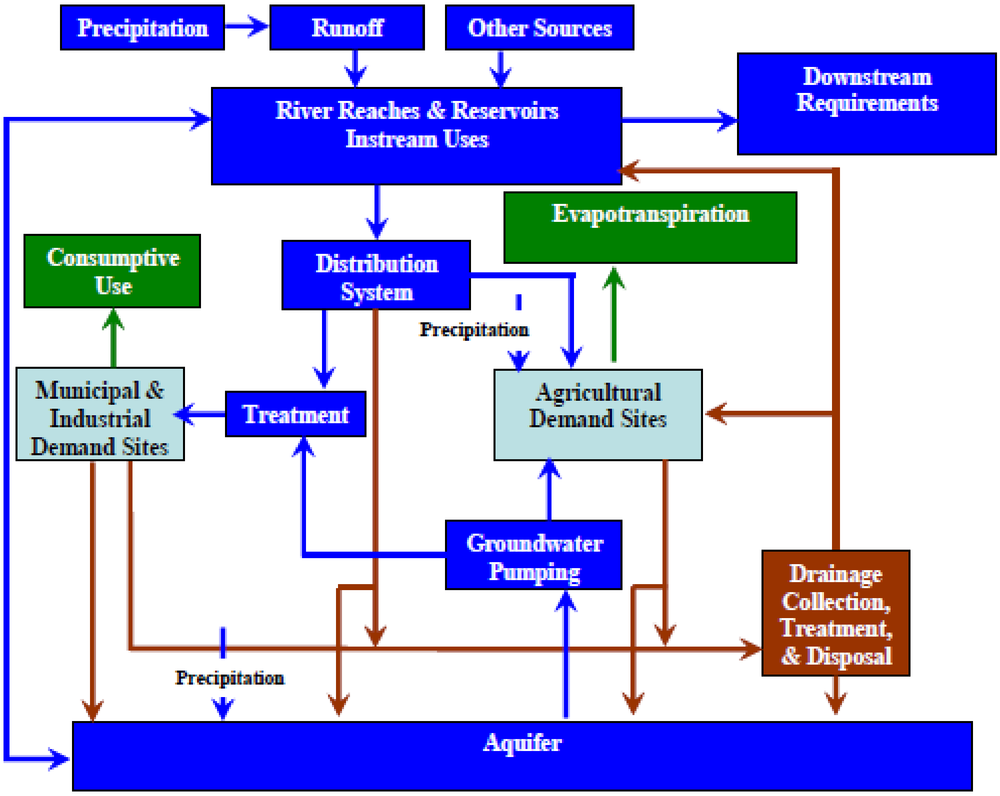

Figure 2.4: Schematic diagram of the components of a river basin system [14].

2.6.2 Process of model building

Following are the steps of river basin model building process:

- Identifying the problem – main aspects of the basin to be modelled should be identified, as well as their relationships and interactions. That is, the model's overall outline and purpose must be determined. Given the time and resources available for modelling, the modeler must choose the right sort of model for the system as well as the level of precision required. In general, the simplest model with the fewest parameters that produces accurate outcomes in the time allotted is selected.

- Conceptualization and development – provide a mathematical representation of the formerly discovered links in this stage, relevant computing approaches for the issue are also developed and implemented.

- Calibration – Obtain trustworthy estimations of the model's parameters. Prototypical outputs are likened to real, past, or assessed system outputs, and model parameters are modified till the values projected by the model coincide with the measured to a fair degree of accuracy.

- Verification – The model uses a separate set of input data, such as a dissimilar form from that utilised in the calibration stage, and the model outcomes are compared to assessed outcomes. If they match, the model has been validated and is complete for utilisation.

- Sensitivity Analysis – Many of the input data and assumptions used to build a model are measured incorrectly, calculated from insufficient data, or are poor estimates. People who build models must understand the influence of these various sources of fault or indecision on their model findings. Sensitivity analysis investigates and computes the effects of potential input data mistakes on anticipated model outputs and system execution indicators. Minor variations in model parameters could sometimes result in huge, sudden fluctuations in model results. Frequently, sensitivity analysis is a trial-and-error method of modifying model parameters, coefficients, and inputs progressively and then solving the model. In this manner, the person who model may see the modification in model output values caused by minor changes in input values and evaluate the significance of inaccuracy or indecision in model inputs in the modelling procedure. [14]

A generic illustration of the stages in the model construction procedure is as of figure 2.5.

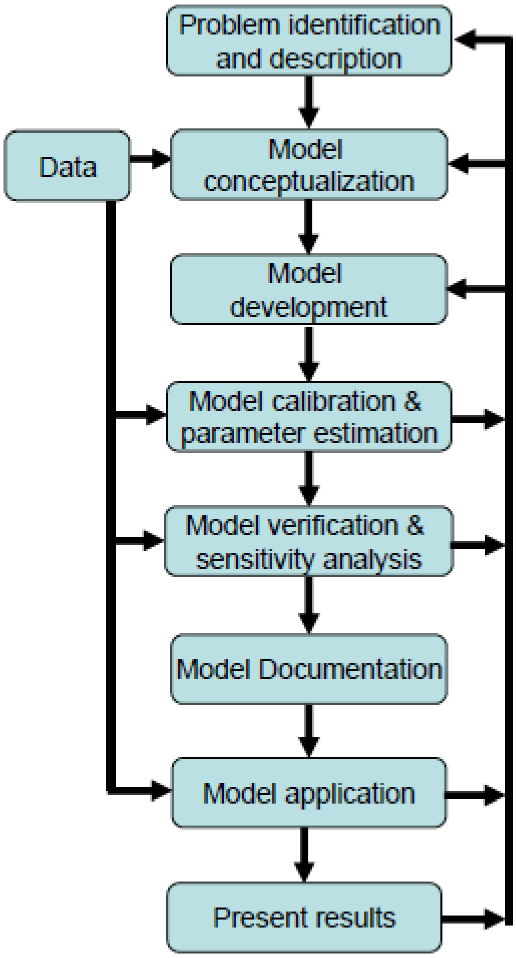

Figure 2.5: Generic illustration of the stages in the model construction procedure [14].

2.6.3 Understanding flood hydrology

While developing flood forecasting models, it is critical to recognise the origins of inundating in each specific catchment or river basin. The catchment's magnitude, form, and geographical construction determine the fundamental response to the primary cause of floods, which is precipitation input. The pace with which the catchment responds to rainfall is affected by land use, geology, soils, and vegetation. Losses to soil and deeper recharging are also important aspects of inundation response [3].

In this context, the characteristic of the rainfall triggering inundation must be completely aware of. Both in terms of incidents and seasonal climatology variables are caused by diverse kinds of rainfall. Reactions in a specific catchment, as well as the comparative significance of the effect of various kinds of incidents, must be examined to determine the best strategy for the development of flooding warnings. Under these situations, contemporary remote sensing techniques may be more valuable than traditional arrangement. It may be feasible to see rainfall via satellite or radar surveillance. River conditions must be monitored in appropriate locations for vulnerable areas, but it is critical that these monitoring offer enough lead time because the rapidity of inundating at a high rate is also prevalent in dry and semi-arid environments [3].

The emphasis on flood risk, as well as the necessary actions for flood forecasting and warning, must be identified via comprehensive investigations. This has recently been described by the "Source- Pathway-Receptor" concept, as shown in Figure 2.6. Flood hydrology must be understood from the watershed and river system to the "targets." [3].

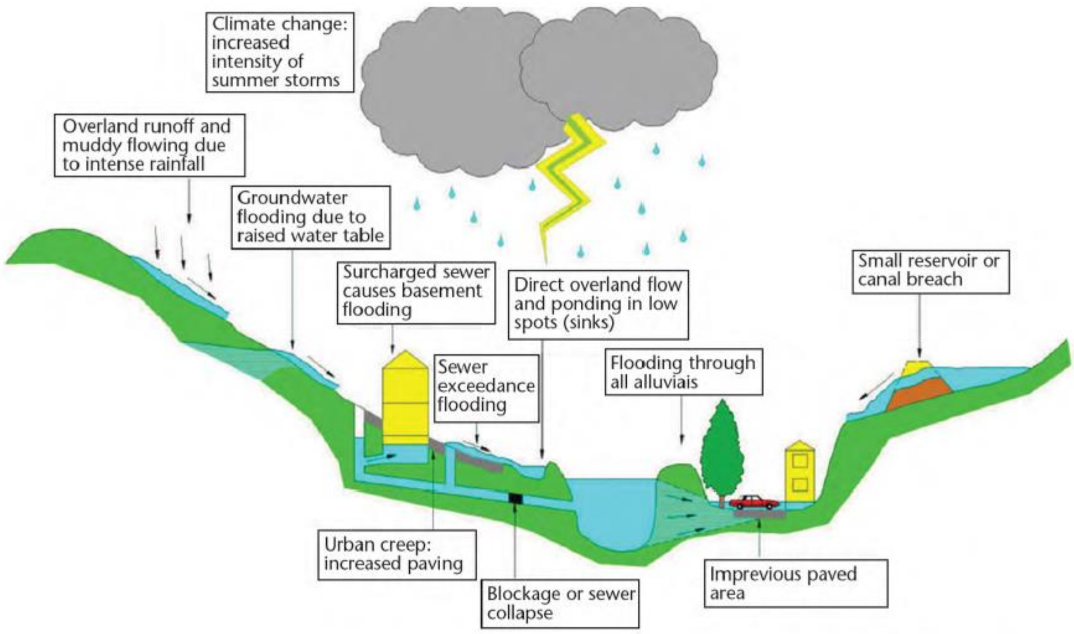

Figure 2.6: The source-pathway-receptor approach (Hankin et al., 2008) [3].

2.6.4 Selection of appropriate lead times

The lead time provided by an inundation alert must be sufficient to allow for responsive action. The delivery of data from the observation system must be included in the lead time, and model prediction turns must be rapid enough to have the information accessible in time for predictions to be provided. Figure 2.7 is an example of a trade-off among the amount of alert time available and the level of precision [3].

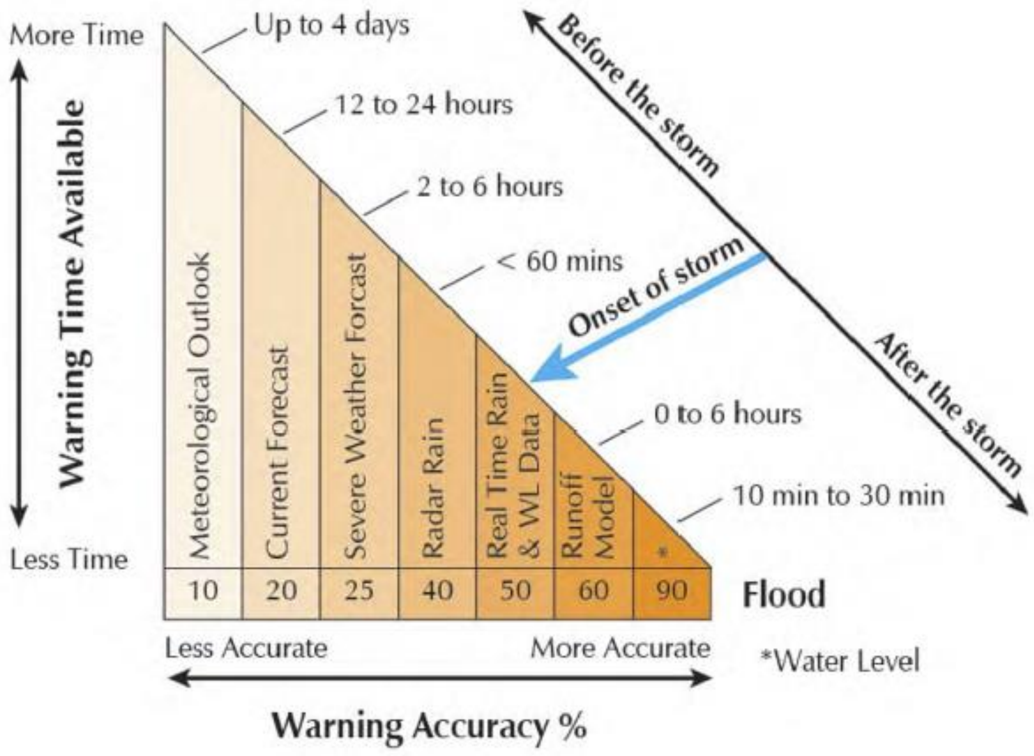

Figure 2.7: The trade-off among alert time and inundation prediction precision for flash flood situations (Wright, 2001) [3].

2.7 Available Technological Options

2.7.1 Artificial Intelligence (AI) based methods

Even though many parameters need to be manually calibrated in traditional hydrological models, they could generate good prediction results by precisely modelling the flood formation process. Based on historical data, data-driven models can readily achieve the short lead time flood-forecasting as an alternative but its performance in long lead time hydrology forecasting is weak. To offset the performance gap between these two types of models, a novel hydrology forecasting model has been proposed in this paper and it uses a convolution regression algorithm based on the basic principle of flood formation. The impact of rainfall on the flow of the basin section is reflected by this model. The output of the model is a series of data rather than a single value because it superimposes the effect of unit hourly rainfall on the future n-hour flow changes. The factors such as predicting the process of a flood, peak value, and its arrival time that is most important in flood forecasting are possible due to that. The flow changes are predicted by superimposing the impacts of hourly rainfall on the future flow changes which are reflected by the model. As the first step, the work is implemented on historical data onto the Xixian River Basin in Henan Province, China. The training set of the model is constructed by using the flood process selection algorithm proposed in the paper through data filtering. The next step is to update the weights of the model using the gradient descent algorithm, and ten flooding events generated in the past ten years were used to verify the optimal weights. The most significant contributions of this article can be generalized as follows:

1) The first main contribution of this paper is it proposed a novel convolution regression algorithm, derived its closed-form expression, and gave its iterative solution by using a machine learning method. Not all samples are required to be structurally consistent because of the characteristics of the convolution function. The number of inputs and outputs of each sample only need to match the same quantitative relationship, and this feature makes sample selection highly flexible, since flood processes of varying duration may be chosen to train the model. This feature is also relevant in the field of signal processing.
2) The second contribution is that a flood process selection algorithm is proposed to extract the flood processes in historical data.
3) Finally, the flood forecasting model based on the proposed CRML is validated by historical flooding events. The results showed that the model has high accuracy in predicting flood peaks and their arrival time.

This study proposes a flood process selection algorithm based on the sliding window to apply the suggested CRML to hydrology forecasting. After using this algorithm, a set of samples consisting of flood processes was generated. The convolution coefficients are obtained after several rounds of iterations with reasonable parameters. Finally, the hydrology forecasting model based on the CRML was verified by 10 flood events, the result shows that it has high accuracy in flood peak and its arrival time and complies with the requirements of hydrology forecasting. The hydrology forecasting model based on CRML can effectively predict short and long lead-time floods due to its physical meaning. The key difference of the proposed model to previous work is that this model does not need to calibrate complex parameters compared with the traditional hydrological forecasting models, but only needs to learn convolution coefficients from historical data. This greatly simplifies the flood forecasting work and improves the forecasting efficiency. Meanwhile, this model could predict flood processes directly by using the rainfall data and the trained convolution coefficients without more complex calculations and has a good effect in long lead-time flood forecasting.

Finally, the numerical results show that the qualified rates of the model in predicting flood peak flow and its arrival time are approximately 90% and 100%, respectively. Compared with the latest popular artificial intelligence schemes, the model structure is clear and concise. And, when coupled with the physical meaning of the traditional model and machine learning technology, the model can perform the work of long and short lead time hydrological forecasting with accuracy. In addition to uncontrollable factors such as manual intervention, rainfall forecasting errors, etc., data processing methods such as quadratic interpolation, smoothing, and other model errors, etc. will affect the result of the model. Therefore, further work needs to be done in the processing and extraction of data. Future study will begin with a quantitative examination of historical data, followed by the development of more scientific and effective experimental procedures and the determination of model parameters. The future work will also investigate the combination of advanced communication technology with artificial intelligence, to introduce real-time flooding measurement monitoring, intelligent parameters filtering, and adaptive model selection, into flood forecasting as well as controlling. [15]

The extreme learning machine (ELM), a well-known single-layer feedforward neural network, has been widely utilized to handle regression and classification issues due to its satisfactory generalization ability and search rate. However, because to the random assignment of network parameters, the conventional ELM approach frequently falls into second-best solutions with a high likelihood. To overcome this problem, this article aims at developing a hybrid model for monthly runoff time series forecasting. The study area is Semarang city of Indonesia in Java. In the hybrid approach, an effective swarm intelligence method, grey wolf optimizer (GWO), is used to optimize the ELM method's input-hidden weights and hidden biases, and the Moore-Penrose generalized inverse method is used to find the hidden-output weights. It can be found that the traditional ANN model provides the worst results among all the considered models, which proves the modelling difficulty of nonlinear monthly streamflow time series. Besides, three other methods produce different results while the results of the standard ELM and SVM model are inferior to the proposed ELM-GWO model at both the training and testing stage, demonstrating the feasibility of swarm intelligence in optimizing the model parameters. For instance, compared with the ANN, ELM, and SVM models at the training phase, the ELM-GWO method can make about 25.6%, 20.1%, and 19.8% improvements in the RMSE value, and about 37.9%, 33.7%, and 37.7% improvements in the MAPE value; at the testing phase, the improvements in the R-value are close to about 7.4%, 5.9%, and 6.4% while the improvements in the CE value are about 15.0%, 11.0%, and 12.2%. Thus, the proposed method proves to be an effective method for monthly hydrological forecasting. In the future, numerous interesting research directions can be considered: One is to assess the viability of recently updated GWO versions in which the algorithm's swarm diversity and global search capabilities are boosted by hybrid techniques such as parallel computing, local search, and chaotic mutations. Besides, the other is to design more effective initial modules that can enhance the network compactness of the extreme learning machine; while the last one is to explore the feasibility of ELM-GWO method in various time-scaled hydrologic forecasting for Three Gorges and other reservoirs around the world. [16]

The Baliqlu Chai Watershed is a study region in Iran's Ardabil province, having an area of 1036 km2 and an average rainfall of 280.9 mm. Mismanagement of water resources has been a problem in the area. Runoff increases when vegetation degrades, which can pose issues. Thus, predicting runoff over the next several years can aid in water resource management. The application of SWAT and ANN models for estimating runoff has been studied in this work, as has been done in previous studies. The key idea and distinction in this study is that an optimum neural network using SWAT and ANN models is utilized to produce more accurate runoff forecast results by minimizing constraints and errors. The research also improves the basic optimization algorithm to resolve the algorithm in terms of premature convergence. This study will be conducted to help spread the research to different regions of the world in a region different from other regions. In this study, the use of the SWAT and ANN models and an improved model of a metaheuristic were employed for resolving the explained shortcoming. The method of optimization is based on a Mutated model of the Whale Optimization Algorithm (MWOA) that enhances the expected results by reducing the error in the ANN. First, the runoff estimated by the SWAT model, for this purpose, is used of 30 years of statistical data for the calibration and validation model. The ANN was fed simulated runoff, which was then assessed, and the MLP/MWOA method was utilized to enhance the accuracy of the projected runoff. The findings demonstrate that the points distribution in the SWAT-MLP/MWOA model is smaller and has the best linear fit, according to the regression model. The results of statistical indices revealed that the SWAT-ANN outperformed the SWAT model, with R2=0.80, RMSE=1.61, NSE=0.79, and RE=-0.11. However, the SWAT-MLP/WOA model has R2=0.84, RMSE=1.42, NSE=0.81, and RE=-0.09, making it the best model for runoff prediction. For future study, a runoff forecast can be conducted using the K-Nearest Neighbour (KNN) and fuzzy meta-heuristic method. Also, in other applied models, the impact of the upstream watershed can be investigated by raising or reducing the coefficients of the valid model equation. [17]

Two spatiotemporal predictive stream-flow tasks from the Yangtze River's main channel and tributaries are assessed. Recent advancements in stream-flow prediction utilizing Recurrent Neural Networks (RNN) or Long Short-Term Memory (LSTM) have sparked interest in their application in hydrology. Predicting hydrological time series is of great importance but is very challenging as it is influenced by many complex factors such as dynamic spatiotemporal feature correlation and nonlinear meteorological-hydrological. In this regard, a framework based on dynamic spatiotemporal attention (DSTA) was suggested to forecast the streamflow of a hydrological station over a period of several days. It is divided into three major modules: a spatial module, a temporal module, and a trend input module. This paper proposes a deep learning model that focuses on the attention mechanism of spatiotemporal flow forecasting features and brings about improved prediction accuracy. Provide three main contributions as listed below. (1) Propose a new Dynamic Spatiotemporal Attention (DSTA) framework, which contains two types of attention modules: temporal attention learned by the same monitoring station input features for temporal correlation, and spatial attention learned by different monitoring station input features for spatial correlation. (2) The decoder of the framework has an additional consideration for the impact of future factors of input to provide a trending direction for the output. (3) Conducted extensive experiments on the research watershed, including the upper, middle, and lower reaches of the Yangtze River. The experimental results show that the method is significantly improved compared with the existing methods and reveal the contribution of all input features. Experiments on real data sets from four watersheds in the Yangtze River's main channel demonstrated that the method outperforms the six baseline methods. Experiments demonstrate that the spatiotemporal attention model framework may greatly improve the standard LSTM model and the generic Attention-LSTM model when tested in four watersheds. In terms of three measures, the model also achieves the best predictive performance for all baselines (MAE, RMSE, and R2). In the future, the approach could be expanded to cover both long-term and real-time flood predictions. Furthermore, the spatiotemporal attention model could be used to investigate more complex flood forecasting problems in small and medium watersheds. [18]

2.7.2 Sensors and Gauges-based measurement

In the study, a novel approach for detecting flooding levels is developed, which requires no additional equipment and hence no installation or maintenance expenses. Smartphone sensors have captured the stride features in various flooding levels, which are subsequently utilized to categorize flooding levels. To do this, 12 volunteers took smartphone sensor readings in pools of varying depths, which were then used to train machine learning models in a supervised way. Support vector machines, random forests, and I Bayes models have all been tried, with support vector machines outperforming the others with a classification accuracy of 99.45 percent. Further analysis of the most relevant characteristics of the gait in different water levels was easily distinguished using accelerometer and gyroscope readings and was using to identify flooding levels. Random forest, SVM, and NB classifiers were attempted to predict the flooding level, of which SVM performed best with 99.45% accuracy. The most relevant features for classification match the intuitive understanding of gait in different flooding levels. In future work, other models for classification like kNN, CNN, deep belief networks, or HMMs may be attempted. Features for classification agree with the intuition of gait characteristics in different depths. In this work, prediction of flooding-level, which could be one of four values, has been performed, and this is a classification problem. It may alternatively be treated as a regression problem, and flooding level may be predicted as a continuous value; this would require data from all flooding levels. To take full advantage of smartphone sensors, the authors believe that a body position-independent mechanism should be used; further, flooding level detection should automatically be triggered without user involvement. A combination of the above two features would enable flooding data to be automatically transferred to the central server, leading to the generation of a 'flood map' of the locality. For this approach to be feasible, continuous mobile sensing, and energy-efficient mechanisms on the lines should be used. Another interesting research direction would be the classification of flooding levels using sensor signals picked up from vehicles moving on flooded roads. [19]

2.7.3 Radar and Satellite-based observation

The goal of this research is to explain the mechanism of the floods that occurred in the Keçidere basin in 2009. The major data sources in this study were discharge data from 1981 to 2009, digital elevation model (DEM), satellite photos, and field investigations. LPT3 was applied to 29-year maximum flow data to generate flood return periods ranging from 2, 5, 50, 100, 200, 500, and 1000 years. The DEM was produced in geographical information systems using 1:25,000 topographic contours and Topo to Raster interpolation methods (GIS). For hydraulic modelling, high-resolution satellite photos were used to digitize land use and certain geometric data. One-dimensional hydraulic modelling using HEC-RAS was used to simulate the 2009 flash flood event and different return periods flow data. In the last step, the simulation and field work outcomes were compared based on fit statistics and mean absolute error in terms of extent and depth. The outcome of an examination of water extent and depth features recorded during the greatest flow ever measured in the basin overlapped with a 500-year inundation extent. Overall, the study's findings show that GIS is an excellent environment for flood plain mapping and analysis.

The possible flow values and ranges of each river must be estimated based on changes in precipitation characteristics in recent years. Inundation hazards must be illustrated using inundation extents acquired. Keçidere, which was improved based on the estuary's 25-year inundation volumetric flow rate of 110 m3/s, is also used for irrigation in the Gönen irrigation region. As a result, the bed improvement plan must be revised to account for the reduction in efficiency that would result from the covering of agricultural areas that were opened to irrigate farming with sediments brought by inundations. A high resolution and precise DEM are necessary to prepare river hydro-geometry and terrain topography for accurate estimation of inundation area extent and flood depth, which are the most important parameters for flood hazard mapping. The inundation area obtained by flood flow simulation could not be verified by comparing it with the actual flooded area derived from satellite images due to the non-availability of satellite data during the flooding. However, the study reveals that micro-topography is not important when the 500-year flood event occurs in the narrow floodplain environment. Also, it shows, some signatures of the real flood event after the flooding can be used as a benchmark to understand the flood magnitude and characteristics. [20]

During recent years, Geographic Information Systems (GIS) as a powerful tool have had a tremendous impact on research techniques in the realm of geography and spatial analysis. The integrative ability of GIS to capture, store, manipulate, analyse, manage, and finally present all types of geographical spatial data, has drawn much attention to it. Water Resources Engineering as an interdisciplinary field requires modelling and analysing data with different spatial resolutions. Therefore, GIS could be utilized as a suitable tool for solving water resources problems from local to global scale. This study attempts to offer a broader scheme of the benefits of GIS applications in water resources, with a focus on hydrological modelling. The primary rationale for combining GIS and hydrological modelling is briefly explained, and several tools are provided. Also, various examples of GIS applications are presented to create a better understanding. Case studies such as the Wadi Madoneh Basin in Jordan, Kuronagi River in Japan, and San Antonio River Basin in Central Texas, USA, are presented. The strong agreement between the findings of a very simple GIS model and observations in examples such as Kuronagi River and Wadi Madoneh suggests that GIS applications in hydrological modelling have a bright future. Finally, the advantages of using GIS in the field are explored and summarized.

GIS (and GIS-based models) might be useful for many hydrological modelling tasks such as rainfall-runoff. A GIS-based model, for example, can be used to calculate runoff or flood in a specific location. For that model one can set parameters such as soil type, topography, vegetation, and so on (which are not changing throughout time rapidly) and then calibrate them based on historical time series. The calibrated model, afterward, could project new data (e.g., flood movement) for different scenarios of future climate and climate change. Using such models in a fairly user-friendly environment of GIS, one can get rid of dealing with lots of equations and calculations of different parameters. Engaging such models, the modification and updating of the model parameters (data sets) would be easy and straight forward and the user is not dealing with equations but the visualized results that could enhance the perception and understanding of different plausible scenarios. It should be noted that the user has to be qualified and aware of the algorithms and mathematical functions behind different commands and operations in the GIS. Lack of sufficient knowledge could lead to a misleading and incorrect solution for the working issue. GIS-based hydrologic models can give a spatial component that conventional hydrologic models lack. This might be accomplished by analysing characteristics such as slope, aspect, and watershed or catchment area. Because water constantly flows down a slope, topography analysis is essential in hydrology. DEMs are particularly useful for hydrological assessments since fundamental terrain analysis of a DEM includes calculating slope and aspect.

Another advantage of using GIS-based approaches in hydrological modelling is the ability to combine different layers of geographic data to generate new integrated information that can be used to create dependent or independent hydrological variables, such as generating evaporation from temperature and relative humidity (RH). Temperature and RH may be kept as dependent variables in distinct layers, and the combination of these two layers could produce the evaporation layer. It should be noted that combining different layers needs all the sources to be projected into the same coordinate system and scale. Moreover, users should be aware of different operations for combining layers otherwise the generated information could be far from reality or might not be the wanted information.

The final stage of every research, i.e., the presentation of results, might be of less importance to many researchers. In most cases, however, both classification and presentation of results could be a serious challenge due to the huge amount of spatial information as the outcome. In some cases, poor presentation of the results could become even misleading and could lead to misinterpretations. A well-structured representation of results will enhance the possibility of better understanding and obtaining a perception closer to reality. GIS as a smart map and through different generalizations, for example, simplification and symbolization, and with the aid of different visualization methods could produce efficient maps and figures which are not only comprehensive but also easy to understand and comfortable for future alterations. [21]

2.7.4 Other modelling methods

The Brahmani-Baitarni River basin is the second-largest drainage basin in Odisha, behind the Mahanadi basin. The Koel River basin, a sub-basin of the Brahmani-Baitarni River basin, was chosen as the research region for the implementation of the GIUH method in the current study. To provide an effective solution technique for producing the geomorphologic transfer function (GIUH) and then construct the geomorphologic unit hydrograph (GUH) for the Koel River basin using Horton’s ratios. This research included geomorphological inquiry and the creation of GUH for the Indian Koel River basin. The primary goal of this article is to create a GUH for the Koel River basin to estimate flood hydrographs. GUH was calculated for the Sankha River basin in India to evaluate the accuracy of the GIUH approach. The comparison of the calculated GUH with the observed UH shows that the suggested technique is appropriate and efficient for the derivation of UH. The second instance illustrates the use of the GIUH approach to calculate GUH for the Koel River basin. The resulting GUH with a dynamic flow velocity of 0.90 m/s (37 pprox.) agrees better with the SUH produced using the CWC method. Because the CWC method is independent of climatic parameters (i.e., dynamic flow velocity) and geomorphologic factors other than slope, drainage area, and length of the mainline, the resultant UH may have a larger computational error. As a result, the GUH-based method will outperform the CWC technique. Finally, it should be noted that the proposed technique will aid engineers in the correct estimate of flood hydrographs as well as the modelling of pollution transport. Aside from that, the given approach is both cost-effective and accurate for estimating the GUH and flood hydrograph for an ungauged catchment, as it just requires the catchment's DEM, which is freely available from the SRTM source. [22]

2.7.5 Integrated methods

The study intends to use GIS spatial analysis functions, data from hydrometric and rain gauge stations, satellite images, and thematic data layers in the form of an Artificial Neural Network Algorithm for the prediction of discharge values and spatial modelling of floods in the Kan River Basin, which is in Tehran province. An optimal artificial neural network with seven inputs, including slope, slope curvature, flow accumulation, NDVI, geological units, soil type, and rainfall data, was created and built, along with eight, sixteen, and one neuron for the first, second, and output hidden layers, respectively. The neural network produced discharge values in stations as its output. In flood modelling, the ANN approach has one of the greatest correlations and lowest RMSE. Precision metrics like R2, RMSE, and MAE were utilized to demonstrate the effectiveness of the suggested model, yielding values of 0.82, 0.18, and 0.13, respectively. The current study shown that combining a GIS spatial analysis function with a neural network algorithm is one of the most effective ways for predicting the possibility of natural catastrophes such as floods. The current study's findings can be used to improve environmental management at the local level in future environmental planning [23].

The research area consists of small watersheds (O[25 km2]) in southern California's mountain areas. This article investigates variations in flash flood incidence caused by anticipated climate change in southern California. The methodology combines aspects of meteorological modelling, hydrology, and geomorphology into an integrated modelling approach to describe flash flood occurrence on a regional scale with high spatial and temporal resolution suitable for flash flooding. To drive simulations for historical and future eras, a single climate model with three-dimensional atmospheric information was utilized as input. The research region's flash flood incidence has increased, according to the findings. The increase in flash flood occurrence frequency is on average between 30% and 40% for the two distributed hydrologic models used. The occurrence of regional flash floods is characterized by close saturation of the upper soil layer and larger variations in lower soil layer saturation and precipitation. Overall, there was a decline in the overall number of precipitation events, but with greater precipitation intensity, longer event length, and higher soil saturation levels during the twenty-first century. This combination may indicate more dangerous circumstances, with fewer precipitation episodes but higher rainfall intensity and over soils with higher initial soil moisture saturation, resulting in more frequent flash floods. A lucrative next step would be to investigate variations in evapotranspiration caused by changes in surface temperature (a more consistent signal across climate models than changes in precipitation). A variable variation in evapotranspiration demand might be included. Another intriguing extension would be to look at not only the prevalence of flash floods but also anticipated changes and regional differences in larger-scale soil moisture throughout the region [24].

After reviewing different technologies GIS technology was selected as the preferred technology to carry out the project which is justified further by the following literature review.

2.8 Geographic Information Systems (GIS)

GIS is said to have originated in the 1960s with Roger Tomlinson's Canadian natural resource inventory computer software [25]. GIS have gained much importance as a tool for understanding and dealing with the world's critical challenges of water and associated resource management. GIS ideas and technology assist us in collecting and organizing data regarding such challenges, as well as understanding their spatial linkages [11]. Database systems offer complete tools for storing, retrieving, presenting, and modifying data that is critical to decision-making. The geographic database (or geographic information system-GIS) conveys information about essential spatial features such as points, lines, and polygons in a tabular format [26].

There are numerous stratagems for coupling ecological models to GIS, ranging from loose couplings in which data is moved among models and GIS, each with distinct database management abilities and systems, to tight couplings in which data management in the GIS and model is integrated and they share the same database. The Arc Hydro data model can easily represent the watershed in the GIS, which improves the connection between the GIS and the watershed model. Arc Hydro created a data structure that includes the catchment area, cross section, measurement point, and time series that correspond to the underlying physical catchment area. It also establishes data links so that the catchment area of the river knows which point represents its outflow, or the measurement point knows the time series record of that location [14][25].

Geographic Information System concepts and technologies are widely used in water resources planning and design, changing the implementation of these operations. We are living in an era where natural resources are increasingly scarce, and the influence of human activities is everywhere. In this case, it is necessary to use the best available technology to define the environment, predict the impact and identify measures to reduce the impact and improve sustainability. GIS technology, tools and processes provide significant advantages for resource inventory, modelling, decision-making, and communication with relevant agencies and data subjects [11].

GIS displays information in the form of maps and feature symbols and is linked to a database that provides attribute data about features. The map provides information about where the objects are, what they are, and how they are linked. GIS can also provide tabular reports on map elements, list all content connected on the network, and simulate river flow, travel time, and pollution distribution. GIS is a computerized information system that can collect, model, modify, query, analyse and display geographic data. This is a common description that does not highlight the role of GIS as an integrator of data management operations and decision support in the organization. The broader view is that the goal of GIS is to provide a framework to support decisions about how to use the earth's resources intelligently and manage established and natural ecosystems [11].

2.8.1 Water resources engineering applications of GIS

GIS provides an integrated data and modelling environment for these operations. GIS is a tool for collecting and archiving environmental data. Location, distance, and flow measurements from various devices are usually processed in digital form and quickly integrated into a geographic database. GIS can be used to support data processing, synthesis, and modelling operations, and can retain analysis results. The spatial and attribute information from the GIS can then be used to generate reports and maps, usually interactively, to help make decisions about which design decisions are best and what impact they will have. Maps are also an effective communication tool; therefore, this information can be displayed in public forums so that those interested in planning and design decisions can better understand and participate [11].

In water management planning and design, maps of different sizes are usually used, and documents are created in map format. For example, in watershed research, the map scale usually spans part of a province, and spans multiple counties and other units. River drainage land with topography, geology (including soil type), vegetation, and hydrological characteristics. Cities and man-made facilities are scattered along the banks of the river and throughout the basin, connected by a network of transportation and pipelines [11].

All these data sets must be developed in a similar geo-referenced framework so that theme overlays and feature coincidences may be detected during the planning and design process. All this data is managed using GIS. It gives a complete method for processing data that would be impossible to do manually. Because there may be many thousands of features with a location, associated characteristics, and relationships with other features, the huge quantity of data involved necessitates the use of a GIS. The GIS allows for the capture and preservation of this data, as well as the reading and evaluation of the data in color-coded map forms. This data-review capability aids quality control by making mistakes more visible. Furthermore, visualization allows the viewer to acquire a deeper grasp of patterns and trends in the data in a way that would be impossible if the data were just in tabular format. The GIS also has analytical capabilities. Computer software can access the information and utilize it as input to various modelling methods to create derived products [11].

Geographic information systems (GIS) have grown in importance as a tool for understanding and dealing with the world’s critical challenges of water and associated resource management. GIS ideas and technology assist us in collecting and organizing data regarding such challenges, as well as understanding their spatial linkages. GIS analytical skills enable the modelling and synthesis of information that contributes to the support of resource management choices at a variety of measures, from regional to international. A GIS also allows for the visualization of resource attributes, which improves knowledge in assistance of decision making [11].

The study of geospatial data is an important part of disaster management decision-making and planning. GIS software, such as ArcGIS, offers extensive analytical and mapping capabilities. We can now gather and store vast volumes of geographical data because to advances in technology. The data formats differ greatly, and analysis necessitates several iterations. These features need the use of computer programming to investigate this data [27].

Esri fully embraces Python for:

1. Data analysis
2. Data conversion
3. Data management
4. Map automation [28]

Table 2.3: Latest remote sensing technology and sensors are used for water resources, hydrological fluxes, drought, and flood mapping [16].

Application Fields	Specific Contents	Examples of Sensors or Satellites
Water resources	Snow	AVHRR, Terra/Aqua MODIS, Landsat, SSM/I, AMSR-E, Cryosat etc.
	Glaciers	Landsat, ASTER, SPOT, ICESat, SRTM, etc.
	Soil moisture	SSM/I, AMSR-E, SMAP, SMOS, etc.
	Groundwater	GRACE
	Lakes, reservoirs, rivers, and wetlands	MODIS, Landsat, SPOT, ICESat, GRACE, SRTM etc.
Hydrological fluxes	Precipitation	NEXRAD, TRMM, GPM, etc.
	Evapotranspiration	MODIS, Landsat, GRACE, etc.
	River, reservoir or lake discharge	MODIS, ENVISAT, Landsat, SRTM, ICESat, etc.
Drought and flooding	Drought and flooding	MODIS, Landsat, GRACE, UAV, AMSR-E, SMAP, SMOS, ENVISAT, ASAR, Sentinel-1A/2A, etc.

GIS (and GIS-based models) can be useful for many hydrological modeling tasks, such as rainfall runoff. For example, a GIS-based model can be used to calculate runoff or flooding at a specific location. Properties such as soil type, topography, vegetation, etc. (which do not change rapidly over time) can be defined for this model and then calibrated using historical time series. The calibrated model can then project new data (e.g., flood movements) for various future temperature and climate change scenarios.

If these models are used in a reasonably user-friendly GIS environment, they can cope with many equations and multi-parameter calculations [30]. Table 2.3 lists the latest remote sensing technologies and sensors used for water resources, hydrological rivers, droughts, and flood mapping.

When using such models, changing, and updating the model constraints (data sets) is simple and straightforward, and the user is not dealing with equations but with visible outcomes that can improve insight and comprehension of many probable situations. It should be emphasized that the user must be certified and knowledgeable about the algorithms and statistical functions that underpin the various commands and operations in the GIS. Inadequate information may result in a deceptive and inaccurate result to the operating problem [21].

2.9 Present Flood Management Systems in Sri Lanka

During the British period, many types of land and water management laws were promulgated from time to time, such as the Crown Land Ordinance, Land Development Ordinance, Irrigation Ordinance, and Wastelands Ordinance. During the British era, institutions such as the Department of Irrigation, the Kachcheri System of Government Agents, and the Land Commission were established for general administration, agricultural crop production, and land and water resource management [41].

There have been programs to develop irrigation infrastructure since gaining independence from the British in 1948. Senanayaka Samudraya, Mahaweli Development projects were some of the major water resources development projects undertaken. Flood protection, hydroelectric power generation and domestic water supply were substantial benefits gained by these projects apart from the impact on agriculture [1].

The deadliest and most common forms of disasters in Sri Lanka are landslides, floods, and droughts and landslides have direct implications on flooding. Inadequate regulations on impact evaluations make it difficult to accurately assess losses [1]. In figure 2.8, disaster occurrence from year 1990 to 2018 in Sri Lanka is given as a pie chart and from the chart it is very clear that flood is the most common form of disaster in Sri Lanka.

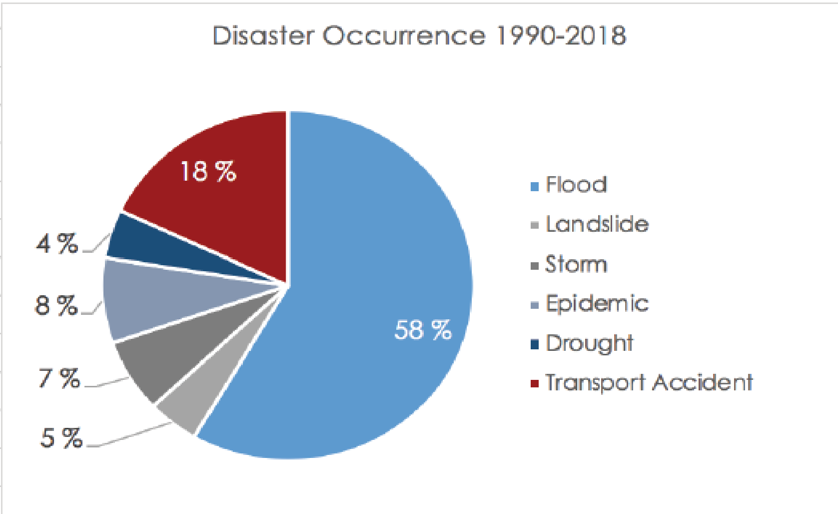

Figure 2.8: Disaster Occurrence 1990-2018 [31].

Structural measures or innovations in reservoirs and flood protection infrastructures, non-structural measures against disasters such as early warning systems, guidelines and practical rules based on research studies can be used as management tools against extreme events [1].

Barriers to the development of efficient and effective emergency response programs include:

- Inadequate data sharing mechanisms.
- Inadequate data storage and distribution resources.
- Lack of consistent obligations and lack of communication between organizations.
- Weaknesses and inadequacy of early warning systems. [1]

Floods are the only natural disaster that has a law that is the flood protection ordinance No. 20 of 1931 implemented by the irrigation department [1].

Following are the four main phases of disaster management covered by the National Disaster Management plan prepared in 1999 by the Ministry of Social Services:

- Mitigation
- Preparedness
- Response
- Recovery [1]

In 2005, the Sri Lankan government took important steps to strengthen legal and institutional arrangements for disaster risk management, largely building on the experience of the 2004 tsunami [7].

To create the legal basis for disaster risk reduction in the country, the Sri Lanka Disaster Management Law No. 13 of 2005 was enacted. The establishment of the Disaster Management Center (DMC) under the National Council for Disaster Management (NCDM), a high-level inter-ministerial body led by His Excellency the President was envisaged. DMC is the supreme body for planning, coordinating, and implementing relevant measures to contain certain forms of natural and other disasters. The development of such plans is required under the Sri Lanka Disaster Management Act and the National Disaster Management Policy. [7]. There are District Disaster Management Coordination Units (DDMCU) as the central point of contact at the district, division, municipal and Grama Niladhari levels for the coordination of the response, as well as the management and dissemination in emergencies [1].

The water-related components of the National Policy Framework have been outlined in the Central Bank of Sri Lanka – 2005 as follows: "Disaster management is recognised as a priority issue. The adverse impact on the economy by natural disasters underlines the necessity for national disaster avoidance and management strategies to address the issue." [1]

2.9.1 Floods in Sri Lanka

2.9.1.1 Flood types

Floods are most severe in the Wet Zone of the country from May to July, and in the Dry Zone from November to January. The country is mostly affected by three types of floods:

1. Riverine floods are another term for river flooding. When a river reaches the flood stage, the water can rise and overflow the banks of the river (Nearly 25 rivers are vulnerable to flooding)
2. Urban floods are floods that occur over a short period and can inundate a region with several feet of water. (Mainly due to intense rainfall)
3. Reservoir Induced floods are defined as floods that happen downstream of a reservoir owing to reservoir spilling during heavy rains or due to dam breach. (Around 100 major/medium reservoirs) [7]

2.9.1.2 Area prone to flood

Of the 103 watersheds, 16 were classified as critical for flood protection and prevention because they are more than 100 kilometers long and have a catchment area of 1,000 square kilometers or more. The catchment areas identified as critical are in places where rapid development has led to the loss of surrounding forests and permeable areas. As a result, surface runoff has increased, causing more water to flow into the ocean than is used. This event has the potential to cause flooding, flood a vast region, and cause significant agricultural and property damage [7]. The names of the major designated watersheds are listed below:

1. Mahaweli Ganga
2. Malwathu Oya (Aruvi Aru)
3. Kala Oya
4. Kelani Ganga
5. Yan Oya
6. Daduru Oya
7. Walawe Ganga
8. Maduru Oya
9. Maha Oya (Mundeni Aru)
10. Kalu Ganga
11. Kirindi Oya
12. Kumbukkkan Oya
13. Menik Ganga
14. Gin Ganga
15. Mi Oya
16. Gal Oya [7]

2.9.1.3 Damage from floods

Table 2.4 illustrates damage from natural disasters in Sri Lanka from 1957 to 2003.

Table 2.4: Natural disasters in Sri Lanka from 1957 to 2003 [5].

	Number of Events	Deaths	Persons Injured	Home-less	Affected	Total Affected	Damage US$ (000's)
Drought	10	0	0	0	8,613,000	8,613,000	
average per event		0	0	0	861,300	861,300	
Flood	36	935	1,000	2,747,601	6,274,127	9,022,728	367,444
average per event		26	28	76,322	174,281	250,631	10,207
Slides	3	119	0	0	130	130	
average per event		40	0	0	43	43	
Wind Storm	5	1,151	5,000	100,000	1,913,000	2,018,000	137,300
average per event		230	1,000	20,000	382,600	403,600	27,460

Damage due to various disasters in year 2015 is in table 2.5, in year 2016 is in table 2.6 and in year 2017 is in table 2.7. Damages caused by disasters from year 1990 to 2018 in Sri Lanka is illustrated as a pie chart in figure 2.9.

Table 2.5: Damage in 2015 [5].

2015						
Disaster	Deaths & Disappear	Injured	Affected population	Affected families 2015	Houses damaged completely	Houses damaged partially
Flood	16	18	237616	61347	423	5112
Drought	0	0	258096	73242	0	0
Cyclone	3	6	4353	1185	122	1007
Landslide	11	8	1854	478	48	232
Fire	3	3	265	64	66	30
Others	81	18	399	93	16	47
Total	**114**	**53**	**502583**	**136409**	**675**	**6428**

Table 2.6: Damage in 2016 [5].

2016						
Disaster	Deaths & Disappear	Injured	Affected population	Affected families 2016	Houses damaged completely	Houses damaged partially
Flood	26	22	448833	110596	385	2549
Drought	0	0	1025839	274242	0	0
Cyclone	5	11	7667	1986	71	1965
Landslide	193	14	42331	11523	274	2370
Fire	4	2	282	70	53	16
Others	33	21	207	53	6	26
Total	**261**	**70**	**1525159**	**398470**	**789**	**6926**

Table 2.7: Damage in 2017 [5].

2017						
Disaster	Deaths & Disappear	Injured	Affected population	Affected families 2016	Houses damaged completely	Houses damaged partially
Flood	210	124	676809	174186	1411	11946
Drought	0	0	2440290	667939	0	0
Cyclone	19	87	129122	36277	860	33290
Landslide	158	18	137721	34866	325	1569
Fire	4	7	357	83	19	24
Others	118	112	2049	485	64	78
Total	**509**	**348**	**3386348**	**913836**	**2679**	**46907**

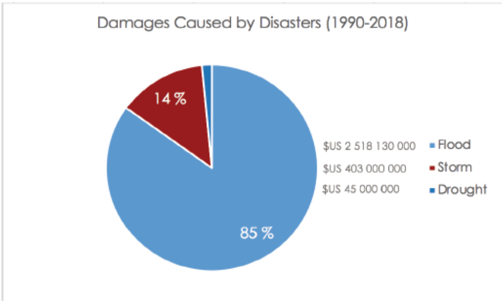

Figure 2.9: Damages caused by disasters between 1990-2018 in Sri Lanka [31].

From these charts and tables, it is clear that how much lives, property and infrastructure are damaged by various disasters in Sri Lanka and how much money that should spent on recovering those losses, but lost lives are irrevocable.

2.9.2 Early warning process

Weather information for decision-making is provided mainly by the Department of Meteorology, which is responsible for weather forecasting in Sri Lanka. For some stations, it has records of rainfall for more than 150 years. Network of 37 automatic weather stations (AWS) which update every 10 minutes are maintained by the department at present. And this data is shared among key organisations like the Irrigation Department, Mahaweli Authority Sri Lanka (MASL), Agricultural department, National Building Research Organisation (NBRO), Fisheries department, Coast Conservation Department, and Ceylon Electricity Board (CEB), etc. as required [7].

In addition, weather stations are maintained by some of these departments. The Irrigation Department presently operates 32 permanent river gauging stations at strategic sites throughout the country's rivers and reservoirs. To guarantee a rapid flow of information, it updates its weather stations to 122 automatic weather stations, as it oversees forecasting floods and early warning of the population for self-protection and evacuation in the event of flooding of rivers or reservoirs. The irrigation department updates the reservoir levels daily, with more frequent entries during times when the reservoirs are at or near full capacity. These sites' water levels and rainfall data are currently being sent online. Close collaboration with the Metrological Department allows for the establishment of a credible forecasting regime. The same occurs with MASL and CEB in the reservoirs managed by them [7].

The river gauges were calibrated relative to the flood status in the respective flood area as follows:

1. Flood alert level
2. Minor flood level
3. Dangerous flood level
4. Critical flood level [7]

These are the authorities in charge of providing early warning in the event of certain catastrophes (table 2.8):

Table 2.8: Authorities in charge of early warning for different disasters [8][29].

Disaster	**Responsible Agency for Early Warning**
Cyclones and heavy rainfall/strong winds	Department of Meteorology
Floods	Irrigation Department
Landslides	National Building Research Organization
Tsunami	Department of Meteorology (with the consultation of Geological Survey and Mines Bureau)
Earthquakes	Geological Survey and Mines Bureau

In the event of a flood, only the Kalani river flood warning system can provide an early warning. Due to the short travel time of the flood wave that reaches the city of Rathnapura in the case of Kalu Ganga, efforts to warn people in the city were unsuccessful. In the other basins, there are no adequate warning systems. Flood alerts are currently issued in these basins based on rainfall events and past experiences. Government Agents/District Secretaries are given such warnings to disseminate among those who live in low-lying areas [1].

Kelani, Kalu, Gin and Nilwala are the most important river basins of the Sri Lankan wetlands that are viable for regular flooding. The stages of flow and precipitation of the most important stations of these rivers are continuously monitored (3 times a day, also on non-working days) by the Colombo Irrigation Department (ID) headquarters. When there is heavy rain and the river level is approaching the lower flood level, a special flood monitoring unit is installed in the Colombo office to monitor the water level hourly, day, and night until the weather situation improves. All these stations have CDMA telephones that are connected to the Colombo office, allowing for real-time data transmission. Prior flood warnings are provided by this agency to the appropriate authorities, including DMC, so that suitable mitigation or preventative measures may be taken [7].

The Department of Meteorology is consulted for rainfall forecasts for the next 24 hours as well as rainfall data from their stations. The data from these gauging stations are currently transferred over the phone to the Irrigation Department's Hydrology Branch [7]. Satellite products used in forecasting is given in figure 2.10 and numerical weather prediction activities in the irrigation department is illustrated in figure 2.11.

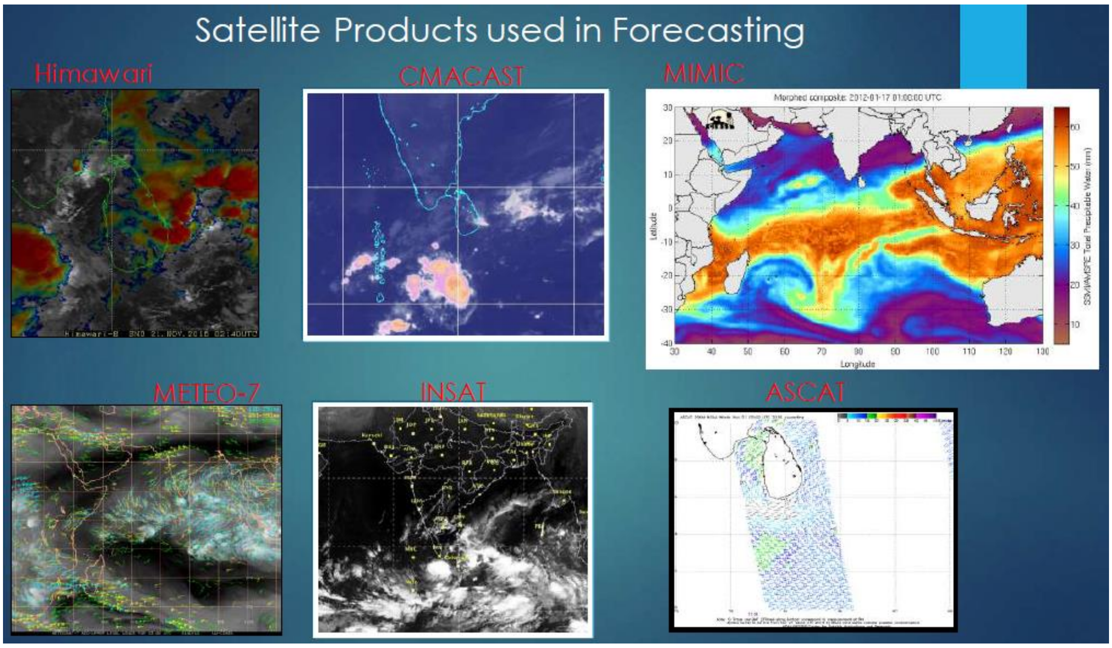

Figure 2.110: Satellite Products Used in Forecasting [8].

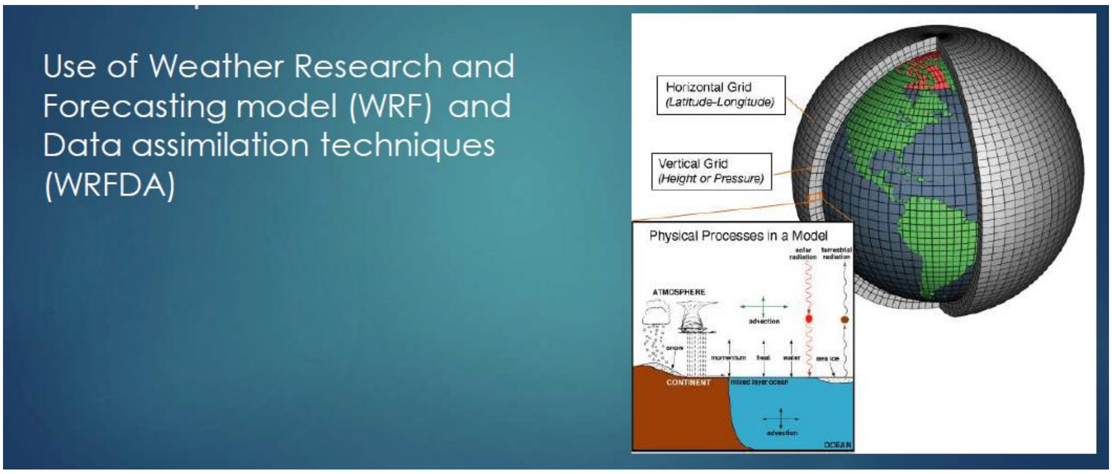

Figure 2.101: Numerical Weather Prediction (NWP) Activities in the ID [8].

The water levels of all of ID's major reservoirs are monitored daily by Divisional Irrigation Engineering division workers and recounted to the District Director and Water Management Division in Head Office daily. When a reservoir's water level approaches the spill level, procedures are made to carefully observe the reservoir. The reservoir data transfer and distribution scheme are as of figure 2.12: [7]

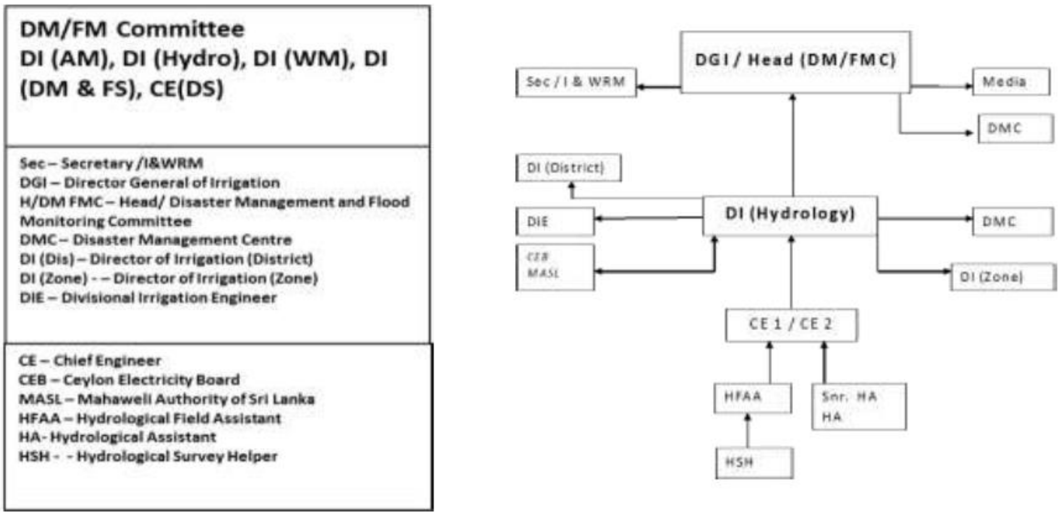

Figure 2.12: Flood Forecasting and Decision Support System of Irrigation Department [7].

The Director-General and Additional Director General (System Management) of Irrigation are directly responsible for the Irrigation Department Flood Monitoring Committee. Directors of Irrigation-Asset Management, Hydrology, Water Management, and Flood Studies, Drainage, and Disaster Management make up the group. The Emergency Operation Room is staffed 24 hours a day, 7 days a week by officers from the Flood Monitoring Committee and their representatives [7].

According to the Early Warning framework, when a disaster is imminent, the technical agency accountable for the threat establishes the severity of the disaster, and the decision is sent to the Ministry of Disaster Management and the Disaster Management Centre's Emergency Operation Centre [7]. Multi-hazard early warning dissemination system is illustrated in figure 2.13.

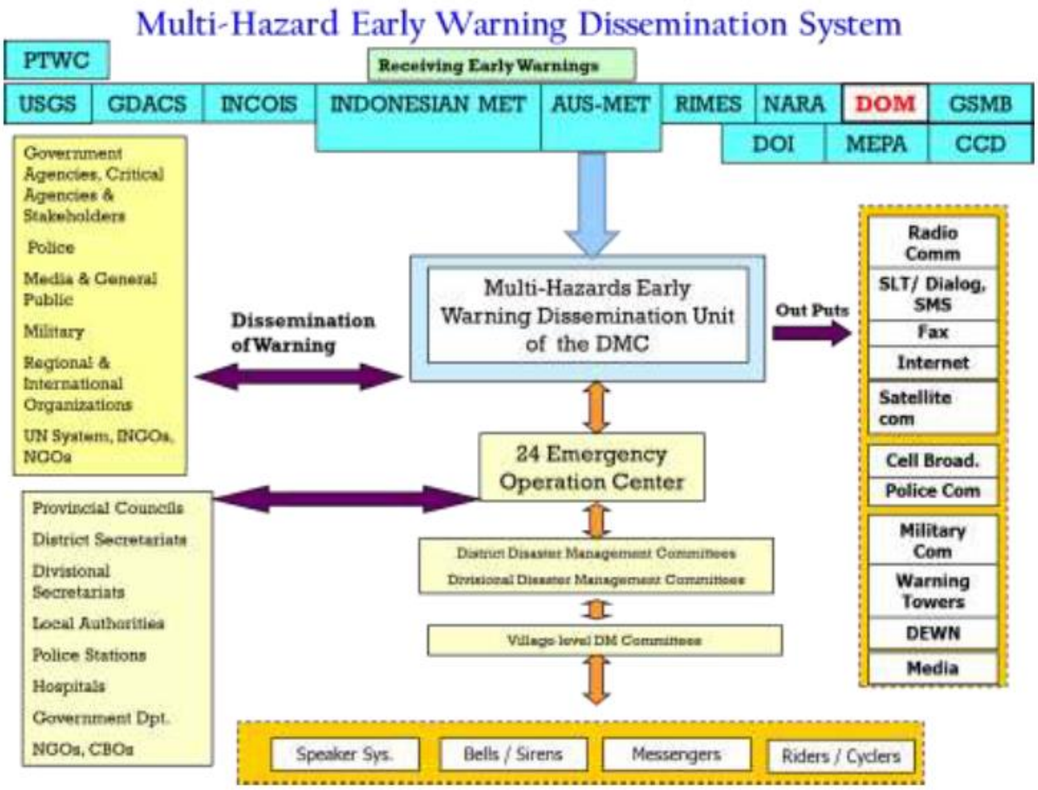

Figure 2.13: Multi-Hazard Early Warning Dissemination System [7].

Early warning system of Sri Lanka is illustrated in figure 2.14.

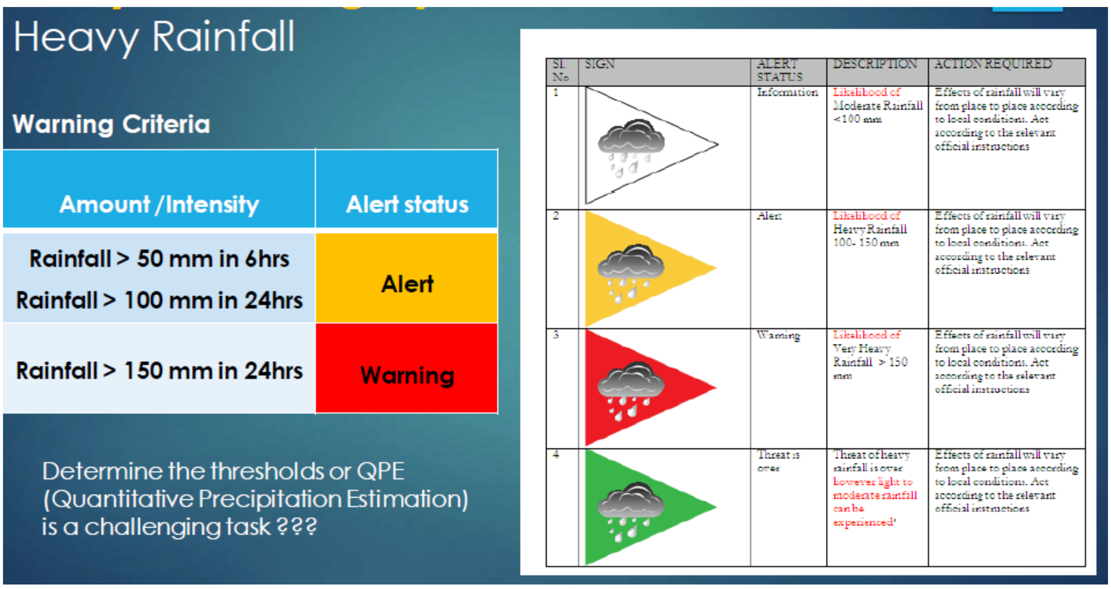

Figure 2.14: Early Warning System of Sri Lanka [8][29].

2.9.2.1 Daily reports issued by the Department of Irrigation to the community

- River Stages at crucial locations
- Rainfalls (Catchment Based)
- Reservoir Status (Through the Irrigation Dept. Website, e-mail and Fax) [8]

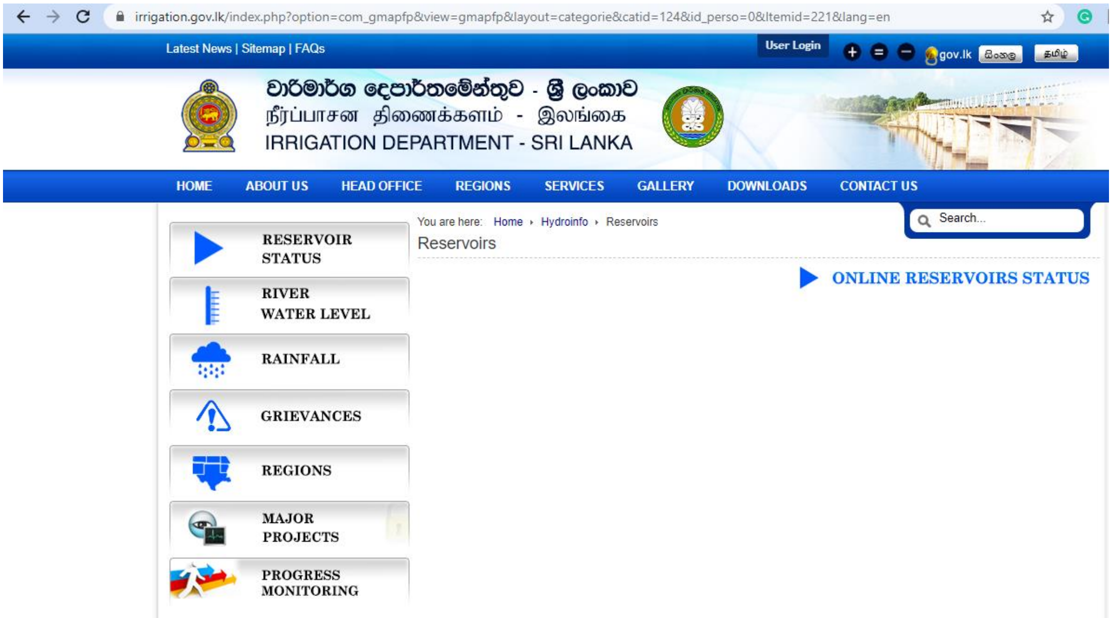

Figure 2.15: Irrigation Department Hydro Information [49].

Sri Lanka Irrigation Department’s hydro information page is as of figure 2.15 and online reservoir status link leads to the following dashboard given in figure 2.16.

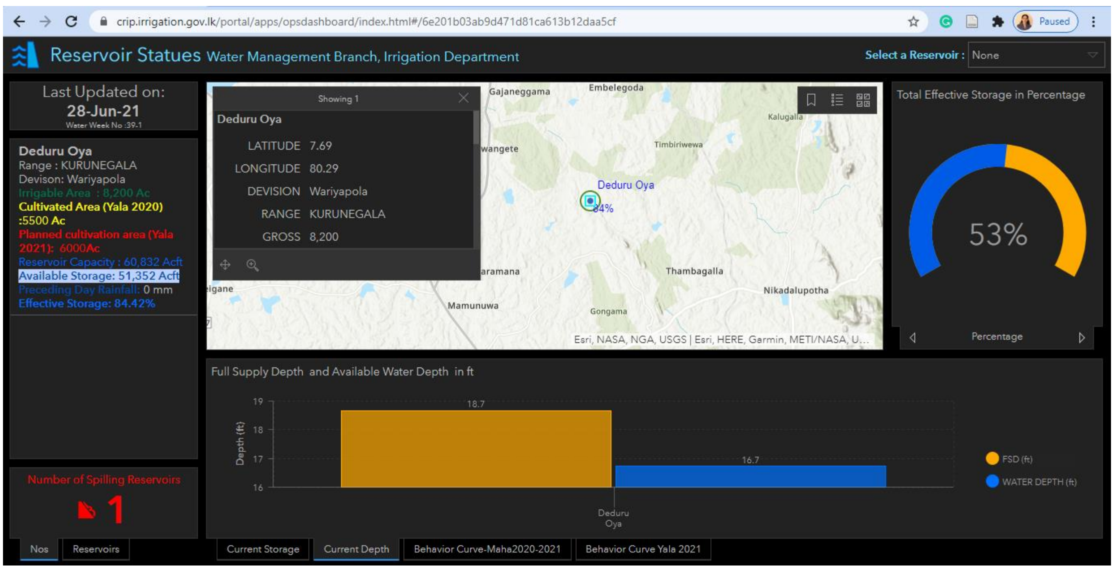

Figure 2.16: Daduru Oya Reservoir Status [50].

Daduru Oya Ridi Bendi Ella station data are as of figure 2.17.

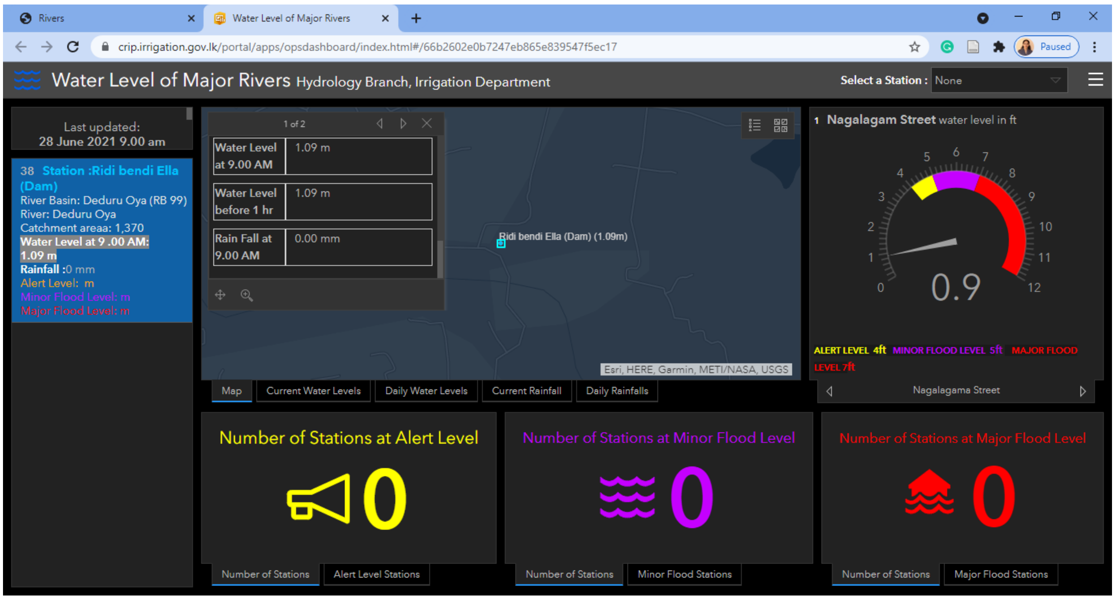

Figure 2.17: Water Level of Daduru Oya at Ridi Bendi Ella [38].

2.9.2.2 Hydro-meteorological network

Hydro-meteorological network in Sri Lanka is given in table 2.9.

Table 2.9: Hydro-meteorological Network in Sri Lanka [8].

Station Type	Number of Stations	Interval of Record	Data Availability
Manual System	35	1 hour	Some of the stations were inundated
Automated System	160	10 minutes	Recently Installed

2.9.2.3 Station distribution

Irrigation Department

Mahaweli Authority

C. E. B.

Total 160

[8][30]

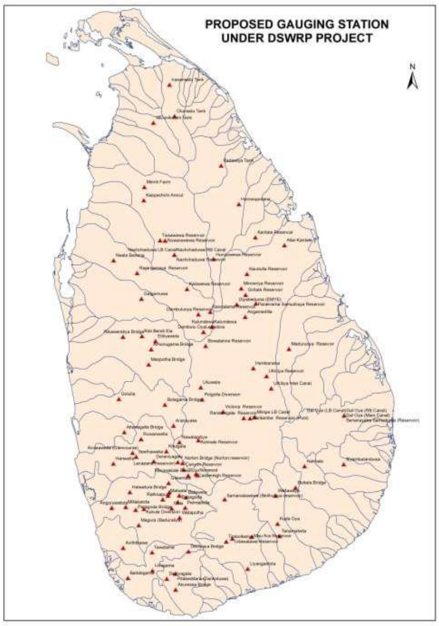

Figure 2.18 River Gauging Station Distribution [8].

Proposed river gauging station distribution in Sri Lanka under Irrigation Department, Mahaweli Authority, and Ceylon Electricity Board are as of figure 2.18. And types and numbers of hydro-meteorological stations in Sri Lanka are as of figure 2.19.

• Rainfall Only	14
• Rainfall / Water Level	23
• Rainfall / Water Level / Discharge	54
• Water Level / Discharge	13
• Rainfall / Evaporation	01
• Rainfall / Water Level / Evaporation	12
• Rainfall / Water Level / Discharge / Evaporation	05
TOTAL	122

Figure 2.19: Types and numbers of Hydro-meteorological stations [30].

Instruments installed in various stations are shown in figure 2.20.

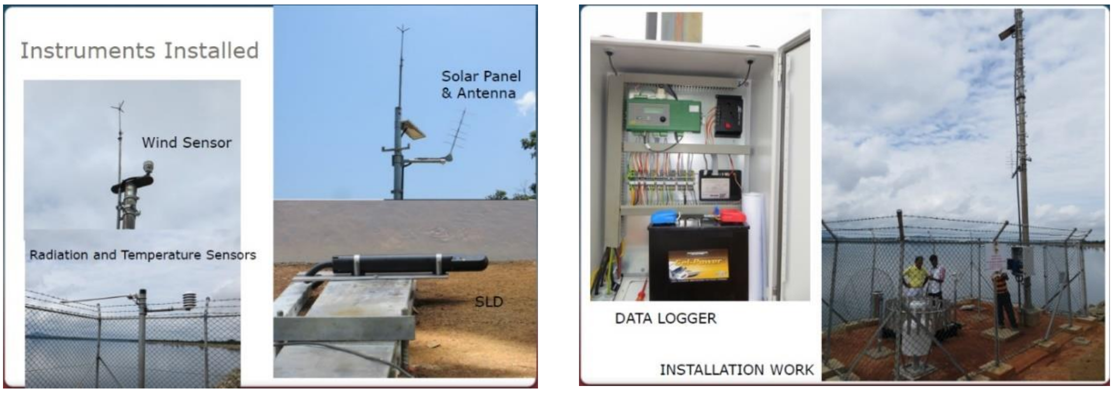

Figure 2.20: Instruments installed [30].

Some of the reservoir stations in Sri Lanka in figure 2.21.

Figure 2.21: Reservoir stations [30].

Side looking doppler sites on irrigation canal Galoya is given in figure 2.22.

Figure 2.22: Side Looking Doppler [30].

2.9.2.4 Forecasting methods

- Mode of Data Transmission: Satellite transmission and GPRS
- Input Data: Observed rainfalls in the upper catchments and the discharges at upstream river gauging stations.
- Mathematical Models used:

  MIKE 11

  HEC HMS

  Flood Routing Methods

- Gaps: The waiting time (between the forecast and the flood) is insufficient to evacuate people and valuables from the endangered areas. [8][30]

2.9.2.5 Real-time rainfall data input

The real-time data input of HEC-HMS model for Kelani River is as of figure 2.23.

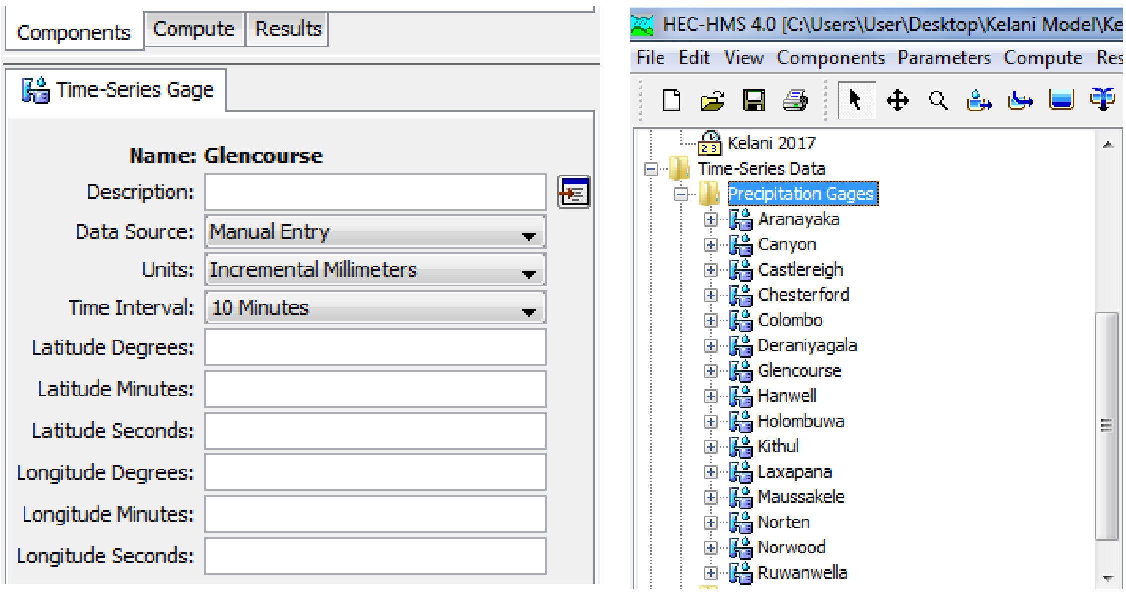

Figure 2.23: Real Time Rainfall Data Input [8].

2.9.2.6 The theory used in the hydrological model

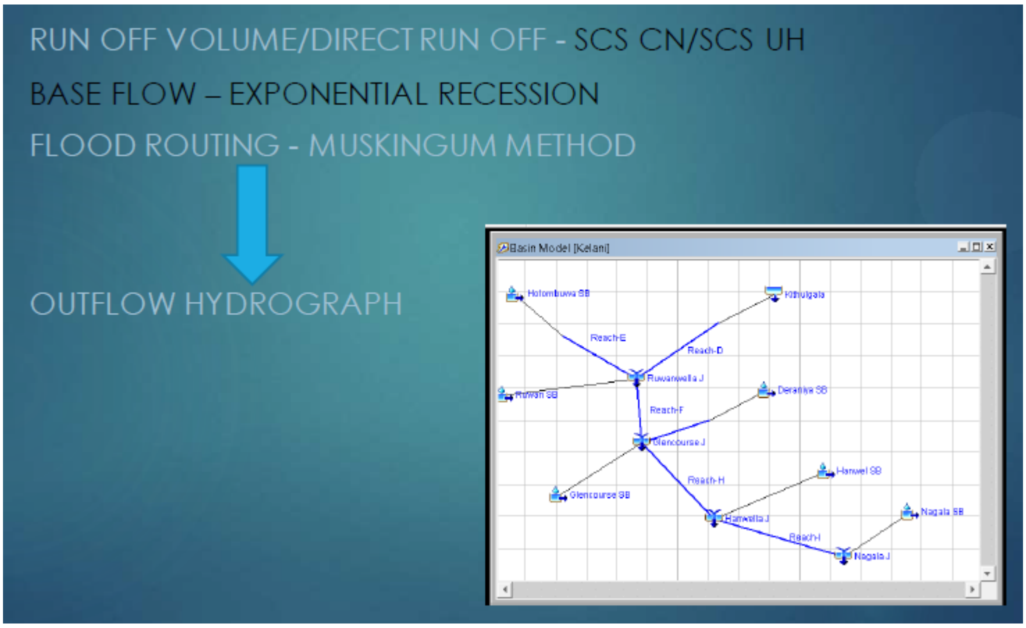

Figure 2.24: Theory used in Hydrological model [8].

Figure 2.24 shows the theory used in hydrological model in Irrigation Department of Sri Lanka.

Figure 2.25 shows flood forecasting and reservoir operation in Daduru Oya river.

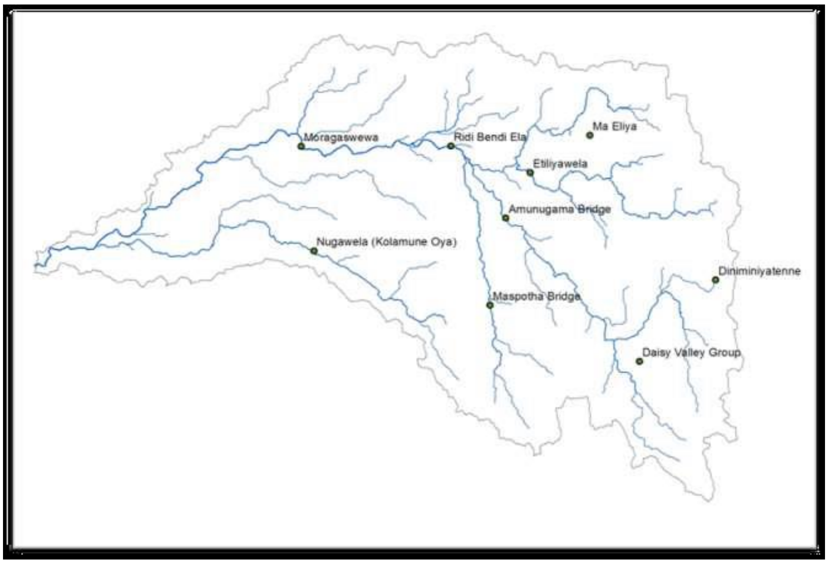

Figure 2.25: Flood Forecasting/ Reservoir Operation in Daduru Oya River [8].

HEC HMS model of Daduru Oya river is depicted in figure 2.26.

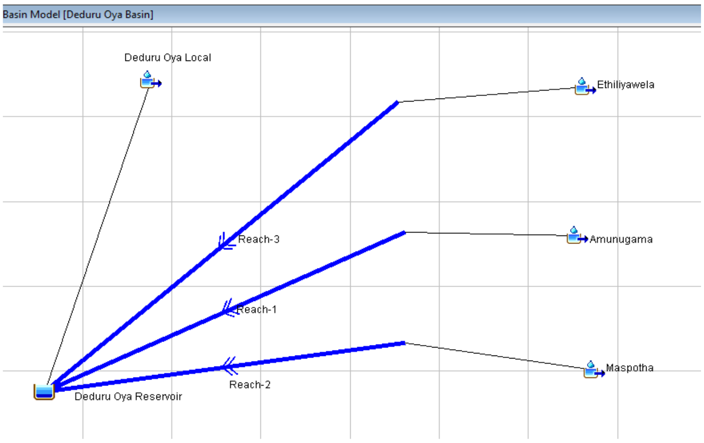

Figure 2.26: HEC HMS model Daduru Oya [8].

Rainfall stations in Daduru Oya basin is given in figure 2.27.

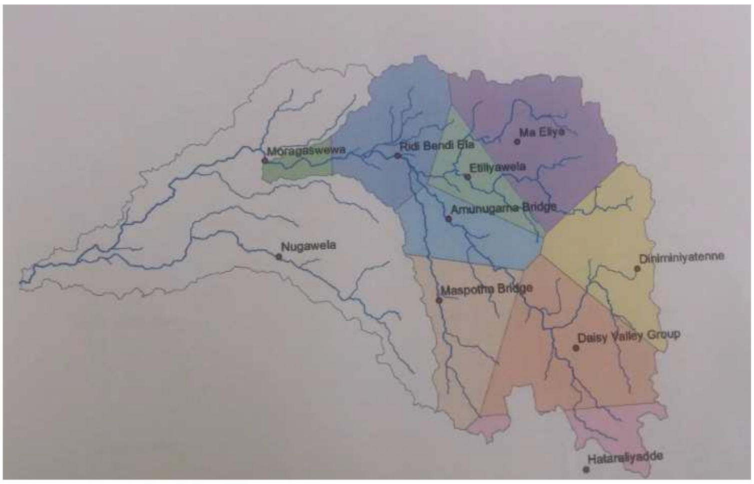

Figure 2.27: Rainfall stations in Daduru Oya basin [8].

2.9.2.7 Warning methods

Mainly through the Disaster Management Centre (Publish forecasting levels at gauging stations together with areas of having flood risk). Figure 2.28 shows a flood status report by the Irrigation Department.

වාරිමාර්ග දෙපාර්තමේන්තුව

நீர்ப்பாசனத் திணைக்களம்

IRRIGATION DEPARTMENT

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My No. } Dr, FS & DM/ IO ROOM/ 115   Your No. }   Date } 24-05-2018

Director General,
Disaster Management Center

Flood Situation Report by Irrigation Department - As at 9.00 AM – 2018-05-24

Flood situation over the Island is as follows.

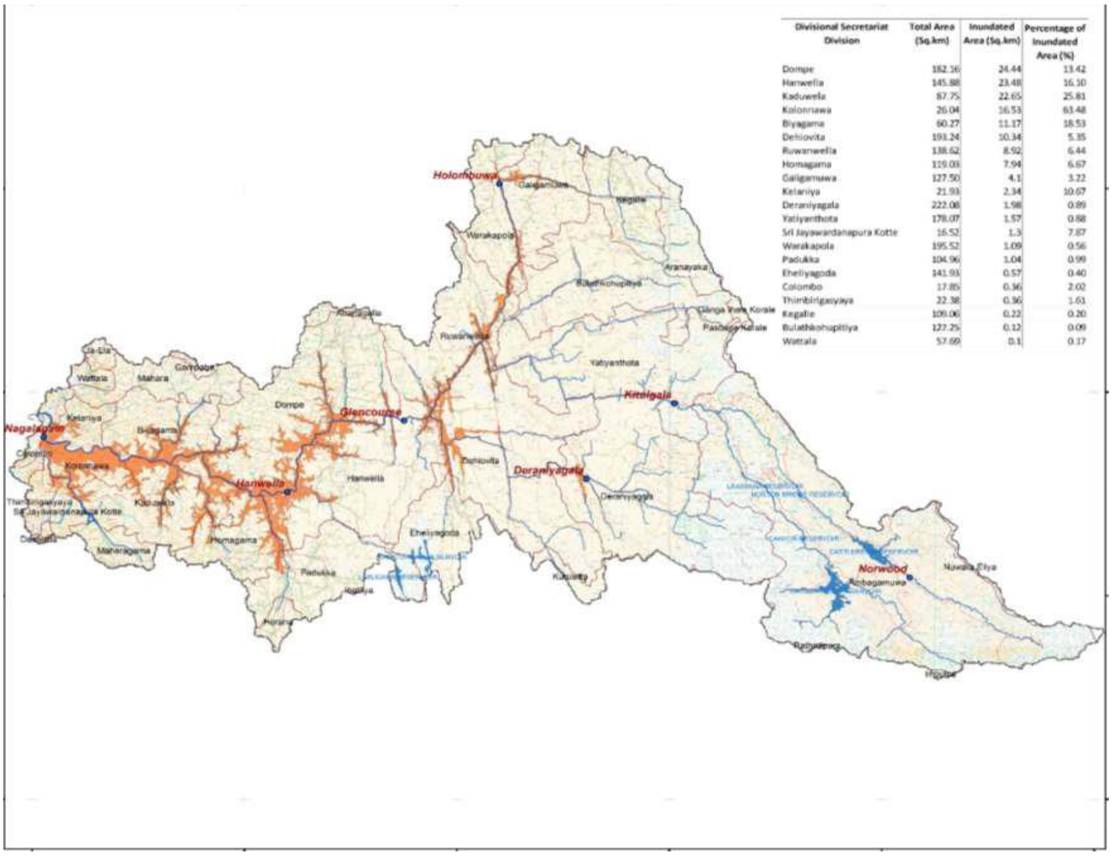
No.	River Basin	Flood Situation	Affected Divisional Secretary Areas
1	Nilwala River	Affected by minor floods. Flood levels of unprotected low line areas which are inundated **decreasing gradually**.	Pitabaddara, Akuressa, Athuraliya, Kamburupitiya, Malimbada, Thihagoda, Kadawathsathara, Matara
2	Gin Ganga	Affected by minor floods. Flood levels of unprotected low line areas which are inundated **decreasing gradually**.	Baddegama, Bope Poddala, Welivitiya, Divithura, Nagoda, Niyagama, Thawalama, Neluwa
3	Kalu Ganga	Affected by minor floods. Flood	Kalutara, Dodamgoda, Millaniya,

Figure 2.28: Flood status report by Irrigation Department [8].

- Directly to the people through the media (television and Radio) by the Disaster Management Centre
- Issue the level of an expected flood (minor, major or critical) with respective levels and the time duration.
- Inundation maps, concerning major floods and above, have been issued to all authorities including Disaster Management Centre. They will take action accordingly. [8]

2.9.2.8 Inundation mapping

Following each major flood occurrence, Inundation Area Survey is done, and a map is created using Arc GIS to assist flood control officials and the general public in future flood situations. figure 2.29 displays inundation map for Kalani river during 2016 major flood [8].



Divisional Secretariat Division	Total Area (Sq.km)	Inundated Area (Sq.km)	Percentage of Inundated Area (%)
Dompe	182.16	24.44	13.42
Hanwella	145.88	23.48	16.10
Kaduwela	87.75	22.65	25.81
Kolonnawa	26.04	16.53	63.48
Biyagama	60.27	11.17	18.53
Dehiovita	193.24	10.34	5.35
Ruwanwella	138.62	8.92	6.44
Homagama	119.03	7.94	6.67
Galigamuwa	127.50	4.1	3.22
Kelaniya	21.93	2.34	10.67
Deraniyagala	222.08	1.98	0.89
Yatiyanthota	178.07	1.57	0.88
Sri Jayawardanapura Kotte	16.52	1.3	7.87
Warakapola	195.52	1.09	0.56
Padukka	104.96	1.04	0.99
Eheliyagoda	141.93	0.57	0.40
Colombo	17.85	0.36	2.02
Thimbirigasyaya	22.38	0.36	1.61
Kegalle	109.06	0.22	0.20
Bulathkohupitiya	127.25	0.12	0.09
Wattala	57.69	0.1	0.17

Figure 2.29: Inundation Map for Kelani Ganga during the previous (2016) major flood [8].

2.9.3 Conclusion

GIS and GIS-based models could be beneficial for various hydrological models, such as stormwater runoff. For example, to calculate runoff or flooding in a certain region, a GIS-based model can be set up. For this model, parameters such as soil type, topography, vegetation, etc. which do not change rapidly over time, can be set and then calibrate them based on historical time series. The calibrated model could then project new data (e.g., flood movements) for different future climate and climate change scenarios. When these models are used in an easy-to-use GIS environment, many equations and multi-parameter calculations can be handled.

Flash Flood Guidance will be extremely useful in improving current flood forecasting facilities for Sri Lanka. It will save the lives of people and reduce the damages and loss of properties. With gauged data and local expertise, model performance should be enhanced even more. Catchment behaviour is influenced not just by soil moisture and evaporation, but also by reservoir status and river channel capacity. It is feasible to give all important data that is now accessible while also collecting data that is currently unavailable.

In the next chapter under methodology could discuss methods that will be used to achieve this target.

Chapter 3

Methodology

3.1 Introduction

Table 3.1 illustrates the methodology followed when carrying out the project. ‘Review’ and ‘Analyse’ parts are done in the Literature Review which is explained in chapter 2. ‘Gather’ and ‘Collect’ activities as well as the initial steps of the ‘Design’ is explained in this chapter and major parts of ‘Design’, ‘Model’ and ‘Forecast’ is explained in chapter 4, Implementation. Finally, ‘Evaluate’ activity will be explained in chapter 5, Evaluation.

Table 3.1: Methodology of the project

Review	**Review flooding and flood prediction.**
Gather	**Gather data about the Flooding conditions in Daduru Oya basin area and prevailing mitigation methods.**
Analyse	**Analyse different flood management strategies and select the best method for the scenario.**
Collect	**Collect data from different weather stations related to Daduru Oya basin.**
Design	**Design a method to quantify, rate and integrate above factors to get more complete and precise outcomes.**
Model	**Do water level modelling based on weather conditions.**
Forecast	**Forecast floods based on weather and geographical conditions.**
Evaluate	**Evaluate the accuracy of the models.**

3.2 Study Area

3.2.1 Topography and climate of Sri Lanka

Sri Lanka is a humid tropical island staying near to the southeast point of India close to the equator with a land area of 65 610 km2 (figure 3.1) [1][4]. With 75m above sea level average elevation, a broad first peneplain covers three-quarters of the land. A second peneplain soars to 500m. A mountain massif that rises steeply and that reaches an elevation of 2500m is formed with a third peneplain towards the south. For administrative purposes, the country is divided into nine provinces: Central, Eastern, North Central, Northern, North-western, Sabaragamuwa, Southern, Uva, and Western [4][31].

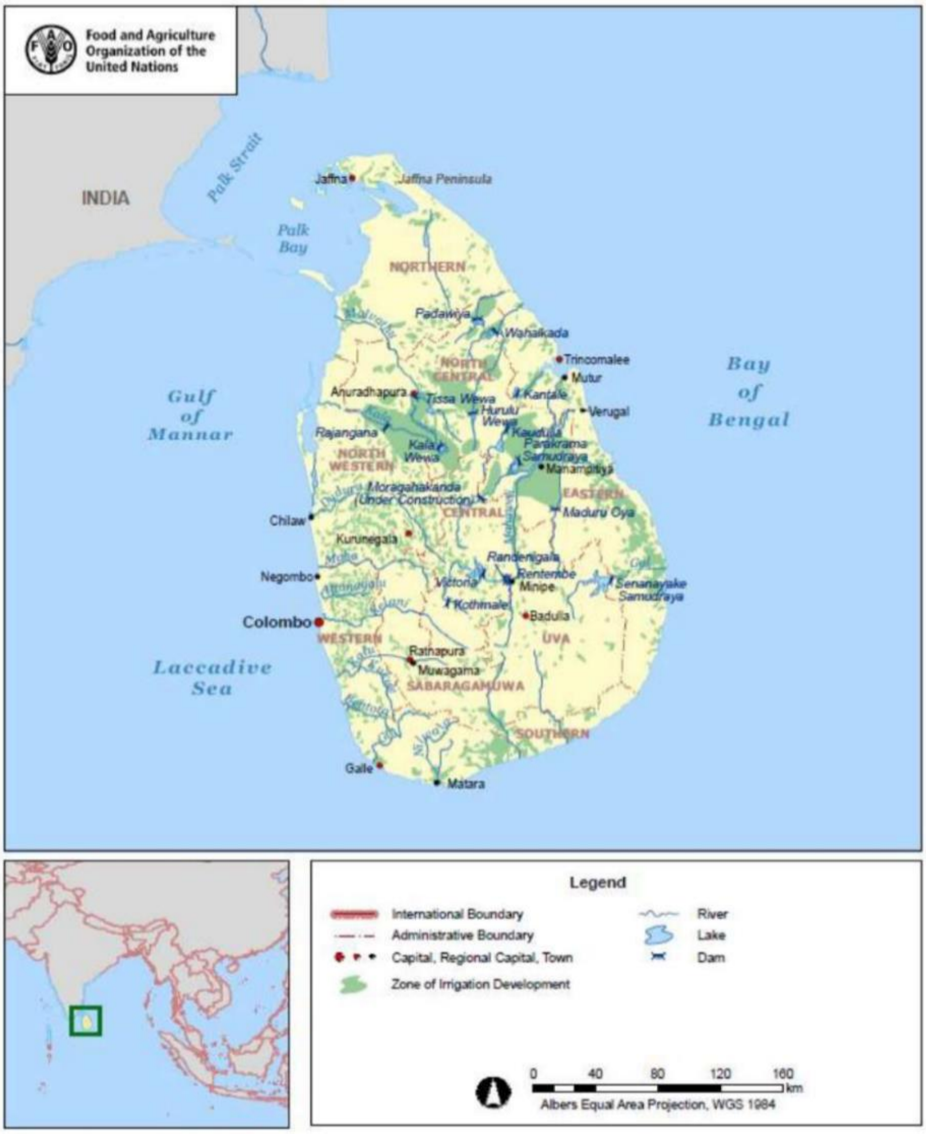


Figure 3.1: Map of Sri Lanka [4].

Sri Lanka is situated in the path of two monsoons, the southwest, and north-east monsoons. High temperatures and monsoonal winds give rise to rainfall patterns with spatial and temporal variations. The major share of the annual rainfall in Sri Lanka is originated from multiple rainfall types such as monsoonal, convectional, and depressional [8]. The mean annual rainfall is 1861 mm, and annual runoff is estimated to be around 35% of the annual rainfall. About half of the annual surface runoff is carried about by 20 out of 103 rivers in Sri Lanka which are classified as wet zone rivers. Building numerous reservoirs and diverting water to the dry zone compensate for the unequal distribution due to considerable variations of individual values across rivers. According to the 'International Commission of Large Dams', 80 dams qualify under the major dam category, and it is estimated that there are about 13, 000 man-made reservoirs in the country. Seven major types of ground water aquifers have been identified and groundwater resources are lesser compared to surface water resources. 7800 MCM per annum is the estimated groundwater potential [1].

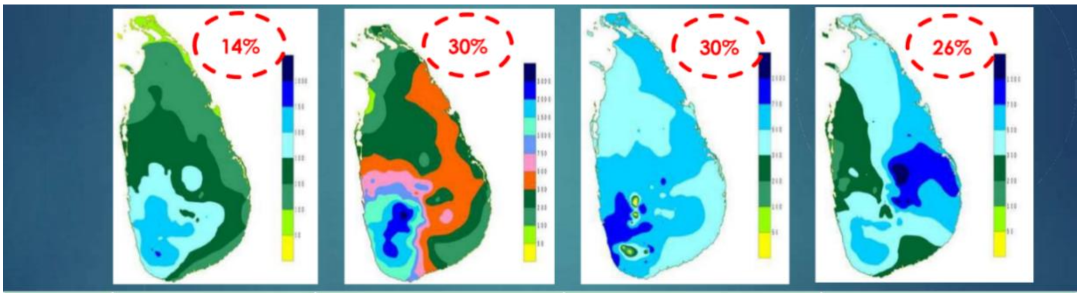
Several agroclimatic regions can be recognized, such as wet zone, intermediate zone, dry zone, and arid zone based on rainfall and Sri Lanka's climatic year can be divided into five seasons depending on the rainfall pattern (table 3.2) [4]:

Table 3.2: Five Seasons in Sri Lanka [4].

Season	**Period**	**Description**
The convectional-convergence period	March to mid-April	when the island comes under the influence of the inter-tropical convergence zone
The pre-monsoon period	mid-April to late May	presents transitional weather patterns, with convectional weather gradually being suppressed by surges of the southwest monsoon
The southwest monsoon	late May to late September	brings the largest amount of rainfall to the southwest lowlands and windward slopes of the central hills. After the rains, dry desiccating monsoon winds blow across the north, north central, and southeast regions
The convectional cyclonic period	from late September to late November	begins with the weakening of the southwest monsoon. This period can include cyclones and may result in heavy rainfall
The northeast monsoon	November to February	though weak compared to the southwest monsoon, brings agriculturally important rainfall to the northern and eastern parts of the island

Rainfall is the only source of useful precipitation, its uneven distribution largely due to two monsoons and the orographic influence of the central mountain region. Local thunderstorms during the transition period between the monsoons and convection effects from depressions in the Bay of Bengal are causes for some of the rains. In October – November which is the inter monsoon periods that have most favourable conditions due to tropical cyclones approaching from the Bay of Bengal, there is heavy rainfall, which could be expected during either monsoon periods as well and their contribution to the total volume of rain during these events is significant (figure 3.2 and 3.3) [1].

The mean annual temperature is about 27ºC in the lowlands and 15ºC in the central highlands. The temperature decreases with increasing altitude, approximately 2ºC per 300 m of elevation [4].



Season	First Inter-monsoon	Southwest Monsoon	Second Inter-monsoon	Northeast Monsoon
Period	March – April	May – September	October - November	December – February
Rainfall	260 mm	546 mm	548 mm	459 mm

Figure 3.2: Seasonal Rainfall Distribution of Sri Lanka [9][10].

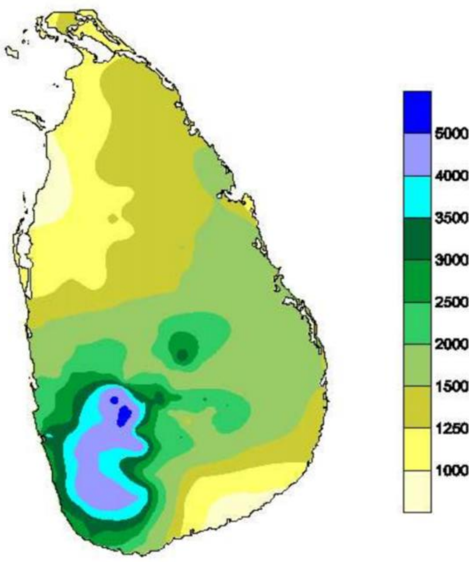


Figure 3.3: Distribution of Mean Annual Rainfall [4] [9].

3.2.2 Water sources

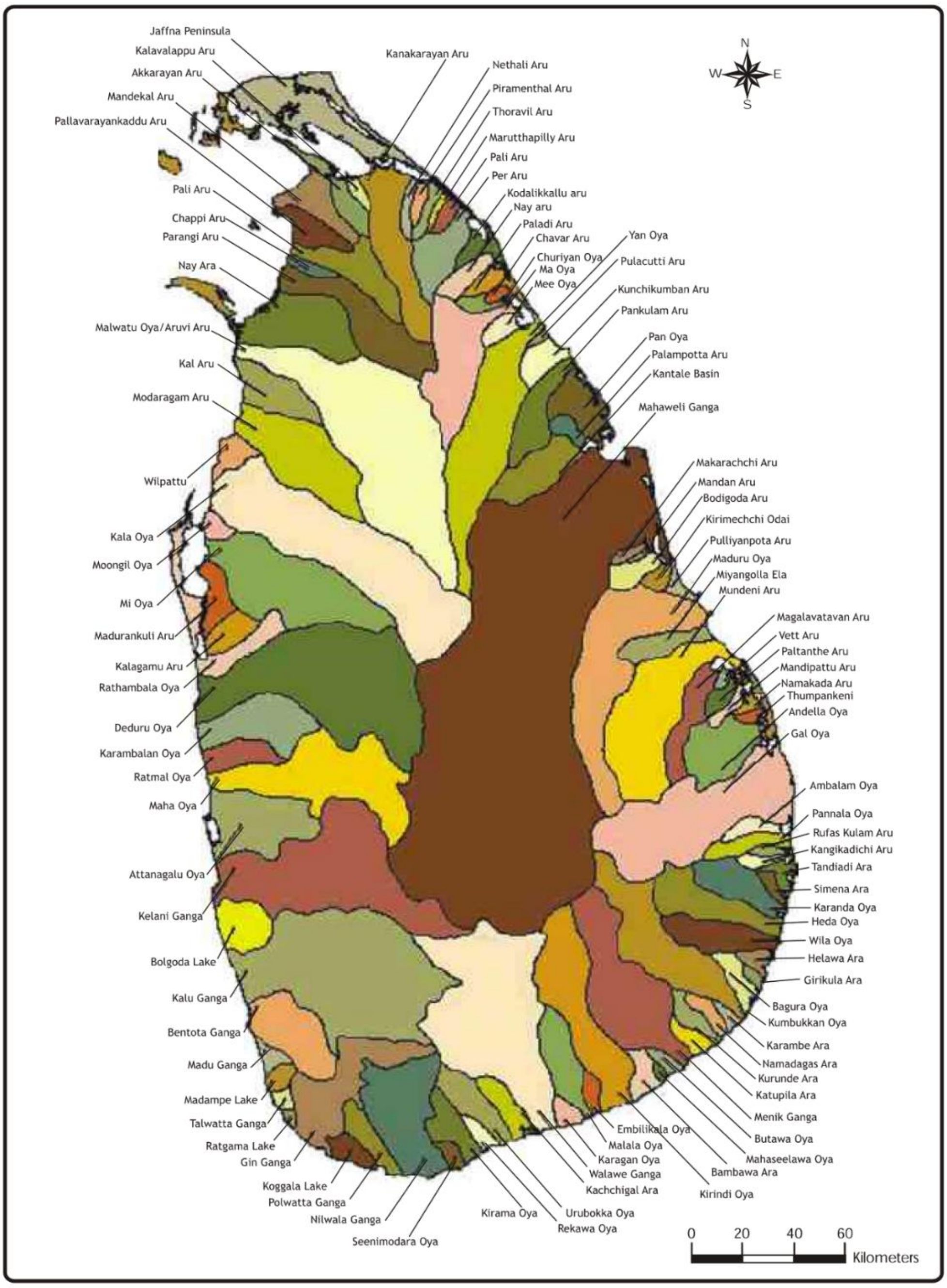


Figure 3.4: River basins of Sri Lanka [1].

The radial network of rivers in Sri Lanka originates in the middle highlands. There are around 103 different river basins that span 90 percent of the island as depicted in figure 3.4. The majority of Sri Lanka's river basins are small. Only 17 of the 103 basins are larger than 1000 km^2. Aside from the Mahaweli basin, four others are larger than 2 500 km^2. Sri Lanka's total runoff is estimated to be 52 km^3/year. Annual runoff estimates with 75 and 50 percent dependable rainfall are 42 and 49 km^3, respectively [1].

Water resources

Renewable freshwater resources			
Precipitation (long-term average)	-	1 712	mm/yr
	-	112 300	million m^3/yr
Internal renewable water resources (long-term average)	-	52 800	million m^3/yr
Total actual renewable water resources	-	52 800	million m^3/yr
Dependency ratio	-	0	%
Total actual renewable water resources per inhabitant	2009	2 555	m^3/yr
Total dam capacity	1996	5 942	million m^3

Figure 3.5: Renewable freshwater resources of Sri Lanka [1].

Internal renewable groundwater resources are projected to be 7.8 km^3, with the majority (about 7 km^3/year) returning to river systems and being included in the estimate for surface water resources. As a result, the total renewable water resources are projected to be 52.8 km^3/year as given in figure 3.5 [1].

Most studies on water scarcity assessment classify Sri Lanka as having little or no water shortage or moderate water scarcity, however they do not consider the geographical and temporal fluctuation of water availability. The bi-monsoonal climate pattern causes significant seasonal and regional variability in rainfall in Sri Lanka (northeast monsoon from October to March and southwest monsoon from April to September) [1].

3.2.3 General information on the Daduru Oya basin

Daduru Oya is considered in the category of both monsoonal basins even though it is not strictly a bi-monsoonal river that is 142 km long [1]. The main water source in the basin is the Daduru Oya river, which originates on the eastern border of the central province. It flows through the districts of Kurunegala and Puttalam before entering the sea in Chilaw. The river's mainstream is approximately 115 kilometres long, and the river consists of nine branches. The basin covers around 2,600 square kilometres, with 3% in the Central Province (Kandy and Matale districts) and the rest in the North-western Province (88 percent in Kurunegala and 9 percent in Puttalam districts) [32].

The Daduru Oya river basin's only source of water is rainfall because there are no trans basin diversions to the Daduru Oya basin. Direct rainfall, streamflow consisting of direct runoff, baseflow or groundwater discharge, surface water storage in reservoirs, and groundwater storage all assist water consumers in this basin. From September through December, the basin area receives monthly rainfall ranging from 108 mm to 280 mm on average and this main agriculture season in the country is known as the ‘Maha’ (wet) season. The ‘Yala’ (dry) season lasts from March to June and is marked by minimal rainfall (table 3.3). The basin region is divided into two climatic zones: wet and intermediate, as well as their subdivisions (figure 3.6). The amount of rain that falls in these three zones varies greatly. The wet zone of the basin's upper watershed generates runoff, which falls into the basin's bottom section (table 3.4)[32]. From year 1992 to 2003 at Chilaw station, the average annual rainfall is 1611 mm, average annual runoff is 947 mm, average annual runoff to rainfall ratio is 59% and three rainfall stations were used for averaging [1].

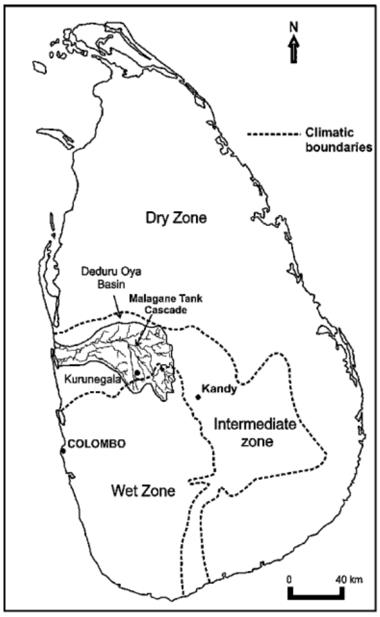


Figure 3.6: Daduru Oya river basin and the study region concerning the climatic zones of Sri Lanka [51].

Table 3.3: Average rainfall in the Daduru Oya basin [32].

Month	Average rainfall (mm)
January	66
February	65
March	72
April	217
May	159
June	87
July	81
August	56
September	108
October	268
November	283
December	146
Average (annual)	1,609

Table 3.4: Monthly long-term, average rainfall (mm) [36].

Location	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wariyapola	122	89	72	212	135	112	113	85	127	288	308	236
Chilaw	39	49	94	232	193	69	70	25	92	277	260	125
Batalagoda	70	66	80	211	155	114	89	69	125	277	256	151
Hakwatuna Oya	66	63	19	218	178	36	81	86	107	210	314	175
Magalla	59	58	29	182	118	63	65	17	65	202	252	104
Kurunegala	59	73	124	262	211	160	112	85	156	359	334	132
Nikaweratiya	45	59	83	198	127	55	40	26	84	263	262	102

Note: Long term averages were calculated for Wariyapola and Chilaw based on data from 1950-1980, for Batalagoda on data from 1950-1999, for Hakwatuna on data from 1995-1999, for Magalla on data for 1996, and for Kurunegala and Nikaweratiya on data from 1971-1998.
Source: Department of Meteorology.

Basic features of Daduru Oya river basin are given in table 3.5.

Table 3.5: Basic features of the Daduru Oya [36].

Name of sub-watershed and no.	No. of meso-catchments	Drainage area (km^2)
Upper Deduru Oya (DE 1)	-	156.3
Delwita Oya (DE 2)	-	122.4
Batalagoda Kuda Oya (DE 3)	-	104.2
Melsiripura (DE 4)	-	93.9
Kimbulwana Oya (DE 5)	-	199.8
Hakwatuna Oya (DE 6)	1	179.8
Talagalla Oya (DE 7)	9	136.0
Mid Deduru Oya (DE 8)	15	216.2
Nabadewa Kuda Oya (DE 9)	8	116.4
Lower Deduru Oya (DE 10)	5	276.9
Kolamunu Oya (DE 11)	28	455.5
Rambukkan Oya (DE 12)	10	136.2
Magauru Oya (DE 13)	5	231.2
Wenuru – Wellawa (DE 14)	2	197.7
Deduru Oya (total)	14	2,622.5

Daduru Oya long-term annual discharge at Chilaw from year 1951 to 1980 is given in table 3.6.

Table 3.6: Daduru Oya run off (Daduru Oya long-term annual discharge at Chilaw) [36].

Year	Discharge (MCM)	Year	Discharge (MCM)	Year	Discharge (MCM)
1951	NA	1961	1,035	1971	1,844
1952	792	1962	1,168	1972	2,014
1953	NA	1963	1,254	1973	795
1954	1611	1964	870	1974	796
1955	1563	1965	1,291	1975	741
1956	NA	1966	1,274	1976	969
1957	NA	1967	1,152	1977	1,620
1958	NA	1968	1,012	1978	966
1959	NA	1969	933	1979	NA
1960	NA	1970	1,545	1980	NA

Note: NA = Not calculated due to non-availability of relevant data.
Source: Long-term hydro meteorological data in Sri Lanka from the Department of Meteorology.

3.2.3.1 Groundwater

The western part of the basin, with its deep weathered profile and sandy soils, may hold a significant quantity of groundwater in the regolith. The basin's north-central region (Wariyapola, Nikaweratiya, and Mahawa regions) has a relatively thin regolith soil profile and little groundwater. Because of the limited circulation of groundwater, a typical trait is poor quality in terms of salinity, hardness, fluoride, and iron [32].

3.2.3.2 Pattern of Land Use

Table 3.7, Land use pattern in the Daduru Oya basin, shows that the majority of the lands are used for coconut, highland crops, paddy, and settlement needs. The basin's forest area has been decreased to 3% of the entire land area (including forest plantations) [32].

Table 3.7: Land use pattern in the Daduru Oya basin [32].

Land category	Usage	Extent (ha)	Land distribution
Developed lands		239,810	91%
	Build up lands	520	0.2%
	Homesteads	35,050	13.4%
	Tea lands	240	0.1%
	Rubber lands	4,680	1.8%
	Coconut lands	95,560	36.4%
	Mixed trees	1950	0.7%
	Paddy lands	48,655	18.6%
	Sparsely used croplands (chena and highlands)	50,500	19.3%
	Planted forests	2,655	1.0%
Undeveloped lands		22,440	9%
	Dense forest	4,225	1.6%
	Open forest	1,155	0.4%
	Scrub lands	4,035	1.5%
	Grasslands	55	0.02%
	Water bodies	11,410	4.4%
	Barren lands	1,420	0.5%
	Mangroves	90	0.03%
	Marshes	50	0.02%

3.2.3.3 Soil Types

Information on soil types in the basin is given in Table 3.8 [32].

Table 3.8: Soil types in the basin [32].

Soil group	% of basin coverage	Average soil depth (m)	Available water (cm/m)
Alluvial soils	6.0	2.34	6
Old alluvial soils	8.0	2.68	8
Non calcic brown soils	36.0	1.32	11
Red yellow podzolic	38.0	0.89	15
Reddish brown latosolic	7.0	1.59	12
Reddish brown earth	2.0	0.82	14
Other soil complex	3.0	N/A	N/A

Source: Soil map of Sri Lanka, Survey Department, 1990.

3.2.3.4 Major and medium irrigation systems including major diversions

In different parts of the basin there are four major and four medium irrigation schemes as indicated in table 3.9. Major schemes are confined to the middle part of the basin [32].

Table 3.9: Basic data on reservoirs (tanks) and diversions (anicuts) [32].

Serial No.	Name of tank/anicut	Classification	Catchment area km^2
1	Batalagoda tank	Major reservoirs	12.9
2	Hakwatuna Oya tank	Major reservoirs	63.7
3	Kimbulwana Oya tank	Major reservoirs	98.4
4	Magalla wewa	Major reservoirs	54.4
5	Meddeketiya tank	Medium reservoirs	10.4
6	Wennoru wewa	Medium reservoirs	10.1
7	Hulugalla wewa	Medium reservoirs	NA
8	Karawita wewa	Medium reservoirs	NA

Note: NA = Data not available.
Source: Register of irrigation projects in Sri Lanka, Irrigation Department, 1975.

3.2.3.5 Small tanks and diversions

More than 3,000 minor irrigation schemes are scattered over the whole basin. Their distribution in sample DS divisions is illustrated in table 3.10. The density of these tank systems increases in the DS divisions Ibbagamuwa, Ganewatte, Wariyapola, and Bingiriya, in the middle portion of the basin [32].

Table 3.10: Small tanks and diversions in the sample DS divisions in the basin [32].

DS division	Agrarian services center	Total No.	Command (ha)	No. of families	% of total families
Ridigama	Dodamgaslanda	35	123	1,409	-
	Karadagolla	18	319	1,315	-
	Ranbadagolla	49	341	2,995	26
Ibbagamuwa	Ibbagamuwa	83	1,364	1,903	-
	Melsiripura	102	542	1,880	20
Ganewatte	Ganewatte	40	332	973	-
	Kumbukgete	53	311	944	21
Wariyapola	Auleagama	192	1,236	3,830	-
	Wariyapola	193	1,595	3,571	42
Nikaweratiya	Nikaweratiya	124	74	3,231	-
	Divullagoda	105	583	2,332	57
Bingiriya	Bingiriya	150	1,143	3,318	-
	Tharana	95	627	2,194	41
Chilaw	Chilaw	17	486	534	10
Arachchikattuwa	Arachchikattuwa	36	-	1,013	10

Source: Agrarian service centers, Department of Agrarian Services.

Since ancient times, the basin's water resources have been used mostly for agriculture, primarily paddy farming. Currently, the basin has four large irrigation systems, many medium schemes, and about 3000 minor tank systems to supply irrigation for about 50,000 ha, or nearly 18% of the basin's developed land area. The primary irrigation systems are restricted to the basin's central section, where river diversion works have been built. The smaller schemes and systems are dispersed throughout the basin [32].

3.3 Users

3.3.1 Identification of stakeholders

As this is a study purpose project it is not needed to consider the investors or funding organisations.

1. Sri Lankan Government stakeholders are
   - Irrigation Department
   - Department of Meteorology
   - Regional Planning Agency
   - National Building Research Organization
   - North-western Provincial Council
   - Kurunegala and Puttalam District Secretariat and Divisional Secretariate offices
   - Urban Councils in Kurunegala and Puttalam Districts
   - Gramaniladhari Divisions in Kurunegala and Puttalam Districts
   - Archaeological centres in Kurunegala and Puttalam districts under the department of Archaeology
   - Department of Forestry
   - Electricity Board
   - Water Board
   - Telecommunication service providers
   - Higher-studies organizations such as Universities, Technical Colleges, Vocational Training Centres
   - Hospitals, Medical Dispensaries, Public Health Inspection Office
   - Postal Department
   - Transport sector
   - Petroleum distribution centres
   - Schools
   - Police

2. Non-Government Organizations in the in Kurunegala and Puttalam Districts
3. Business Community in the North-western Province
4. Local Community in the affected area
5. Insurance Organization and Doners for the flood-affected people

3.4 Inputs

Inputs to the proposed systems are the DEM (Digital Elevation Model) of Daduru Oya with 30m resolution, outlet pour point shape file of Daduru Oya, Flood Model geodatabase, snap distance for pour point, lower and upper limits for velocity, flood depth and reclassification values for isochrone map as a text file.

3.5 Outputs

System outputs are the unit hydrograph, flood extent map and the flood depth map and related tables.

3.6 Data Collection

It has been collected data from the Department of Irrigation Sri Lanka and some of the data was available from stations managed by Faculty of Information Technology of University of Moratuwa. And DEM data was available from the Department of Earth Resources Engineering, University of Moratuwa.

1. Sri Lanka DEM with a resolution of 30m
2. Daily rainfall 2016-2019

   Ethiliyagala

   Diniminiyatenna

   Ridi Bendi Ela

   Daisy Maspotha

   Valley

   Vijaya Katupotha

   Amunugama

   Ma Eliya

3. Daily Water level in meters 2016-2019

   Amunugama – 2 times daily – max 3.98, avg 1.24

   Ridi Bendi Ela – once daily

   Ethiliyagala– 2 times daily – max 6.67, avg 1.71

   Maspotha– 2 times daily – max 7.10, avg 0.84

4. Daily discharge in cumecs 1990-2019

   Chillaw

   Ridi Bendi Ela

3.7 Selection of Models/ Tools for Analysis

3.7.1 Spatial analysis in ArcGIS Pro

Spatial analysis enables to solve complicated location-based issues, discover patterns, evaluate trends, and make decisions. Beyond mapping, spatial analysis allows to investigate the features of locations and their interactions. Spatial analysis broadens the decision-making horizons. By using a set of spatial operators, it is possible to integrate information from many sources and extract new information via spatial analysis. It may use this set of spatial analysis tools to address complicated spatial problems. Statistical analysis can help to evaluate whether the patterns seeing are significant. Could use image analysis to detect change over time and evaluate multiple layers to determine the appropriateness of a location for a specific activity. These tools enable to answer critical problems and make decisions that go beyond the realm of basic visual examination [33].

Following could be done using spatial analysis:

- Determine relationships.
- Understand and describe locations and events.
- Detect and quantify patterns.
- Make predictions.
- Find the best locations and paths.

ArcGIS Pro's analysis and geoprocessing capabilities may be used to answer a variety of geographic queries and perform spatial analysis. To begin doing geographical analysis, frame the inquiry. Then must prepare and evaluate the data. Finally, must make a visual representation of the findings and share them to others. ArcGIS Pro's spatial analysis has been expanded from 2D to 3D and through time [33].

Using geoprocessing tools in ArcGIS Pro, it is possible to perform the following types of operations on geographic data:

- Extract and overlay data.
- Add and calculate attribute fields.
- Summarize and aggregate data.
- Calculate statistics.
- Model relationships and discover patterns. [33]

3.7.2 Modelling and scripting

ModelBuilder is a tool for creating, editing, and managing geoprocessing models that automate those techniques. Models are processes that connect sequences of geoprocessing tools by feeding the result of one tool into the input of another. ModelBuilder is also a visual programming language for creating processes [33].

To create a geoprocessing model in ModelBuilder, should add tools and data to a model and connect them to determine the order of execution. Models could reduce the time spent on repetitive procedures, minimize errors, and iterate the analysis more effectively. By combining models and spatial algorithms into a single process, could create end-to-end workflows. ModelBuilder allows to construct fully functional models without writing a single line of code or can use Python to script the workflows and produce ready-to-share models [33].

ModelBuilder in ArcGIS Pro allows to do the following:

- Build a model by adding and connecting data and tools.
- Iteratively process every feature class, raster, file, or table in a workspace.
- Visualize the workflow sequence as an easy-to-understand diagram.
- Run a model step-by-step, up to a selected step, or run the entire model.
- Make the model into a geoprocessing tool that can be shared or can be used in Python scripting and other models. [33]

3.7.3 What is geoprocessing?

Geoprocessing is a framework and collection of tools used to handle geographic and related data. The full range of geoprocessing tools may be used to undertake spatial analysis or automate the management of GIS data. A typical geoprocessing tool works with a dataset, such as a feature class, raster, or table, to generate an output dataset. In addition to the tools, geoprocessing provides a sophisticated framework that allows the user to control the processing environment and develop new tools to further automate the job. ArcGIS Pro's geoprocessing tools may be used as building blocks to develop an unlimited number of custom tools that automate repetitive activities or solve complicated issues [34].

3.7.4 Create a model tool

A geoprocessing model is kept in a toolbox as a model tool. Model tools, like every other geoprocessing tool in the Geoprocessing pane, may be utilized in other models and Python scripts. It could create a model tool to process different datasets with different parameters than those supplied in the model without having to change the model variables in ModelBuilder [35]. To make a model tool, perform the following steps:

1. Create and save a model in ModelBuilder.
2. Configure the model parameters.
3. Specify the model tool's attributes.
4. Make a record of the tool. [35]

3.7.4.1 Add data

Models operate on data, with the output of one geoprocessing tool being utilized as the input to another. It could begin creating the model by first importing the data that need to process [35].

3.7.4.2 Add geoprocessing tools

Geoprocessing technologies are an essential component of the model. ArcGIS Pro has a plethora of geoprocessing capabilities for performing a wide range of GIS operations.

Once it is identified the appropriate tools for the job, it's simple to include them into a model [35].

3.7.4.3 Connect data and tools

Geoprocessing models enable the integration of data and technologies into processes. It must indicate which of the model's data variables should be handled by which geoprocessing tools [35].

3.7.4.4 Change tool parameters

Tools in ModelBuilder, like geoprocessing tools in the Geoprocessing pane, contain required and optional parameters. For the tool to operate within the model, the required parameters must be supplied [35].

3.7.4.5 Set model parameters

Any variable may be converted into a model parameter. There are two main reasons for making a model variable a parameter:

- When the model is performed as a geoprocessing tool, the output variables that are set as model parameters are added to the map.
- When the model is run as a geoprocessing tool, variables defined as model parameters appear as tool parameters, allowing to specify different data or values for the model to process than what was supplied when the model was constructed. [35]

3.7.4.6 Validate a model

When building a model, the data and tools that are added and connected are automatically validated or reviewed to ensure that the data exists, is valid for use with a tool, and that the tool parameter settings are correct. It might manually validate the model by going to ModelBuilder > Run > Validate. This is generally only necessary when a model's data or tools have been changed, relocated, renamed, or deleted. It must also verify the model if you it is to execute all the processes in the model again [35].

3.7.4.7 Validate data variables

Data variables are used to refer to data routes and to hold descriptive data information. When a model is validated, each data variable is reviewed to ensure that it exists and can be used by the tools to which it is attached [35].

3.7.4.8 Validation of a tool

Each parameter of a geoprocessing tool automatically validates the data or value given for that parameter [35].

3.7.4.9 Run the model

The model is ready to run after it is built and verified that all processes are legitimate. In ModelBuilder, you can run the model step by step or as a whole, and it can also be used as a geoprocessing tool in the geoprocessing panel [35].

3.7.4.10 Add to Display

It could add output datasets to a map while executing a model in the ModelBuilder window [35].

3.7.4.11 As a geoprocessing tool, run a model

Models might be stored in a toolbox as geoprocessing tools [35].

3.8 Technology Adopted

Arc GIS Pro 2.7.3 which is a current version of Arc GIS software by Esri was selected as the main software package in which an education license was given to University of Moratuwa to use for educational purposes.

It is selected over other available GIS software due to reasons such as:

- It has higher data management, map creation, and spatial analysis capabilities.
- Simplicity of the product which provide learnability.
- Easy navigation of file system and management of geodata.

- ArcGIS Online is a richer source of GIS data.
- Variety of specialised tools.
- ModelBuilder and ArcPy to automate everything.
- More options for advance editing, visualisation, analysis, sharing and collaboration, big data analytic, machine learning and artificial intelligence.
- There is a bigger user community and lot of resources available for learning.

Python is the scripting language of ArcGIS that help to automate GIS tasks.

Following are the tools used for the project:

- ArcGIS Pro

  Spatial Analysis and Data Science Tools

  ArcPy

  ArcGIS API for Python

  ModelBuilder

  Arc Hydro Tools
- ArcGIS Online
- StoryMap Builder

3.9 Summary

In this chapter the methodology that pave the path to model building process was discussed. A comprehensive insight into the area of study, users, inputs and outputs were discussed. Which followed by a discussion about the underline tools and technology that will be used throughout next steps of the research to give a foundation for the project. In following chapters implementation and evaluation of the project that was carried out based on this chapter will be discussed in detail.

Chapter 4

Implementation

4.1 Model Developed for Daduru Oya Flood Forecast

A Model was created to forecast Daduru Oya floods as illustrated in figure 4.1 and then later developed to forecast floods for any given digital elevation model and pour point is illustrated in figure 4.2, it was developed so that it could be used for any DEM pre-processing and watershed delineation as well as creating hydrographs and Hand-based flood depth and flood extent mapping. For this purpose, it was necessary to change the model so that the user can change inputs to the model and get the desired outcome that is needed as well as to save the output in the desired geodatabase very easily.

Coloured processes are in 'ready-to-run' state or 'has been run' state. If any process is in 'not ready-to-run' state it will be in grey colour. Input data are in blue colour, Derived data are in green colour, and Tools are in amber colour. Letter 'P' appears near model parameters which becomes tool parameters, allowing to specify different values or data.

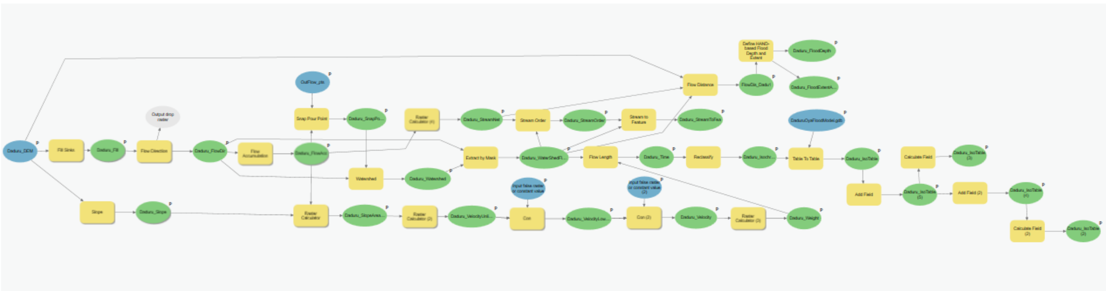


Figure 4.1: Developed flood model for Daduru Oya

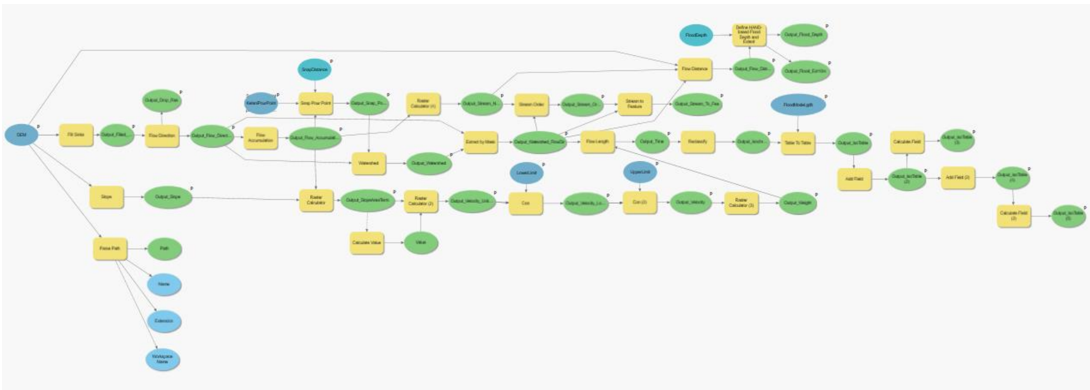


Figure 4.2: Generic flood model.

Following sections will explain the model building process and underlying techniques and theories which are used to build the model for flood analysis.

4.2 Understanding Drainage Systems

A drainage system is the region where water falls and the network that it flows through to reach an exit. Water flow via a drainage system is just one part of the hydrologic cycle, which also includes precipitation, evapotranspiration, and groundwater flow. Hydrology instruments are focused with the movement of water across a surface [36].

A drainage basin is a site where water and other pollutants are drained to a single point. A drainage basin may also be referred to as a watershed, basin, catchment, or contributing area. This region is sometimes referred to as the whole area flowing to a certain outlet or pour point. A pour point is generally defined as the lowest point along the drainage basin's boundary where water departs a region. A drainage divide, often known as a watershed border, is the dividing line between two basins [36].

The network that transports water to the outflow may be seen as a tree, with the outlet at the trunk's base. The tree's branches indicate stream channels. A node, also known as a junction, is the point at where two stream channels intersect. Stream links are sections of a stream channel that connect two consecutive junctions or a junction and the outflow [36]. Figure 4.3 illustrates components of drainage basin.

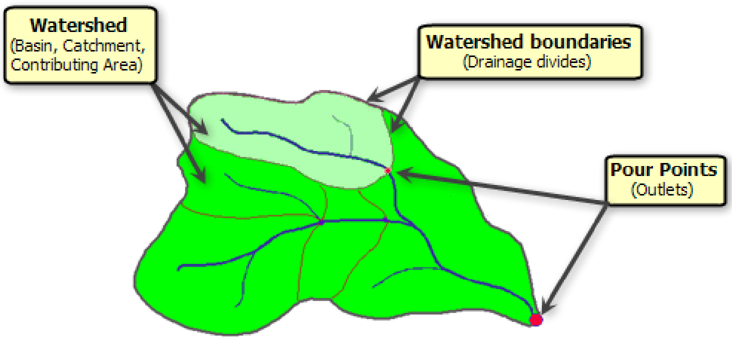


Figure 4.3: Components of drainage basin [36].

4.3 Digital Elevation Models (DEM)

A digital elevation model (DEM) is a raster depiction of a continuous region, most often the earth's surface. The resolution is the major factor of the accuracy of this data (the distance between sample points). Other factors impacting accuracy include data type (integer or floating point) and surface sampling during the original DEM generation [37]. Figure 4.4 illustrates a DEM [38].

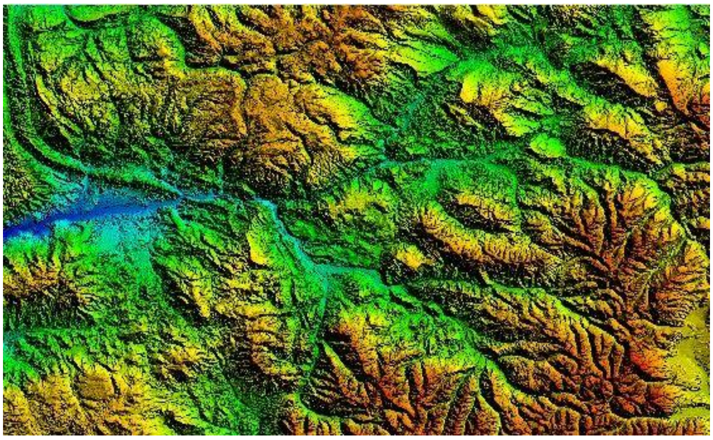


Figure 4.4: A Digital Elevation Model. [38]

The first main input to the model is the DEM of the river basin, and a DEM of Sri Lanka with a resolution of 30m was available. It was necessary to extract the Daduru Oya DEM from that. First, using Raster Functions -> Data Management -> Clip tool the unnecessary parts of the Whole DEM was clipped to get a neater DEM of Sri Lanka. For that purpose, as the clipping geometry raster, LKA_Adm0 shape file was downloaded from ‘diva-gis.org’ [39] and used in the tool. Then using ‘Export Raster’ tool the DEM was clipped to get a smaller DEM of Daduru Oya watershed area to minimise processing load and to reduce running time of the model. This process is illustrated with screen shots of each step in ArcGIS Pro in the Appendix – A and the outcome is as of figure 4.5.

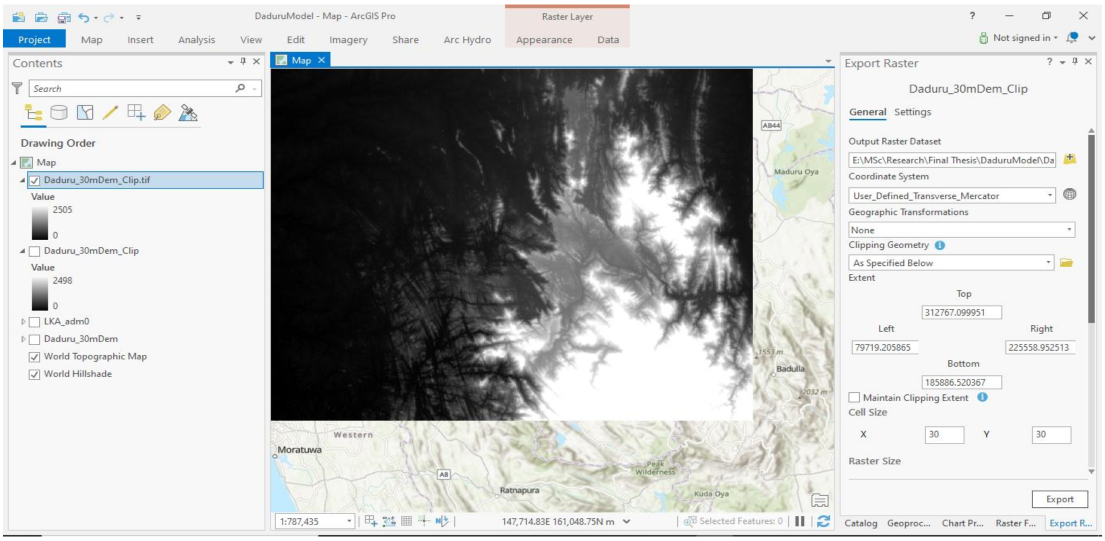


Figure 4.5: Daduru Oya DEM.

Then a special tool, 'Parse Path' from ModelBuilder 'Utilities' toolbox is used as given in figure 4.6. The reason for using this tool is, then for any given DEM input it will be able to extract path, name, extension, and workspace from the file path and later could use these to generalise the model. In subsequent steps this usage will be explained in detail.

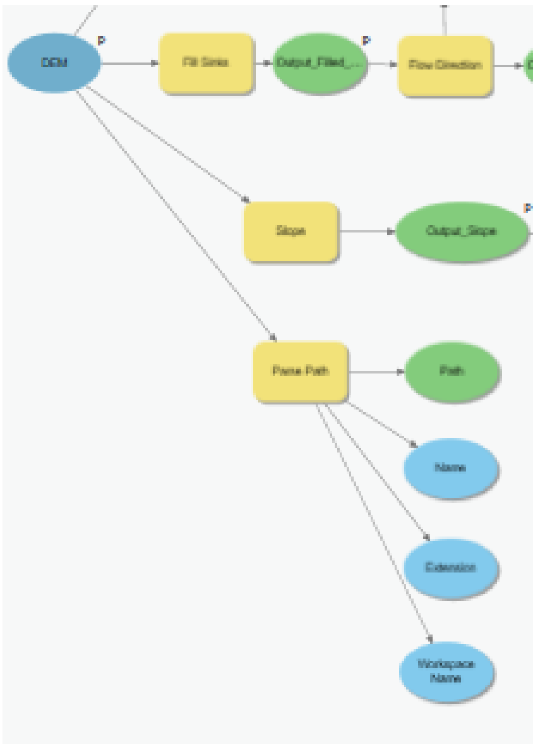


Figure 4.6: Parse Path tool.

4.4 Deriving Runoff Characteristics

It should go through a variety of procedures while outlining watersheds or defining stream networks. Depending on the properties of the supplied data, certain stages are essential, while others are optional. Flow will always be in the sharpest downslope direction over a surface. It is feasible to identify which and how many cells flow into any cell once the direction of flow out of each cell is known. This data may be used to establish watershed boundaries and stream networks [40].

4.4.1 Hydrologic conditioning

The model will begin with preconditioning of the elevation model that requires DEM preparation to get accurate hydrological analysis for the area around Daduru Oya basin. And the steps are:

1. Assessing flow direction.
2. Identifying and fulfilling the sinks.

"Digital Elevation Models comprise sinks which are areas of low elevation enclosed by higher elevation values and sinks can happen naturally but are more often data errors in a DEM raster data set. To remove imperfections in elevation models it is imperative to identify sinks" [40].

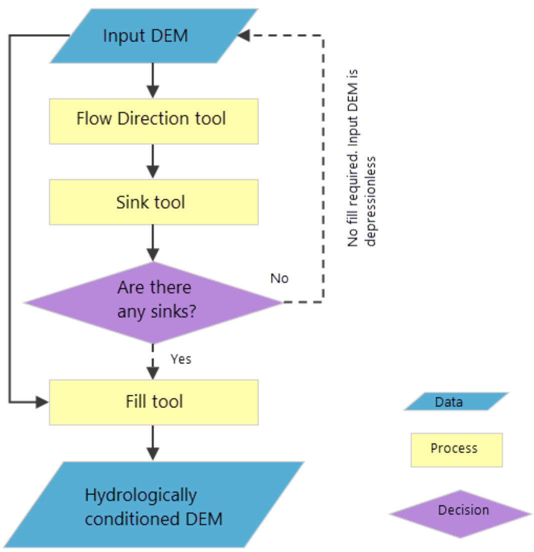


Figure 4.7: Hydrologic conditioning flowchart [40].

As given in the flow chart (figure 4.7) After identifying the flow direction for the region with the 'Flow Direction' tool, it is possible to locate sinks, which are locations where water can no longer flow. The 'Sink' tool is then used to detect regions of internal drainage (sinks) inside the flow direction layer. The sink raster will be the output.

In the implemented model ‘Sink’ tool is not used because it was not necessary to get the sink raster for this analysis. Instead ‘Fill’ tool has been directly used to fill the sinks in the DEM.

4.4.1.1 Fill sinks

All sinks in the new DEM will be modified to have the elevation value of the lowest cell close to the sink (figure 4.8). Each cell in the new DEM will be a component of at least one continuous decreasing route of cells heading to the dataset's edge. This updated DEM will enable more precise hydrological study of the region.

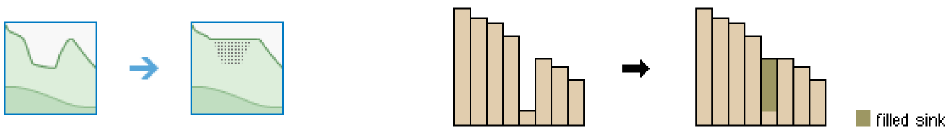


Figure 4.8: Filling sinks [40].

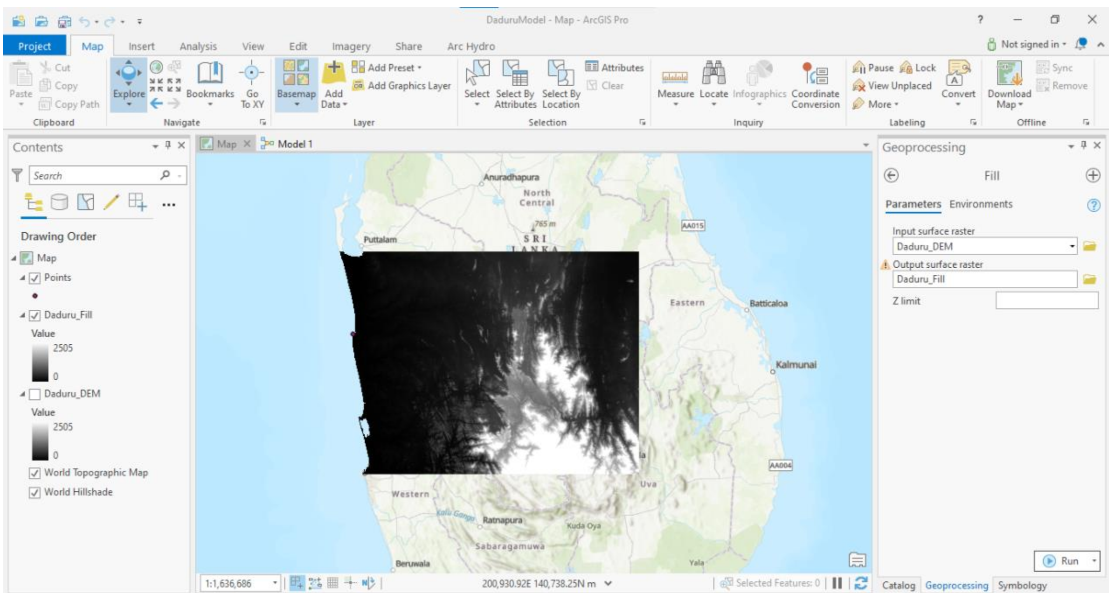


Figure 4.9: Using the Fill tool.

In figure 4.9 it has been illustrated how the ‘Fill’ tool is used. Input is the clipped DEM and the last option, Z limit, allows you to specify the greatest elevation difference at which sinks can be filled. If the height difference between a sink and its edge exceeds the limit, the sink will not be filled. [41]. Since it is needed to fill all the sinks in the data, it was decided to leave this parameter unchanged.

Output raster is given as an inline variable substitution '%Path%\%Name%Fill' as of figure 4.10. 'Path' and 'Name' variables will be given by the 'Parse Path' tool. Then the output will be saved in the same geodatabase that the DEM is saved and will have DEM name as first part of the output file name. This process was carried out for all the tools to make things easier and neater. Could refer Appendix – E for python code of the model to see how this is applied.

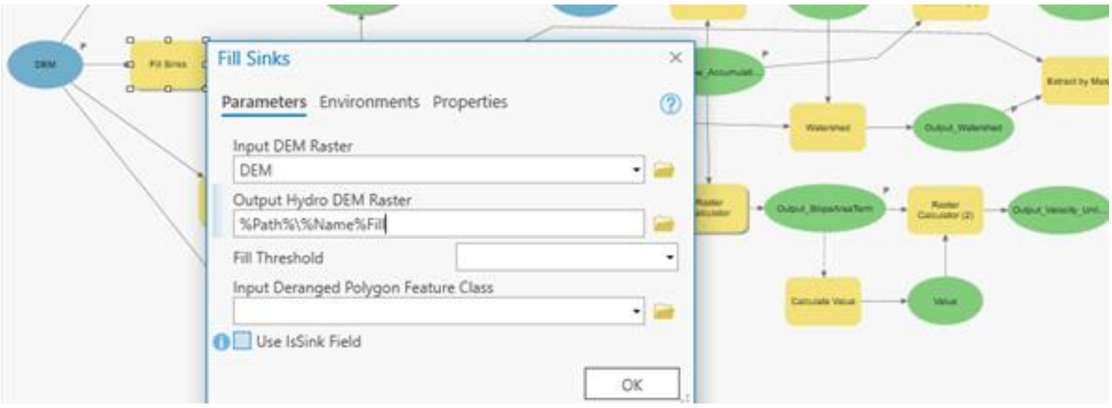


Figure 4.10: Fill sinks tool parameters.

4.4.2 Watershed delineation

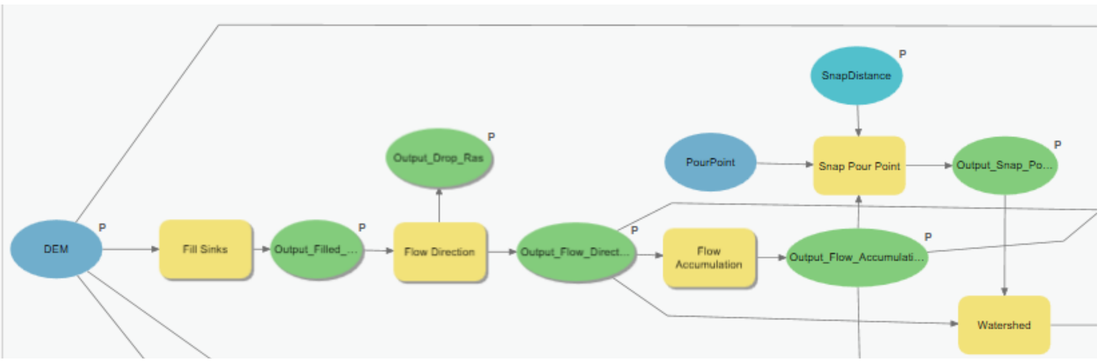


Figure 4.11: Model part for watershed delineation

As of figure 4.11, The hydrologically conditioned DEM was then used to calculate the watershed area for the Chilaw outflow point. A watershed area is defined as a region in which all flowing water flows toward a single point—the outflow. It will be able to confine the future analysis findings to the appropriate area for the outflow using the watershed area. [41]. The flow chart given in figure 4.12 depicts this process.

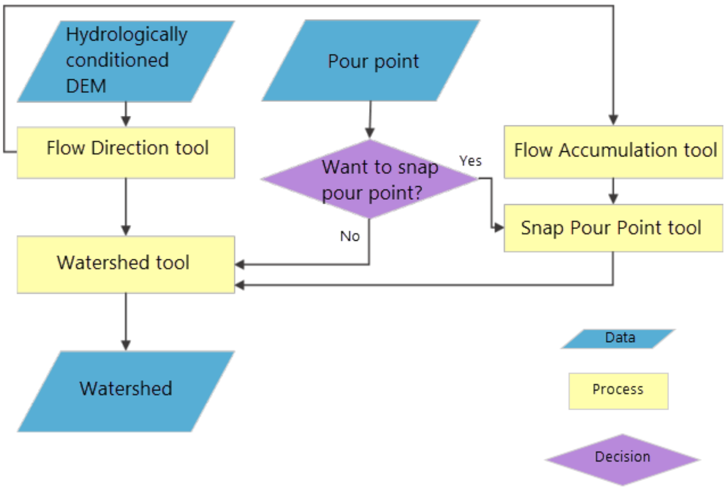


Figure 4.12: Watershed delineation flow chart [40].

To delineate the watershed should assess flow direction to determine the area where water will flow to the outlet.

4.4.2.1 Estimate flow directions

The first stage in defining a watershed is determining the direction of water flow in the DEM. As a result, it will be able to calculate the places where water will flow to the outlet. To accomplish so, a flow direction raster layer with filled sinks must be created for the DEM. The D8 flow technique was used to assign it a flow direction. This method assigns flow direction to the steepest downslope neighbour as depicted in figure 4.13 [42].

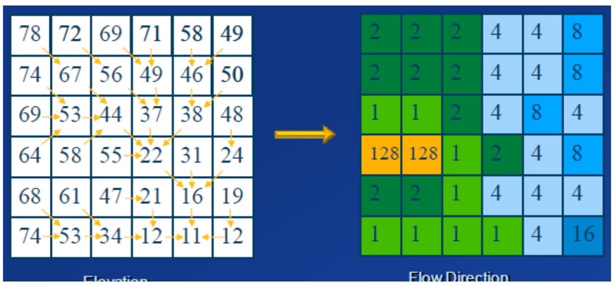


Figure 4.13: Flow direction D8 method [42].

A flow direction raster layer's cell values can typically only be one of eight integers: 1, 2, 4, 8, 16, 32, 64, and 128. These eight numbers represent the eight different flow directions (as any given cell is surrounded by eight cells). Because the new flow direction layer only contains eight values (figure 4.15), each value was automatically represented by a different colour (figure 4.14) [41].

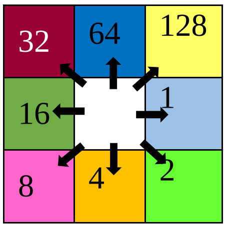


Figure 4.14: Flow direction coding [41].

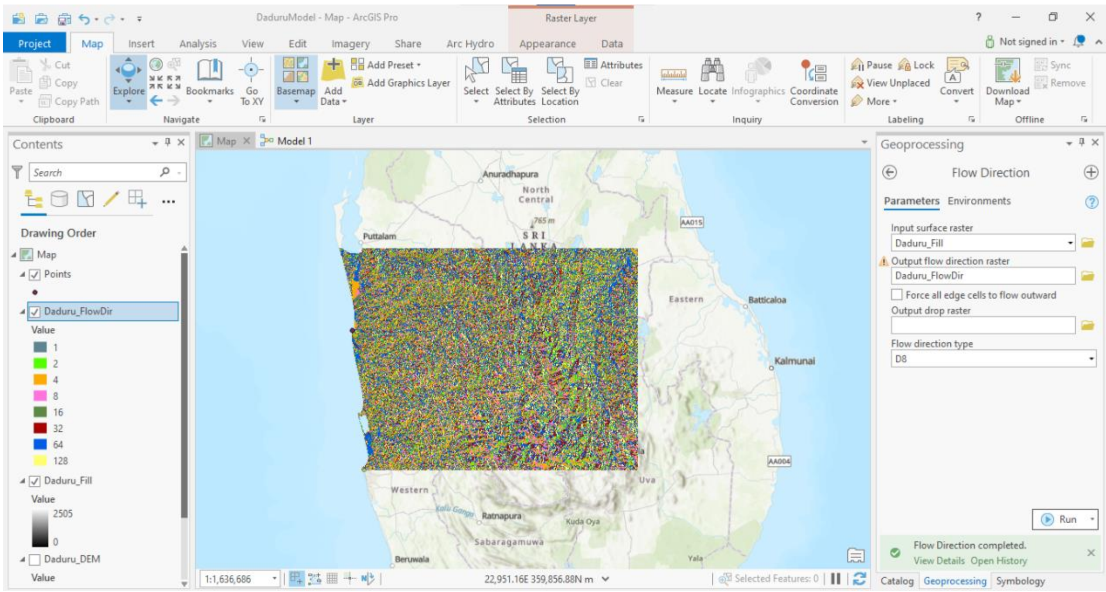


Figure 4.15: Using flow direction tool.

4.4.2.2 Flow accumulation

Then should assess flow accumulation. The 'Flow Accumulation' tool generates a raster layer that indicates the areas where water is most likely to accumulate. Figure 4.16 depicts the flow accumulation for each cell as a numeric value depending on the number of cells that flow into that cell. Cells with high values of accumulation often coincide with the locations of flowing water bodies. With the flow accumulation raster, could identify the Daduru Oya that flows through the region [43].

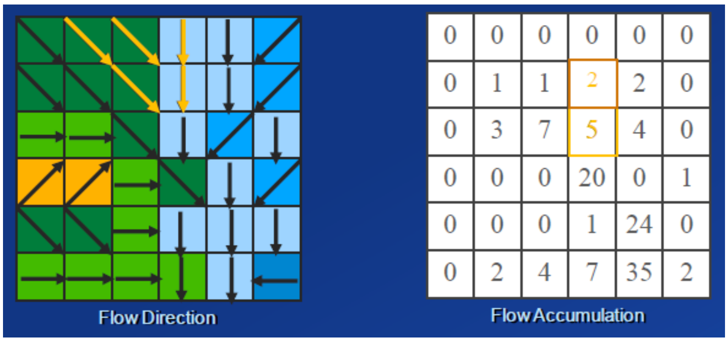


Figure 4.16: How flow accumulation works [43].

In figure 4.17 the ‘Flow Accumulation’ tool is depicted. Input for the tool is ‘Flow Direction’ raster. The remaining settings remained unaltered. The first parameter provides a weight to each cell, which is useful when water is expected to be distributed in non-uniform ways, such as in larger study areas where precipitation levels vary significantly. The second option determines whether accumulation is tracked using integers or floating points. The floating-point value, which is the default, allows for the addition of decimal places, making it more accurate in most instances. The third parameter, D8, specifies the direction of the input flow [41].

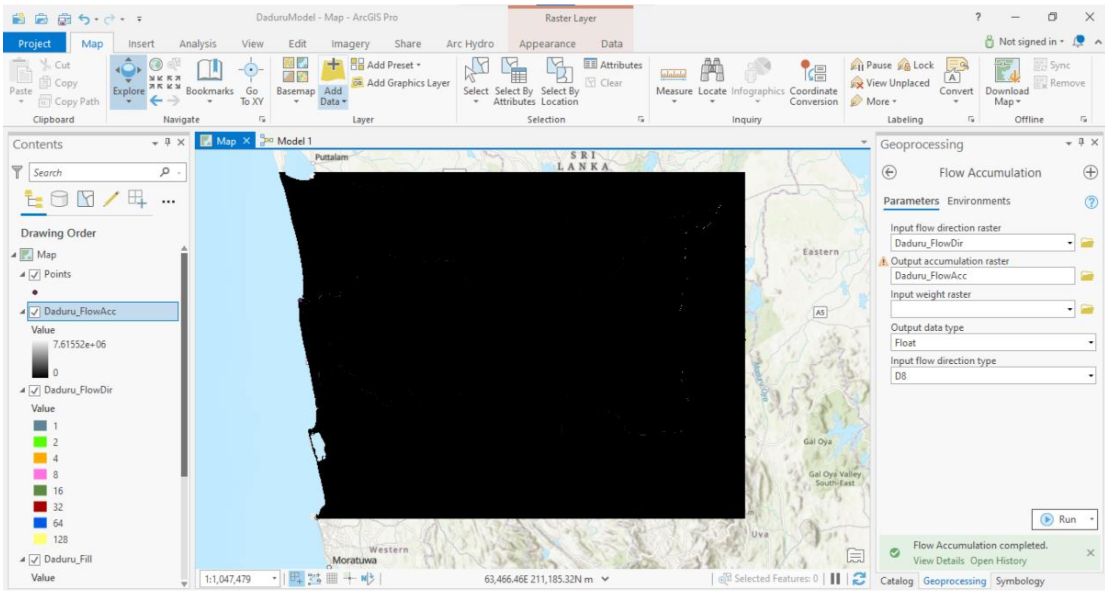


Figure 4.17: Using flow accumulation tool.

4.4.2.3 Snap outlet to stream

The flow direction layer completes the first component for defining a watershed. The position of an outlet point is the other component. The pour point layer represents the outlet downstream of Daduru Oya in Chilaw.

For an appropriate watershed, the outflow must be precisely located on the stream as represented in the DEM (which may differ somewhat from the actual location of the stream due to DEM resolution or other issues). First, the exact position of the stream must be determined by determining the areas where the most water collects. This was done in the previous phase. The output point's location should then be snapped to exactly match the stream. The 'Snap Pour Point' tool automatically clips a point feature to the cell with the largest flow accumulation within a given distance. Because of the magnitude of the watershed, the snap distance was set at 500 in this case. The snapped outlet raster layer is added to the map when the tool is executed. The raster shows a single cell that reflects the new position of the outlet [41]. This process is illustrated with screen shots of each step in ArcGIS Pro in the Appendix – A and the outcome is as of figure 4.18.

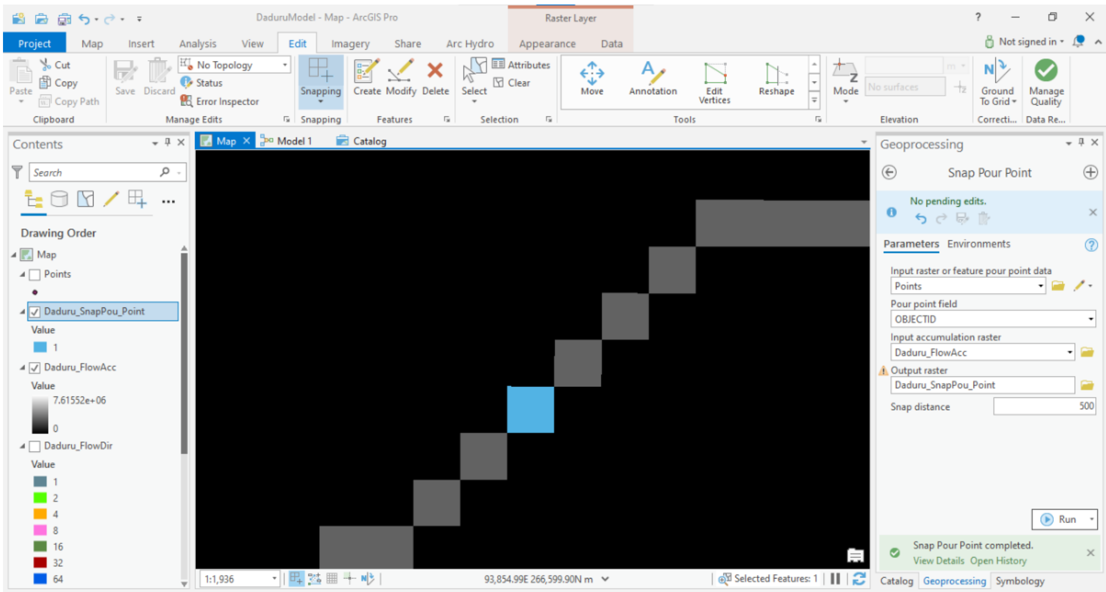


Figure 4.18: The snap pour point tool.

In the model it was created so that both pour point and snap distance could be input to the model as variables. Therefore, those two could change as required to calibrate the model.

Now that both the flow direction layer and the precise outlet layer are available, it could determine the area of the basin upstream of the outlet. The watershed was derived from the ‘Watershed’ tool as given below in figure 4.19. Inputs to the tool are flow direction raster and output of the snap pour point tool. Pour point field value is taken, not the count.

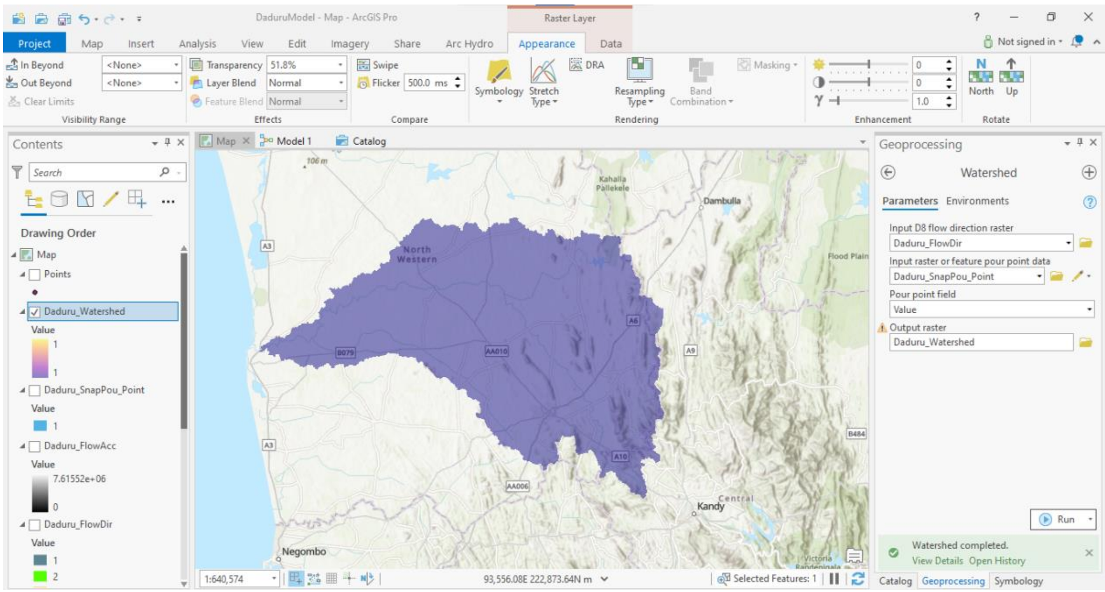


Figure 4.19: Watershed tool.

The next step is to utilize the previously constructed hydrologic and elevation layers to calculate how quickly water will flow to the output point.

4.4.3 Construct a velocity field

The previously constructed Daduru Oya watershed will be used as the research area for the ensuing investigation. Following that, it will begin calculating how long it takes water to reach the exit, allowing officials to better anticipate when flooding will occur during a simulated rainfall storm. To calculate how long it takes for water to go someplace, first needs to determine how quickly water flows. A velocity field, a different form of raster layer, might be used to compute the speed of flowing water. There are many different types of velocity fields, and they may be computed using a wide range of mathematical formulae. It was chosen to generate a velocity field that is spatially variable but time and discharge invariant for the investigation. The velocity field makes the following assumptions to do this:

- Velocity is influenced by spatial variables such as slope and flow accumulation (spatially variant).
- Over time, the velocity at a specific point remains constant (time invariant).
- The velocity at a given location is unaffected by the rate of water flow at that location (discharge invariant).[41]

In fact, velocity may fluctuate over time and is plainly discharge-dependent. However, including these variances would involve the use of additional information that might not be available, as well as modelling techniques that would not be repeatable in a GIS environment. Although any approach will only provide a rough estimate of visible events, the spatially varying, time- and discharge-invariant velocity field will provide a reasonably accurate result. [41].

A technique for generating velocity fields proposed by [44] is used in the study. In this method, each cell in the velocity field is assigned a velocity based on the local slope and the upstream contributing area (the number of cells that flow into that cell, or flow accumulation). They used (1):

$$V = V_m * (s^b A^c) / (s^b A^c_m) \quad (1)$$

Where 'V' represents the velocity of a single cell with a local slope of 's' and an upstream contributing area of 'A' Calibration, a statistical process of modifying model parameters such that projected data is as near to observed data as feasible, may be used to calculate coefficients b and c. In this case, the method's suggested value of b = c = 0.5 was utilized, and V_m is the average velocity of all cells in the watershed. It is possible to assume an average velocity of $V_m = 0.1$ m/s. Finally, $s^b A^c_m$ is the watershed's average slope-area term. Set boundaries for minimum and maximum velocities to avoid outcomes that are unreasonably fast or sluggish. The lower limit is 0.02 meters per second, while the top limit is 2 meters per second [41].

4.4.3.1 Generate the slope raster

The key variables in the velocity field equation are slope and upstream contributing area. The flow accumulation layer that was generated in the previous phase already has a raster layer for the upstream contributing area. So, now need to create the slope layer. The part of the model depicting this process is given below in figure 4.20.

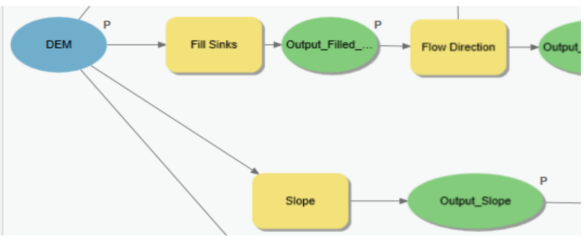


Figure 4.20: Model part for slope tool.

In Figure 4.21, it is shown how to utilize the 'Slope' tool. In contrast to a measurement in degrees, the ‘Percent increase' measurement option calculates slope as a proportion of vertical elevation over horizontal elevation. The remaining settings remained unaltered. The planar approach is ideal for usage on small size regions, but geodesic method gives a more accurate slope since it uses 3D cartesian coordinate system. Therefore, it was used in this watershed. The Z unit is given as Meters [41].

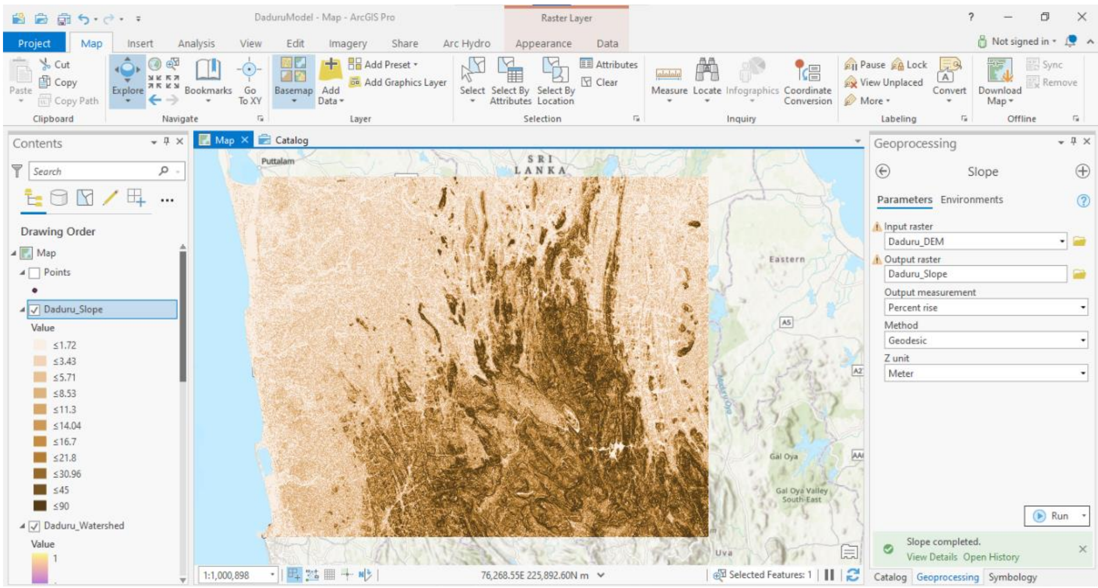


Figure 4.21: The slope tool utilisation.

The slope is steeper in the deeper colours. While mountain peaks have the steepest slopes, stream beds have a comparatively level slope.

Figure 4.22 illustrates the next few steps of creating the velocity field.

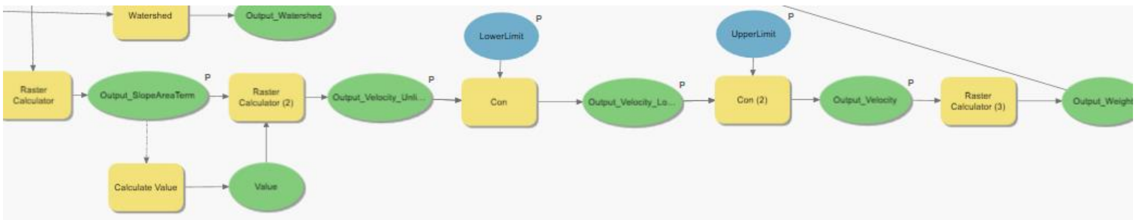


Figure 4.22: Creating the velocity field steps.

4.4.3.2 Determine the slope-area term

Now that a raster layer for both slope and flow accumulation area is available, a new raster layer that combines both may be calculated. The slope-area term will be shown on this layer (the value s^b A^c from the [44] equation). This process is shown in figure 4.23.

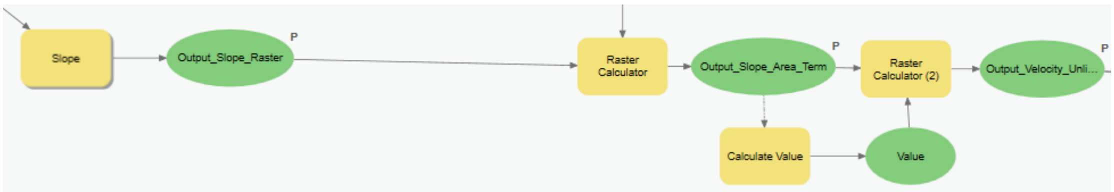


Figure 4.23: Calculating slope area term and velocity unlimited.

The following step is to employ the ‘Raster Calculator' tool, which enables the creation of bespoke raster layers based on an equation provided below.

For ‘Map Algebra expression’, (2) is entered:

```
SquareRoot("Daduru_slope") * SquareRoot("Daduru_FlowAcc")    (2)
```

The square root of the slope and flow accumulation are calculated because the suggested coefficients (b = c = 0.5) of [56] are used. A coefficient of 0.5 is equal to the value's square root [41]. This process is shown in figure 4.24.

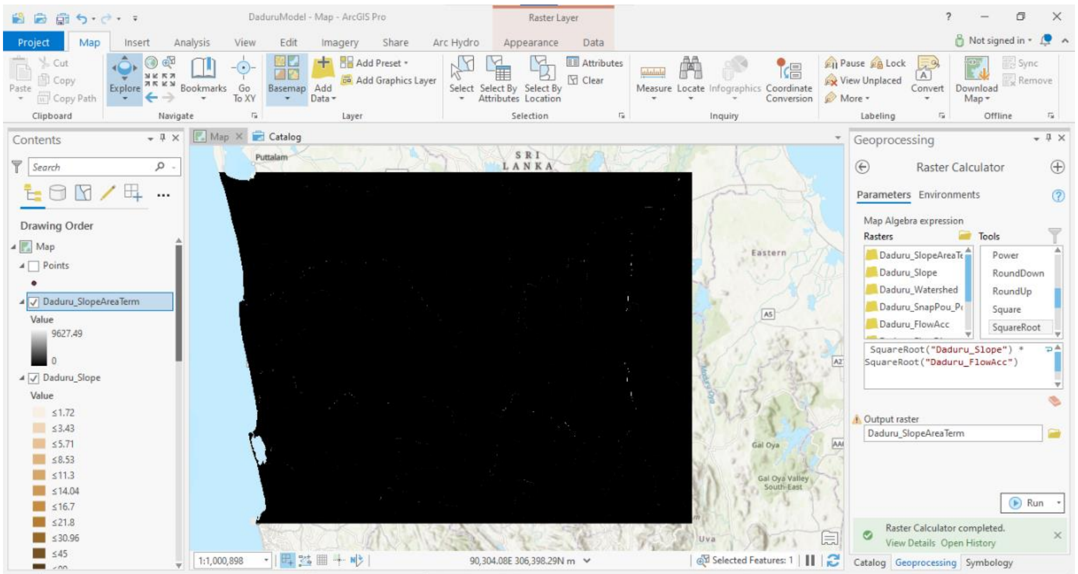


Figure 4.24: Raster calculator tool.

To generalise the model, it was needed to find a way to enter these two values as variables so it could take any DEM's slope and flow accumulation for the calculation. This is achieved by using inline variable substitution as of figure 4.25 in the final model.

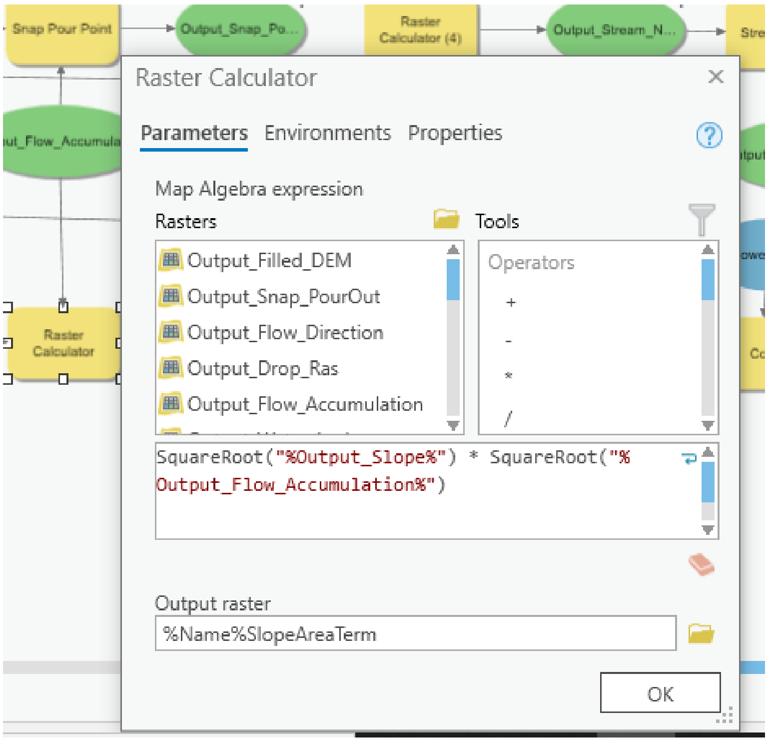


Figure 4.25: Developed Map Algebra expression for the model.

And the python code for this step is given below in figure 4.26.

```
77
78      # Process: Raster Calculator (Raster Calculator) (sa)
79      Raster_Calculator = Output_SlopeAreaTerm
80      with arcpy.EnvManager(mask=r"%Path%\%Name%Watershed"):
81          Output_SlopeAreaTerm = SquareRoot(Output_Slope) * SquareRoot(Output_Flow_Accumulation)
82          Output_SlopeAreaTerm.save(Raster_Calculator)
```

Figure 4.26: Code part for raster calculator.

Finally, the environment for the geoprocessing tool must be changed so that the output layer is masked (or limited) by the area of the Daduru watershed. This allows it to later compute the average slope-area term throughout the watershed, which is a critical component of the velocity field equation [41]. This step is illustrated in figure 4.27 and could see how it was done in python code line 79 of figure 4.26.

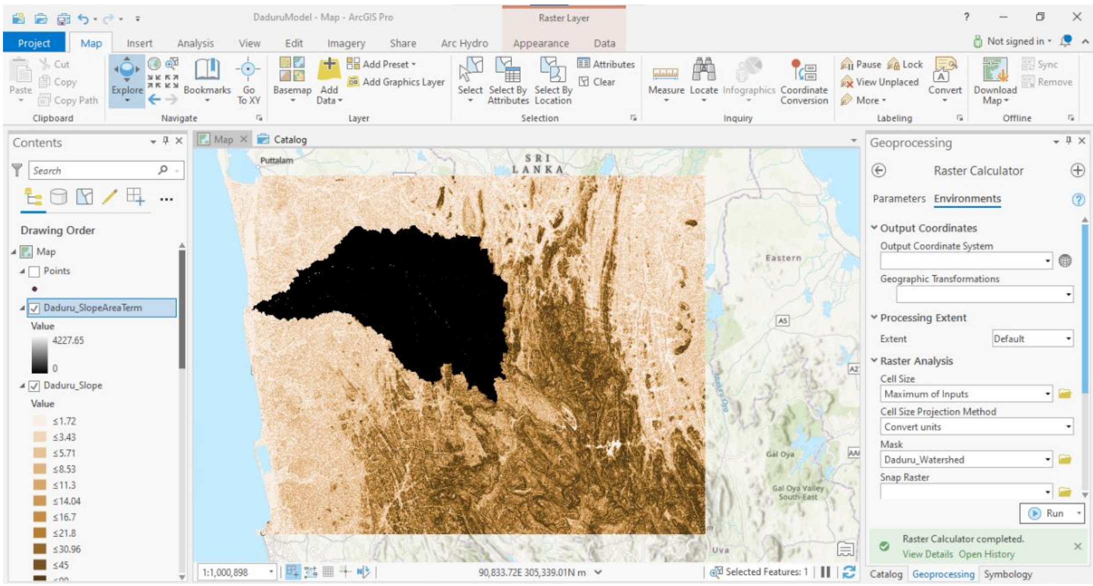


Figure 4.27: Change environment for raster calculator tool.

4.4.3.3 Compute the velocity field

Now that the slope-area term is known, it is possible to compute a velocity field using it (1) which was explained in the previous part:

$$V = V_m * (s^b A^c) / (s^b A^c{}_m) \qquad (1)$$

As previously stated, V_m is the average velocity of all cells in the watershed. The assumed average value of $V_m = 0.1$ was utilized, as advised by [56]. Similarly, $s^b A^c{}_m$ is the watershed's mean slope-area term. Because the slope-area term for the watershed had already been computed, the precise average could be determined rather than relying on an assumed value [41]. The mean could be found at 'Layer Properties' -> 'Statistics' as given in figure 4.28.

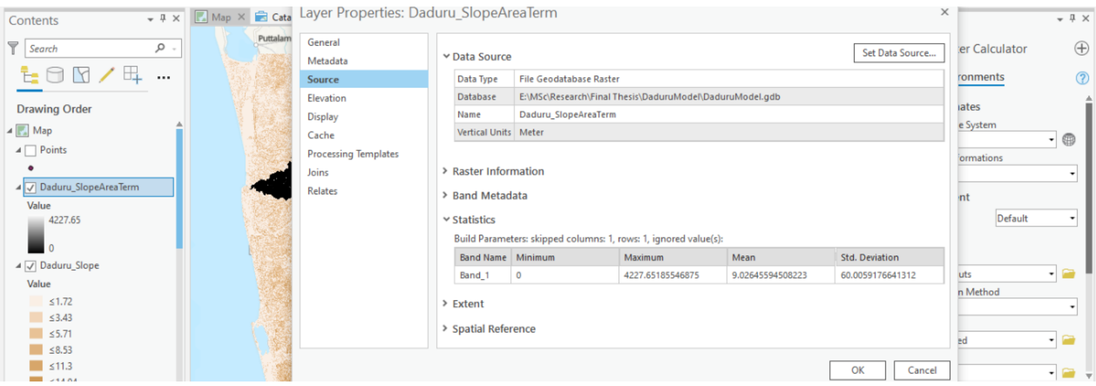


Figure 4.28: Finding mean value of slope area term.

If the model is created to use in only Daduru Oya flood modelling, this value could be hard coded into the raster calculator equation as given in figure 4.29.

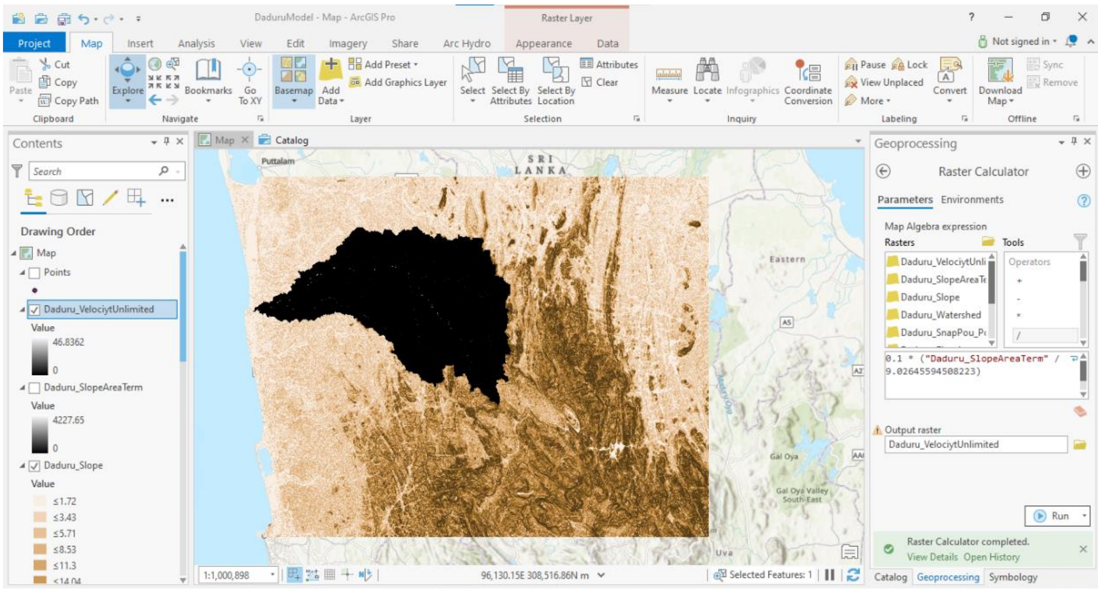


Figure 4.29: Raster Calculator to get velocity unlimited.

The layer is added to the map when the tool is run. The new layer resembles the slope-area term layer since it was calculated by multiplying the cells in the slope-area term layer with fixed values. The layer symbology values confirm that the two layers are distinct as in figure 4.30, even if they look the same in the map.

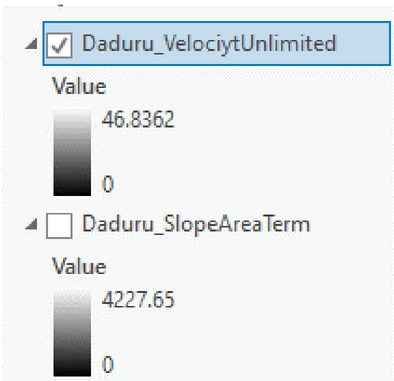


Figure 4.30: Layer symbology compared.

To use the model for any DEM there should be a way to get this value automatically without hardcoding. For that purpose, it was decided to use the ‘Calculate Value’ tool to get the raster property ‘MEAN’ to use as a variable in the ‘Raster Calculator’ tool.

This process is shown in the part of the model in figure 4.31 and the code snippets to achieve the result are given in figure 4.32, 4.33 and 4.34.

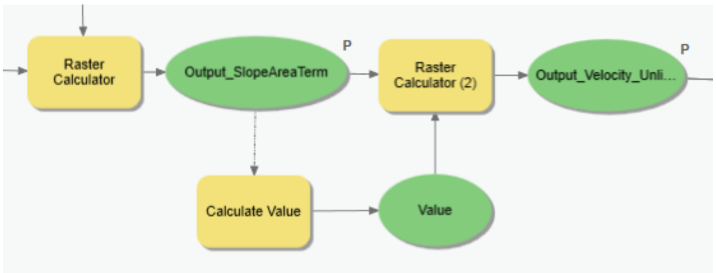


Figure 4.31: Model part for calculate value tool and raster calculator tool.

To get the property 'Mean' from the 'Slope area term' raster, the method 'GetRasterProperties_management()' from 'arcpy' was used as of figure 4.32.

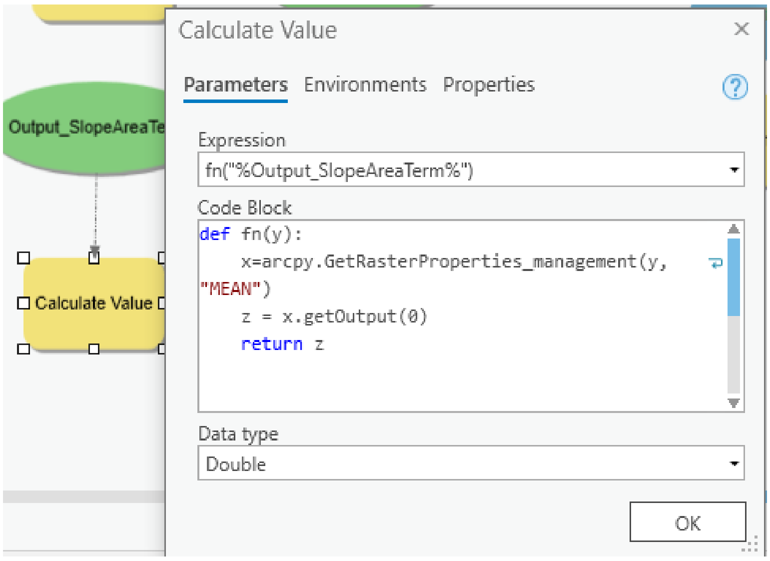


Figure 4.32: Calculate value tool's parameters dialog box.

```
import arcpy
from arcpy.sa import *

from sys import argv
def fn(y):
    x=arcpy.GetRasterProperties_management(y, "MEAN")
    z = x.getOutput(0)
    return z

```

Figure 4.33: Code snippet 1 for calculate value tool.

```
# Process: Calculate Value (Calculate Value) ()
if Output_SlopeAreaTerm:
    Value = fn("Output_SlopeAreaTerm")

# Process: Raster Calculator (2) (Raster Calculator) (sa)
Raster_Calculator_2_ = Output_Velocity_Unlimited
if Output_SlopeAreaTerm:
    with arcpy.EnvManager(mask="%Output_Watershed%"):
        Output_Velocity_Unlimited =  0.1 * (Output_SlopeAreaTerm/Value)
        Output_Velocity_Unlimited.save(Raster_Calculator_2_)

```

Figure 4.34: Code snippet 2 for calculate value tool.

4.4.3.4 Bound the velocities

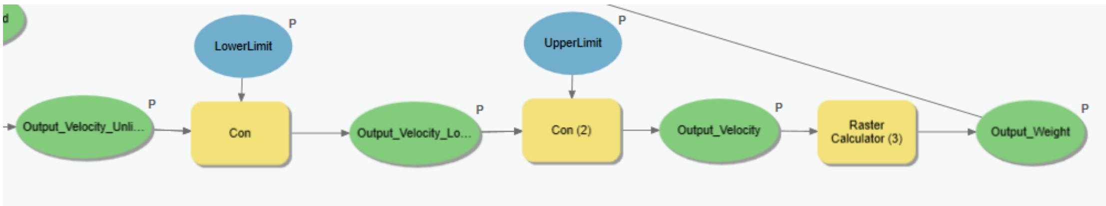


Figure 4.35: Model part for calculate the velocity field and weight raster.

The generated raster layer is a velocity field, but its velocities are unnaturally high and low. Some values in the field, for example, have a velocity of 0 meters per second, which is improbable during an intense rainfall event. Similarly, even with a large flood, the maximum figure of roughly 46.8362 meters per second is impractical. It was agreed to set a lower restriction of 0.02 meters per second and an upper limit of 2 meters per second for the velocity data. And in the final model, those two values could change at any time using ‘LowerLimit’ and ‘UpperLimit’ variables. Because of that model calibration is possible with those two values.

Model part for this process is given in figure 4.35.

The Con tool is used in the first phase of this task to execute a conditional assessment of the values in a raster layer depending on an expression that was supplied. First, the lowest limit for velocity must be established. It could be done as given in figure 4.36.

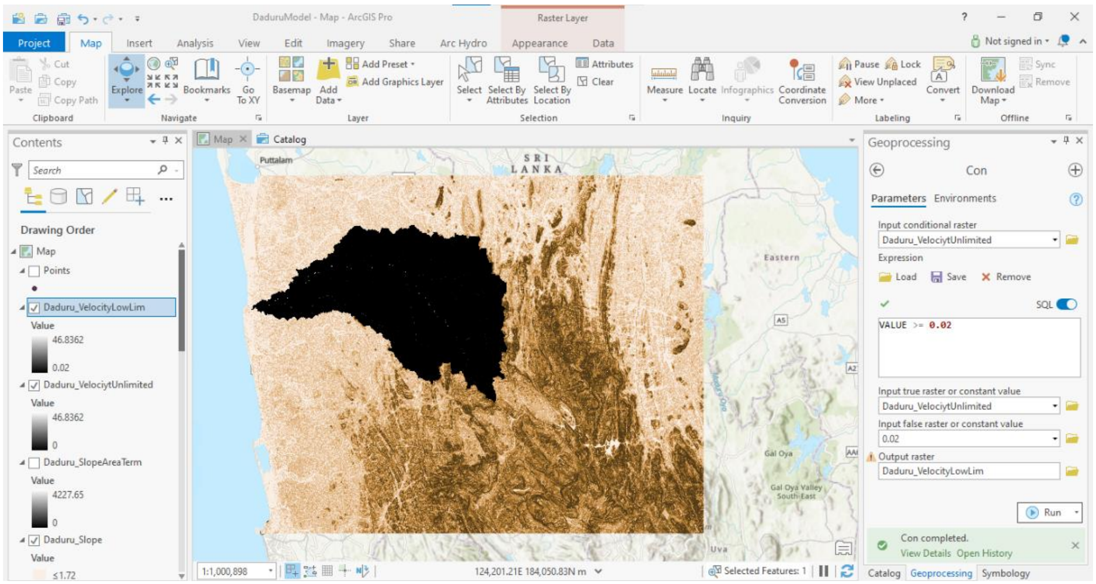


Figure 4.36: Setting the velocity lower limit.

If the clause is true, the value to use for each cell should be added next. Because it must maintain the same values if they are higher than or equal to 0.02, it will utilize the same raster layer as the input layer. If the clause for a cell is false (meaning the cell value is smaller than 0.02), the cell value is set to 0.02.

The new generalised model is modified to take this value in to a variable 'LowerLimit' so that user can change it any time and could run the model to see the effect. It is illustrated in figure 4.37 in the model and figure 4.38 of the code snippet.

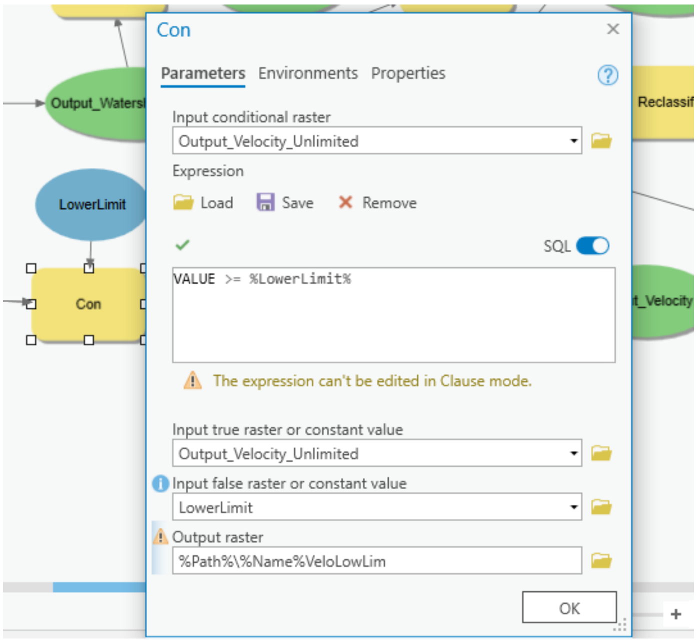


Figure 4.37: Con tool parameters for velocity lower limit.

```
# Process: Con (Con) (sa)
Con = Output_Velocity_LowLimited
if Output_SlopeAreaTerm:
    Output_Velocity_LowLimited = arcpy.sa.Con(in_conditional_raster=Output_Velocity_Unlimited,
        in_true_raster_or_constant=Output_Velocity_Unlimited,
        in_false_raster_or_constant=LowerLimit, where_clause=f"VALUE >= {LowerLimit}")
    Output_Velocity_LowLimited.save(Con)
```

Figure 4.38: Code snippet for velocity lower limit.

The tool is launched, and a new layer is added to the map. However, the new layer is merely an intermediate layer because the higher limit must still be added. The Con tool is also used in the task's last phase, as seen in figure 4.39.

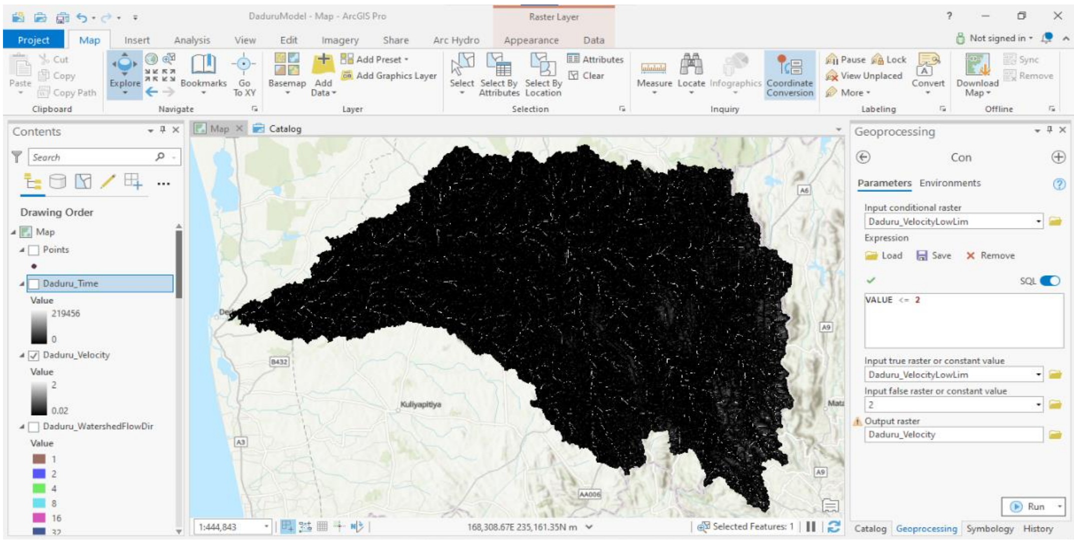


Figure 4.39: Setting the velocity upper limit.

The new generalised model is modified to take this value in to a variable 'UpperLimit' so that user can change it any time and could run the model to see the effect. It is illustrated in figure 4.40 in the model and figure 4.41 of the code snippet.

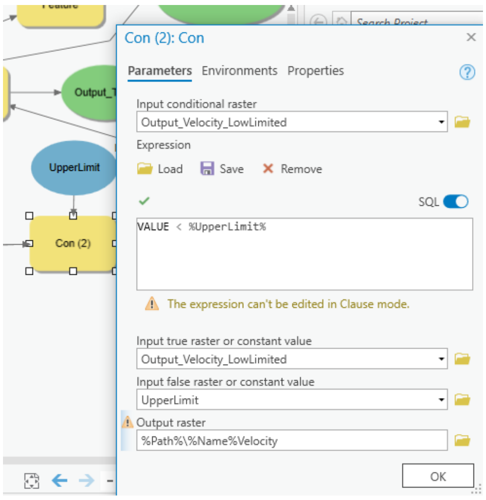


Figure 4.40: Con tool parameters for velocity upper limit.

```python
        # Process: Con (2) (Con) (sa)
        Con_2_ = Output_Velocity
        if Output_SlopeAreaTerm:
            Output_Velocity = arcpy.sa.Con(in_conditional_raster=Output_Velocity_LowLimited,
                in_true_raster_or_constant=Output_Velocity_LowLimited,
                in_false_raster_or_constant=UpperLimit, where_clause=f"VALUE < {UpperLimit}")
            Output_Velocity.save(Con_2_)
```

Figure 4.41: Code snippet for velocity upper limit.

In this stratum, darker colours indicate slower velocity, whereas brighter colours indicate rapid velocity. Water flows quickest in streams that have accumulated the greatest water. It indicates that when water is funnelled downstream of the river's outflow point, it will flow the fastest.

From flow accumulation and slope raster layers, a spatially varied, time- and discharge-invariant velocity field was constructed. Now that it knows how fast water flows through Daduru Oya during a hypothetical rainfall event, could estimate how long it takes for water to reach the outlet.

4.4.4 Generate an isochrone map

The velocity field revealed that water moves fastest along the streams that go through town, but can not build a unit hydrograph since it do not know how long it will take for water to flood to the outflow point. The next stage is to construct an isochrone map, which shows how long it takes to go from one point to another in a certain region. It should first construct a weight grid before creating the isochrone map. The time it takes for water to reach the outflow may then be assessed and reclassified into isochrone zones [41]. The steps are as of figure 4.42.

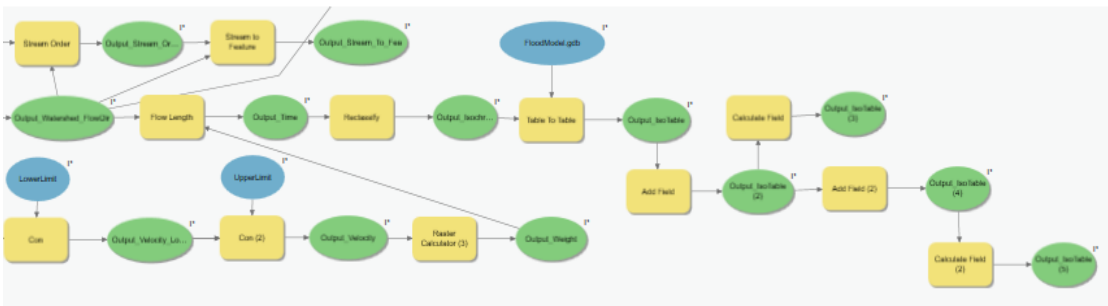


Figure 4.42: Steps of creating an isochrone map.

4.4.4.1 Produce a weight grid

A reasonably simple equation is used to determine flow time: The length of the water flow must be divided by the rate of flow. The velocity field tells how fast water flows, but it doesn't tell how long it flows. To calculate flow length, two variables are required: flow direction (which is known) and weight (which still do not know). In terms of flow, weight indicates impedance. Water running across wooded area, for example, takes slower than water flowing over smooth rock because it is obstructed by topography. While calculating weight may appear challenging in the absence of precise topographical data, it is possible to develop an equation based on the following two equations (3) and (4) for determining flow time:

$$\text{Flow time } [T] = \text{Flow Length } [L] \;/\; \text{Velocity } [LT^{-1}] \qquad (3)$$

$$\text{Flow time } [T] = \text{Flow Length } [L] \;*\; \text{Weight } [L^{-1}T] \qquad (4)$$

By combining these equations, it may obtain the following new equation (5):

$$\text{Weight } [L^{-1}T] = 1 \;/\; \text{Velocity } [LT^{-1}] \qquad (5)$$

As a result, weight may be calculated using the velocity field layer. Later, the weight grid layer, in conjunction with the flow direction layer, could be used to calculate flow length and flow time [41].

The first step is to launch the Raster Calculator tool and enter the weight equation to generate a weight grid of the Daduru watershed, as shown in Figure 4.43.

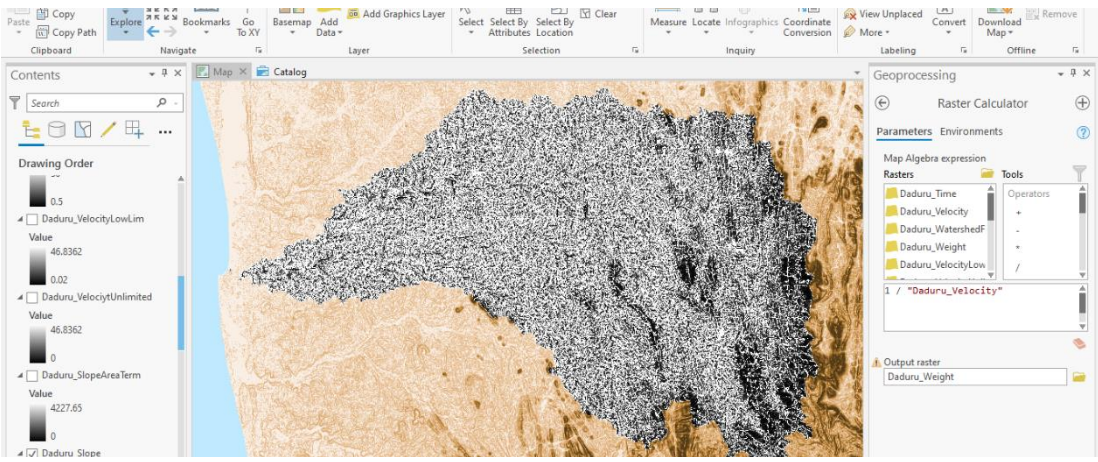


Figure 4.43: Using raster calculator to create weight raster.

Figure 4.44 shows parameters of 'Raster Calculator' to create weight raster to generalise the model using inline variable substitution.

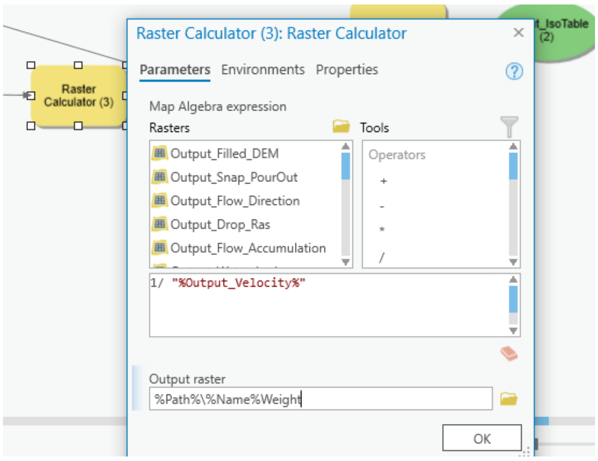


Figure 4.44: Creating weight raster.

While this layer does not provide much information on its own, it can be combined with the flow direction layer that was built before to determine flow time.

Because the flow direction layer was produced prior to establishing the Daduru watershed, its length extends well beyond the region of interest. As a further step, a new version of the flow direction layer that just covers the watershed may be extracted.

For that, could use the 'Extract by Mask' tool, which trims a raster layer to a specific extent based on the extent of another layer. Figure 4.45 shows the part of the model, and figure 4.46 shows how to utilize the tool.

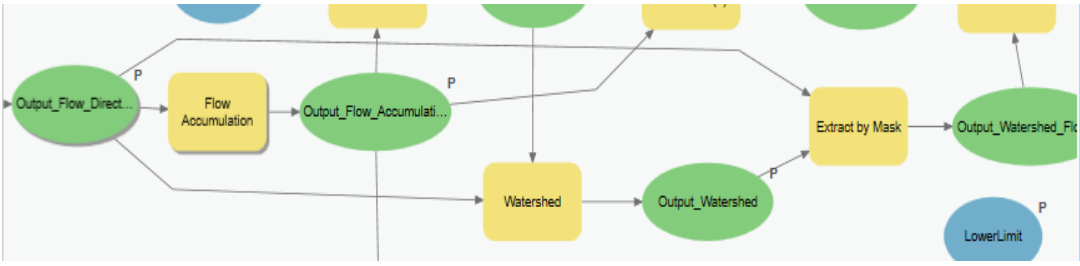


Figure 4.45: Part of the model for extracting flow direction for the watershed.

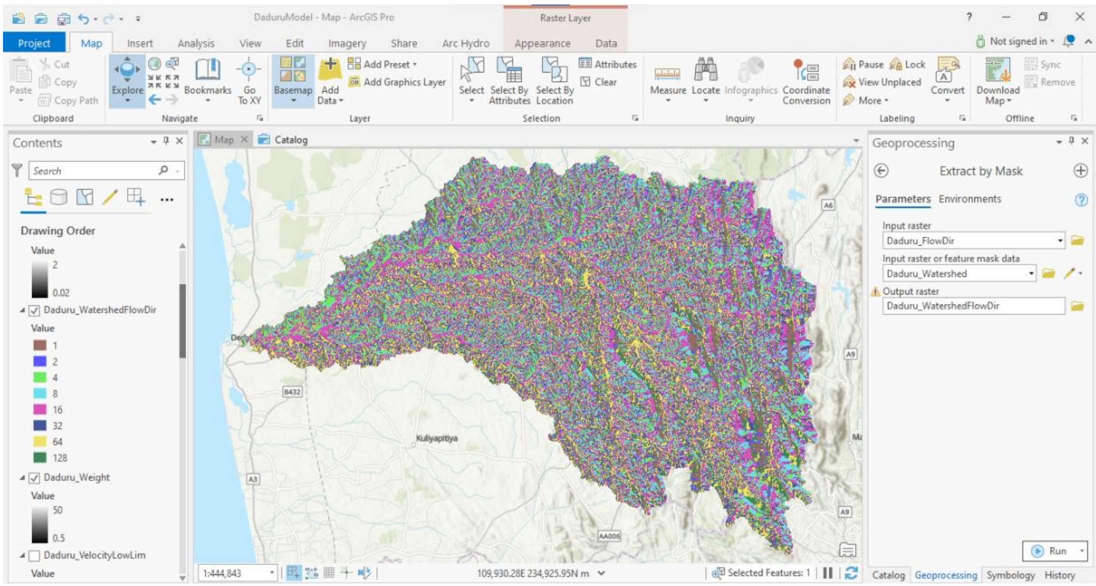


Figure 4.46: Use of extract by mask tool.

4.4.4.2 Calculate the flow time to the outlet pour point

All of the layers needed to calculate flow time are now available. The ‘Flow Length' tool is used in the task's following stage. While this tool is typically used to compute flow length, it also provides an option to incorporate a weight raster. The utility instead calculates flow time when a weight raster is included [41]. Following figure 4.47 depicts this process in the model.

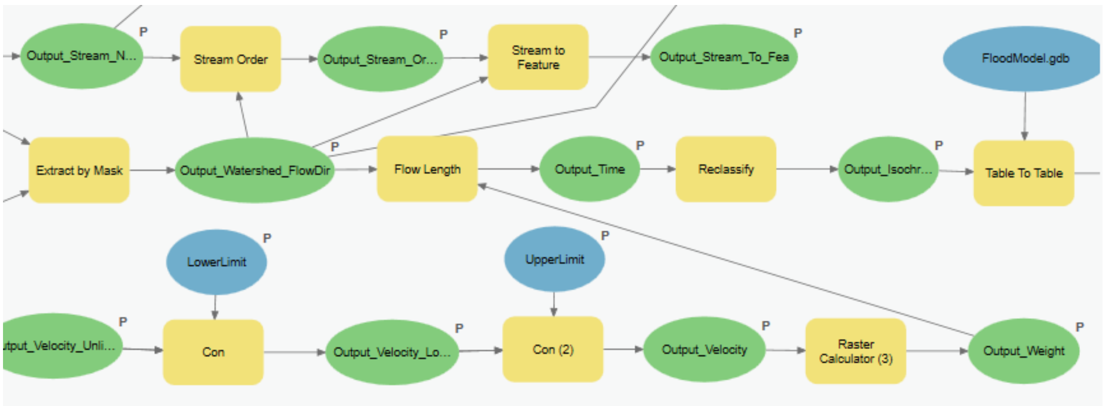


Figure 4.47: Model part to assess flow time.

The tool is run, and a raster indicating the flow time to the outlet, as shown in figure 4.48, is added to the map. Each cell in this raster layer has a number that indicates how long it takes for water to flow from the cell to the outlet in seconds. Shorter flow periods are indicated by darker colours. Water flows the quickest from low-lying stream beds closest to the exit, whereas water descending in the mountains takes the longest.

The time it takes water to flow to the outlet ranges from 0 seconds (rain that falls on the outlet itself) to about 219456 seconds—over 60.96 hours.

219456 seconds = 60.96 hours = 2.54 days

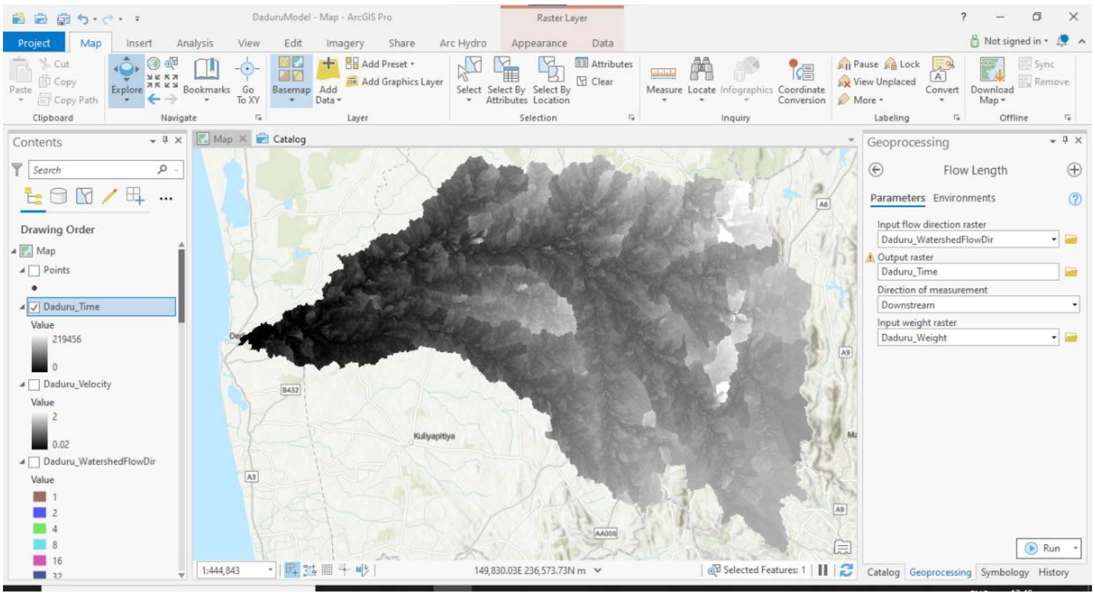


Figure 4.48: Using flow length tool.

4.4.4.3 Flow time reclassification into isochrone zones

The flow time raster layer has a large number of unique data, making further analysis difficult and time-consuming. To make things easier, the flow time layer must be reclassified into isochrone zones.

An isochrone is a contour line that connects points with roughly equal travel times to the watershed's outlet. Isochrones with equal time intervals of 7200 seconds were defined. For smaller areas, isochrones can use different intervals, but for the Daduru watershed, this time interval should be appropriate. With this time interval, every cell in the first isochrone zone will take about 7200 seconds to reach the outlet, every cell in the second isochrone zone will take about 14400 seconds, and so on. It will later use these time intervals as the ordinate in the unit hydrograph.

The task's following step, as shown in figure 4.49, opens the 'Reclassify' tool for this purpose. This tool will be used to categorize flow time values that lie between a particular range of values (for example, 0 and 7200 or 7200 to 14400) to the upper limit of the range. Should input the reclassification values for this. Because the times in the flow time layer span from 0 to about 219456 seconds, reclassification intervals that cover all values are required. This is given as a notepad text file in to the ‘Reclassify’ tool then it takes the values and display it as a table as shown in the figure 4.49. The notepad text file is given in Appendix – B.

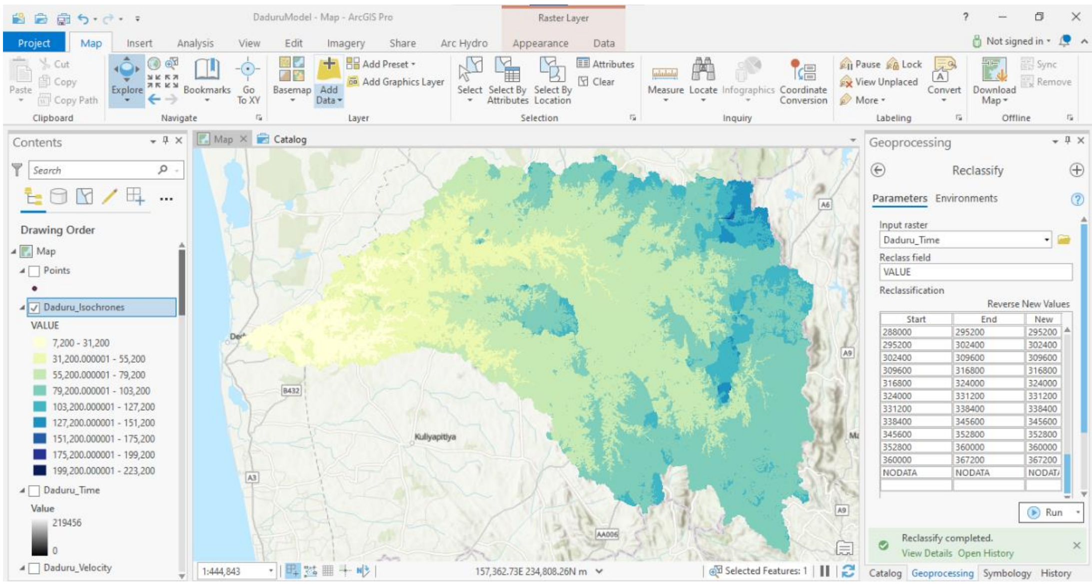


Figure 4.49: Reclassifying Isochrones.

With the symbology as in figure 4.50, it is easier to pick out the individual isochrones.

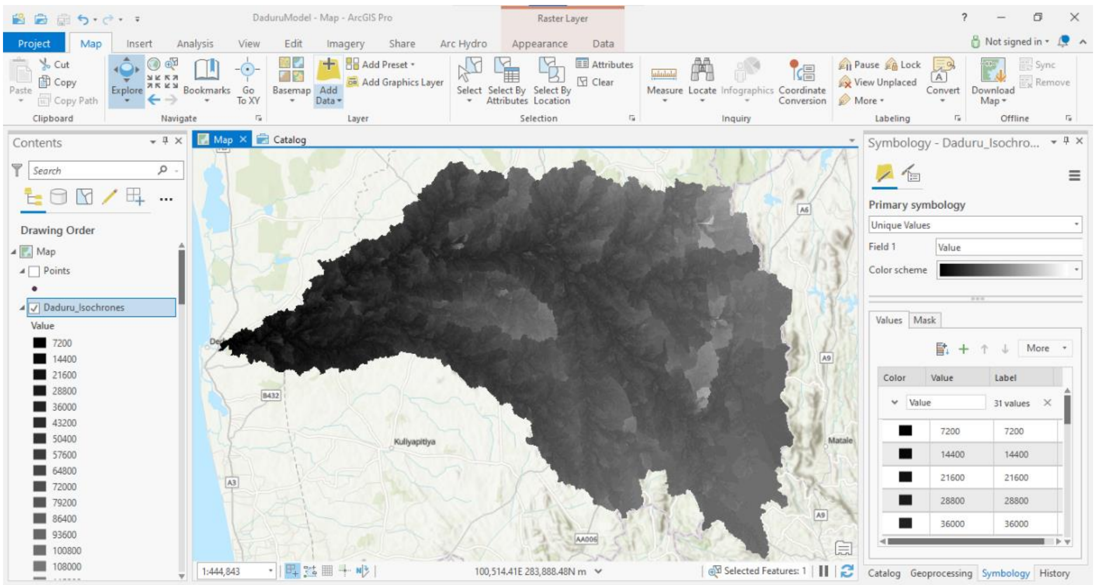


Figure 4.50: Output of the reclassification of Isochrones.

The layer's attribute table was then analyzed to see how many cells were classified as each isochrone and to choose certain isochrones for further research (figure 4.51).

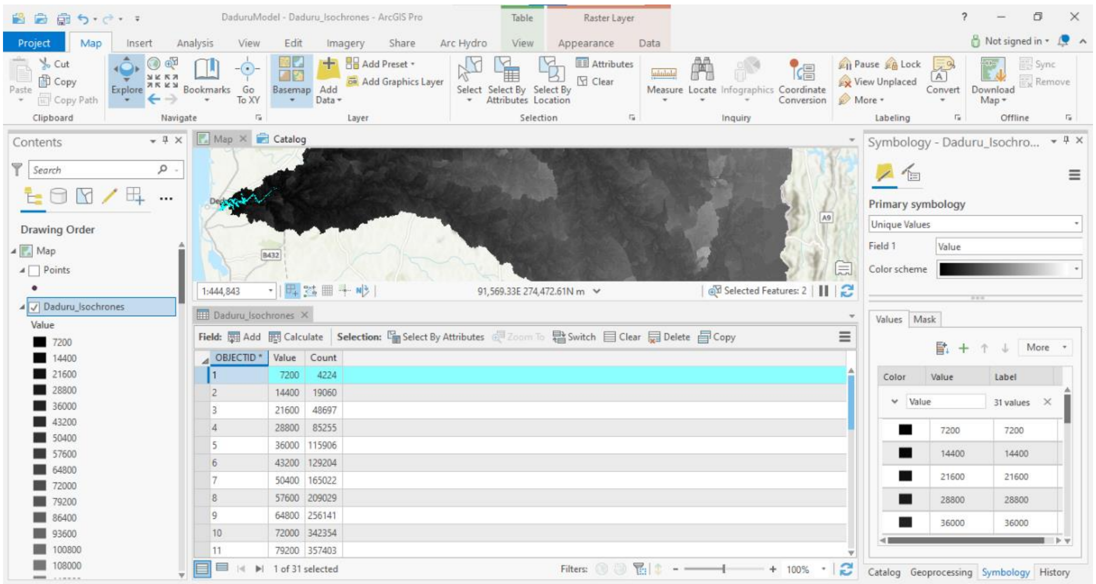


Figure 4.51: Picking the Isochrone nearest to the outflow for analysis.

The stream bed closest to the outflow creates the first isochrone. According to the table data, only around 4224 cells are present in the first isochrone, indicating that water arrives at the outlet in 7200 seconds (2 hours). Other isochrones have far more cells, which indicates that significantly more water will reach the outflow point many hours after a rainfall event than when it first begins, as seen in figure 4.52.

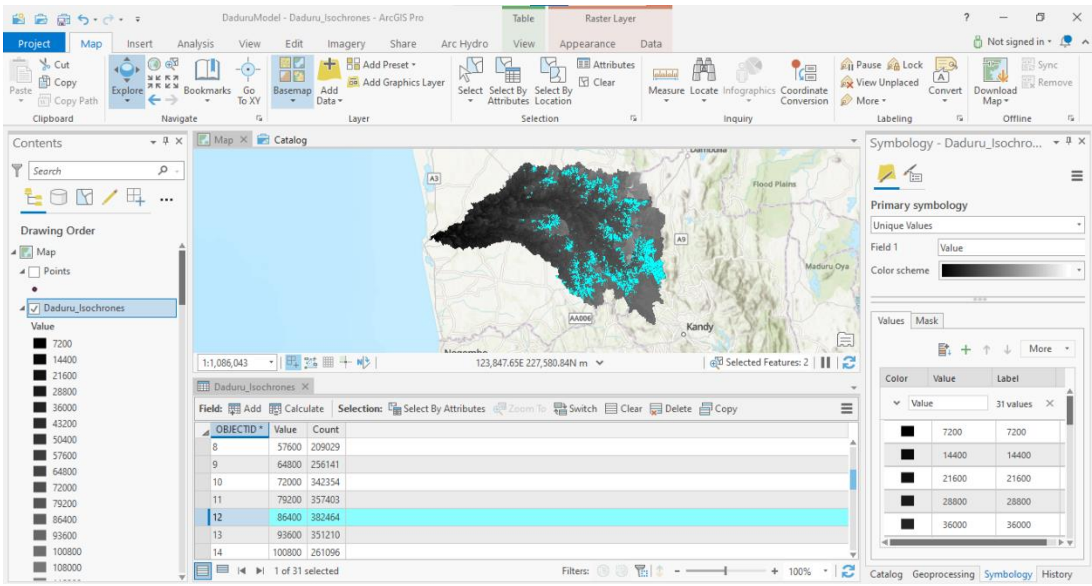


Figure 4.52: Picking an Isochrone near to Kandy for analysis.

The bigger isochrones frequently comprise cells from all across the watershed that happen to rush to the outflow around the same time.

4.4.5 Create a unit hydrograph

The isochrone map will then be converted into a table that shows the link between time and the area of water flowing into the outlet. The model portion for this procedure is depicted in Figure 4.53. The table may then be used to create a unit hydrograph that shows the times when the most water flows into the outflow, allowing for better flood prediction in future rainfall events.

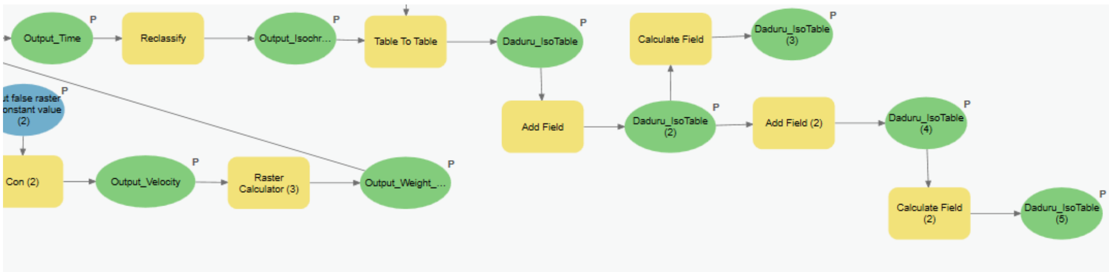


Figure 4.53: Part of the model for creating Unit Hydrograph table.

4.4.5.1 Formulate the unit hydrograph table

To build a unit hydrograph, first it needs to create a stand-alone table from the attribute table of the isochrone map. The area of each isochrone is currently measured in number of cells in the attribute table; consequently, the area should be changed to metric units as well. The first step is to start the 'Table to Table' tool, which may convert a table (including an attribute table) into a standalone table in a geodatabase, as shown in figure 4.54.

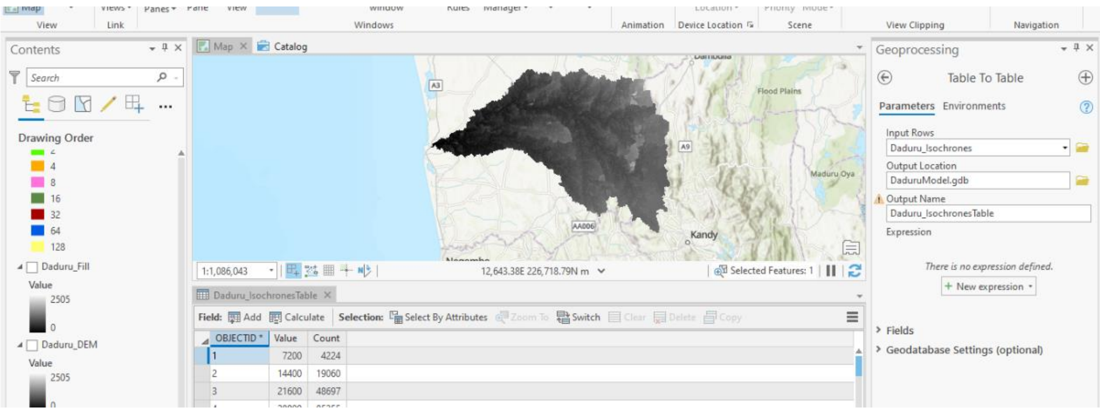


Figure 4.54: Using table to table tool.

The tool is run, and a new table is added to the window titled 'Contents.' Now, this data is similar to the Daduru isochrones layer attribute table. The table has fields for both sets of information necessary to produce a unit hydrograph (time and drainage area per time), however the drainage area is measured in cells rather than metric units. The next task step starts the 'Add Field' tool, which is used to add a new field to the database to compute area in square meters.

The 'Double' field type may hold data with several decimal places. Using this approach, the area values will be more accurate. The 'Field Precision' and 'Field Scale' options allow you to limit the number of digits and decimal places in the field. The remaining options provide further field options. To keep things simple, we chose to leave these fields alone.

The tool is executed, and a new field is added to the stand-alone table. To ensure that the field was successfully added, examine the table as shown in figure 4.55.

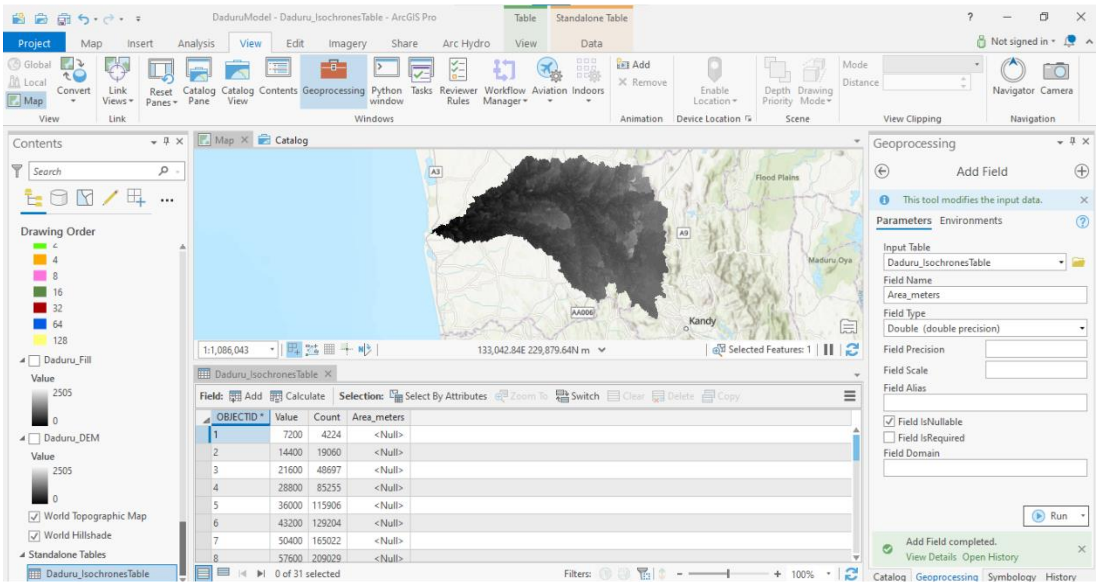


Figure 4.55: Using add field tool.

The field was successfully inserted using the field alias, however there are presently no values in the field.

The next task step launches the 'Calculate Field' tool. This tool might be used to compute the area of each isochrone in square meters. The initial Daduru DEM layer had 30-meter cell sizes, which meant that each cell contained a 30 meter by 30-meter area. Because all subsequent layers were based in some way on the DEM layer, they all have the same cell size. That is, it may compute area by multiplying the 'Count' field of the table by the size of a single cell. Figure 4.56 shows an example of this.

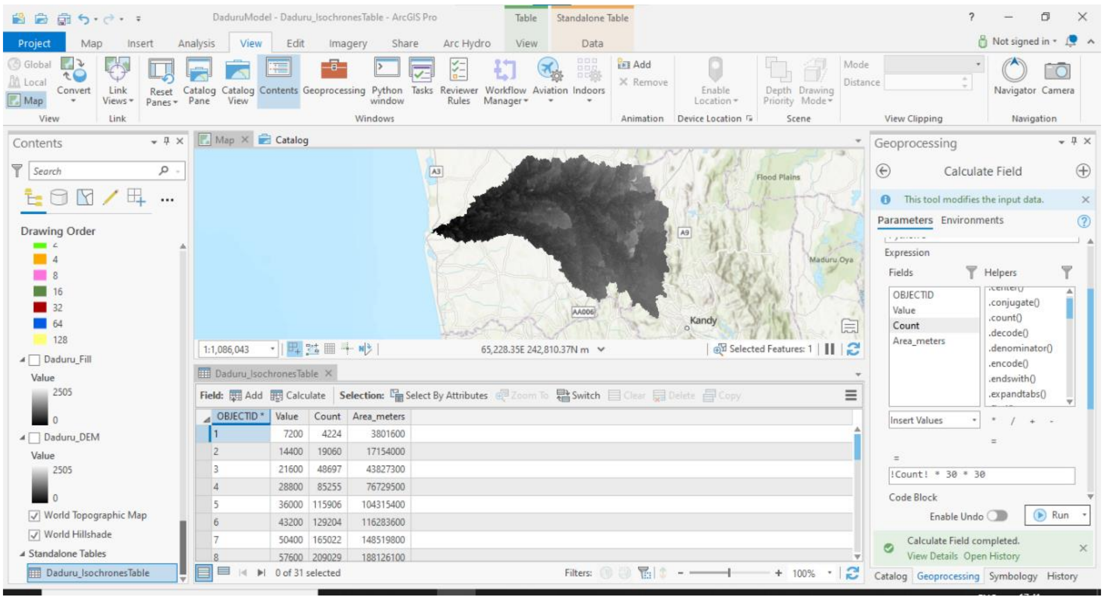


Figure 4.56: Using calculate field tool.

The tool is executed, and the field is calculated. Because there is still one more field to add to the table, the task's next step reopens the 'Add Field' tool, as shown in figure 4.57, but it is based on the table's existing fields. This field will hold the unit hydrograph ordinate, which indicates the discharge at the outlet per second.

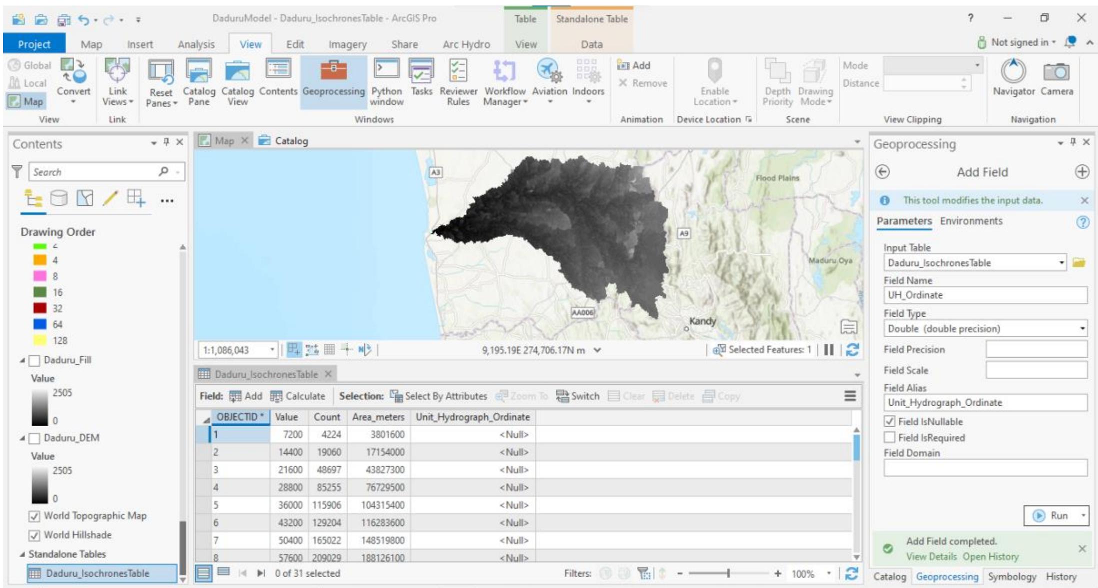


Figure 4.57: Using add field tool to add one more field.

It could only know how much water is reaching the exit at 7200 second intervals (or 2 hours) if a graph was created with time on one axis and drainage area on the other. This interval was useful in lowering the enormous number of unique values in the original flow time layer to a more manageable 31 unique values. However, in a true emergency, 2 hours might be the difference between life and death. Authorities will want a more precise time frame to plan. The new field will compute how much water goes through the outlet each second.

The slope of the time-cumulative area diagram across the period $[(i - 1)\Delta t, i\Delta t]$ gives the unit hydrograph ordinate, Ui, at time $i\Delta t$, where i = 1,2,....n. This is demonstrated by the following (6):

$$U_i = U(i\Delta t) = (A(i\Delta t) - A[(i - 1)\Delta t]) / \Delta t \quad (6)$$

where:

- A(t) is the total drainage area that drains to the outlet since rainfall commenced at time t.

The following is a rewrite of (6):

$$U_i = A_i / \Delta t \quad (7)$$

where:

- A_i is the i^{th} isochrone zone's incremental drainage area.

The tool is executed, and the field is appended to the table. As previously, the field should be calculated. The task's next step reopens the 'Calculate Field' tool. To compute area per second, divide the drainage area by the time period (7200). Figure 4.58 depicts this procedure.

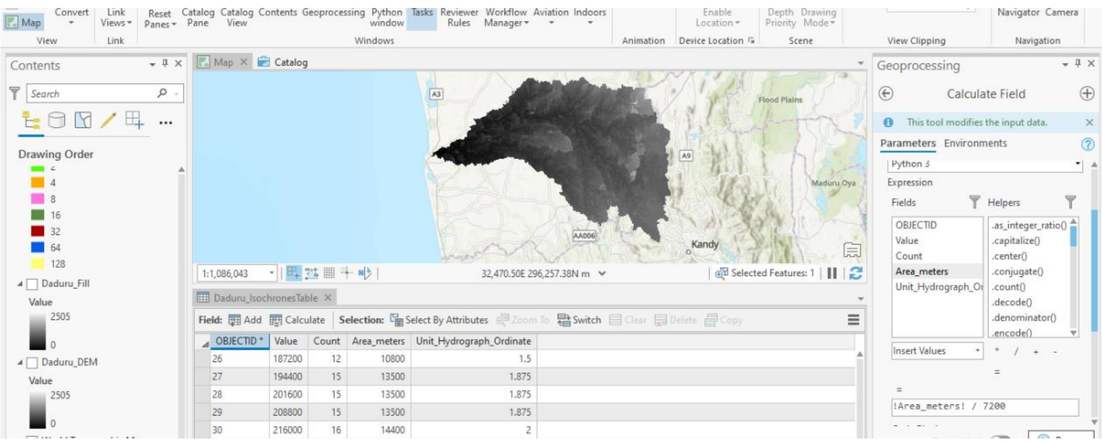


Figure 4.58: Calculating the field.

4.4.5.2 Develop a unit hydrograph

In ArcGIS Pro, a chart could be created from any standalone table. This capability may be used to generate a unit hydrograph using the table's ordinate field.

Finally, as shown in figure 4.59, utilize the table to generate a unit hydrograph that indicates when water outflow at the outlet is at its peak during a projected rainfall event. Finally, the findings will assist officials in Daduru Oya in better planning for and responding to flood occurrences.

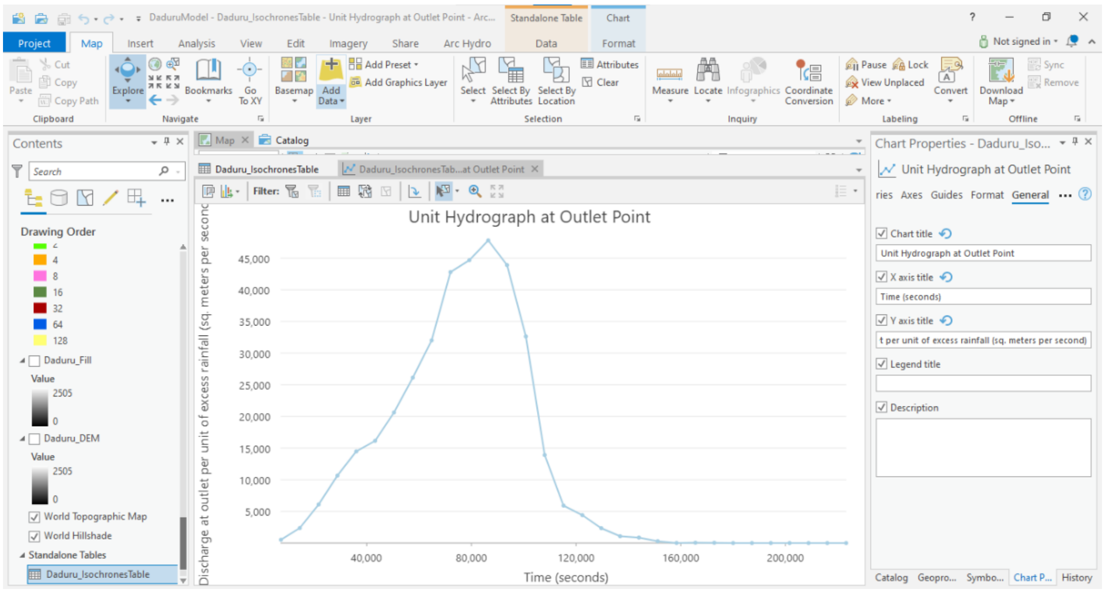


Figure 4.59: Unit hydrograph at outlet point of Daduru Oya.

4.4.6 Additional processes

4.4.6.1 Identifying stream networks

Stream networks may be defined from a digital elevation model (DEM) using the output of the 'Flow Accumulation' tool. A stream network can be delimited by using the 'Con' or 'Set Null' tools to apply a threshold value to the results of the 'Flow Accumulation' tool (figure 4.60). For example, to create a raster with the value 1 indicating a stream network on a 'NoData' background, the tool settings may be as follows (figure 4.61) [45]:

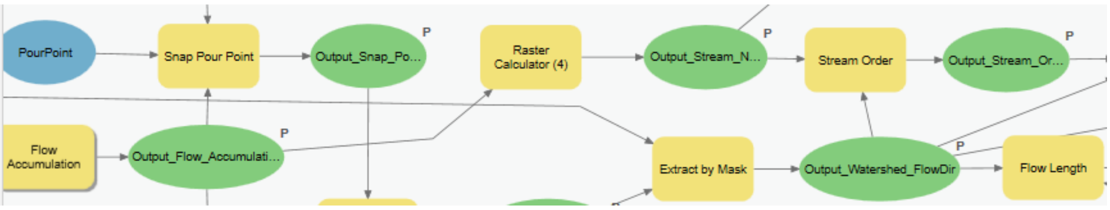


Figure 4.60: Model part for stream networks.

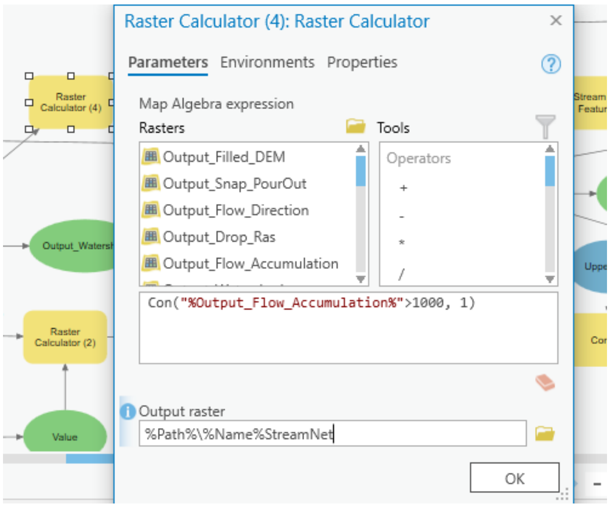


Figure 4.61: Raster calculator to calculate stream network.

All cells with more than 1000 cells flowing into them are assigned a value of 1, while all other cells are assigned a value of 'NoData'. The stream network, which is a collection of raster linear features, must be represented as values on a 'NoData' background for future processing. The tool's operation is depicted in Figure 4.62. The stream network can then be studied further with the 'Stream Organize', 'Stream Link', and 'Stream to Feature' tools, which allow you to order (rank) the streams, assign unique IDs to stream connections, and create a feature dataset, respectively. The threshold for determining the starting point of a permanent river or canal is affected not only by the area of contribution, but also by climate, slope, and soil characteristics [45].

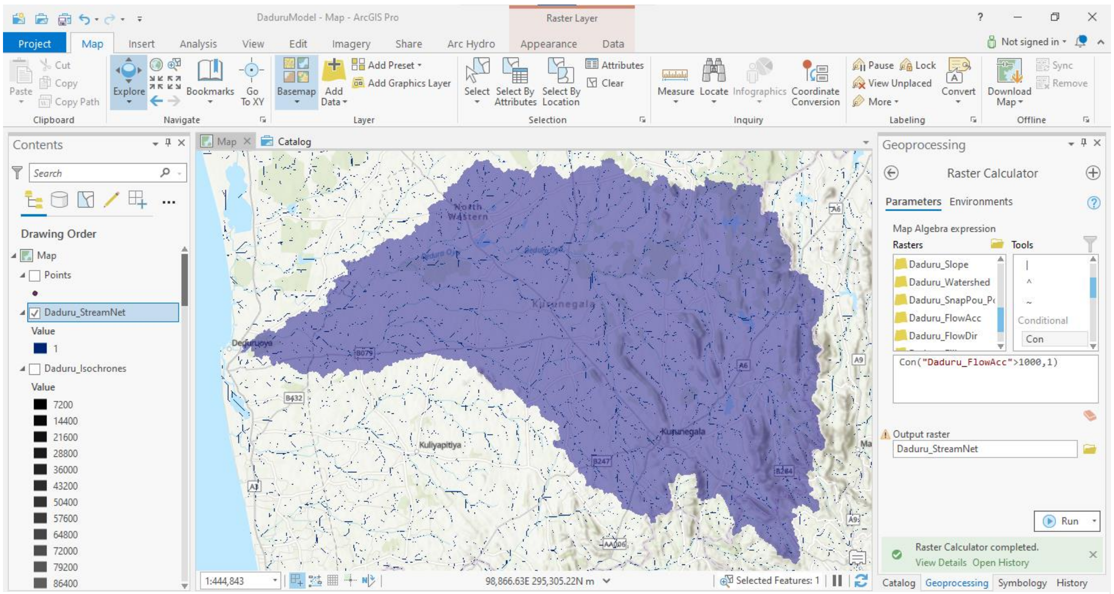


Figure 4.62: Stream network calculation by raster calculator.

4.4.6.2 Stream ordering

This program provides a numerical order to raster segments representing linear network branches. There are two ways to apply a numerical order to links in a stream network using the ‘Stream Order’ tool. While the default ‘Strahler’ approach is the most often used, the ‘Shreve’ method has the advantage of being less sensitive to the inclusion and removal of connections from further analysis.

Strahler — Strahler's stream ordering technique, developed in 1952. When streams of the same order cross, the order of the streams rises. As a result, the intersection of a first-order and second-order link will result in a second-order link rather than a third-order connection. This is the default setting.

Shreve – A technique of ranking streams by size suggested by Shreve in 1967. A magnitude (order) of one is applied to all connections that have no tributaries. Downslope, magnitudes are cumulative. When two links meet, the magnitudes of the intersecting links are summed and allocated to the downslope link. [45]

In Daduru Oya model, how the stream order tool was used is given in figure 4.63. Stream network is the input stream raster and watershed flow direction are the input flow direction raster to the tool. Method of stream ordering was selected as ‘Shreve’ since it gives flexibility.

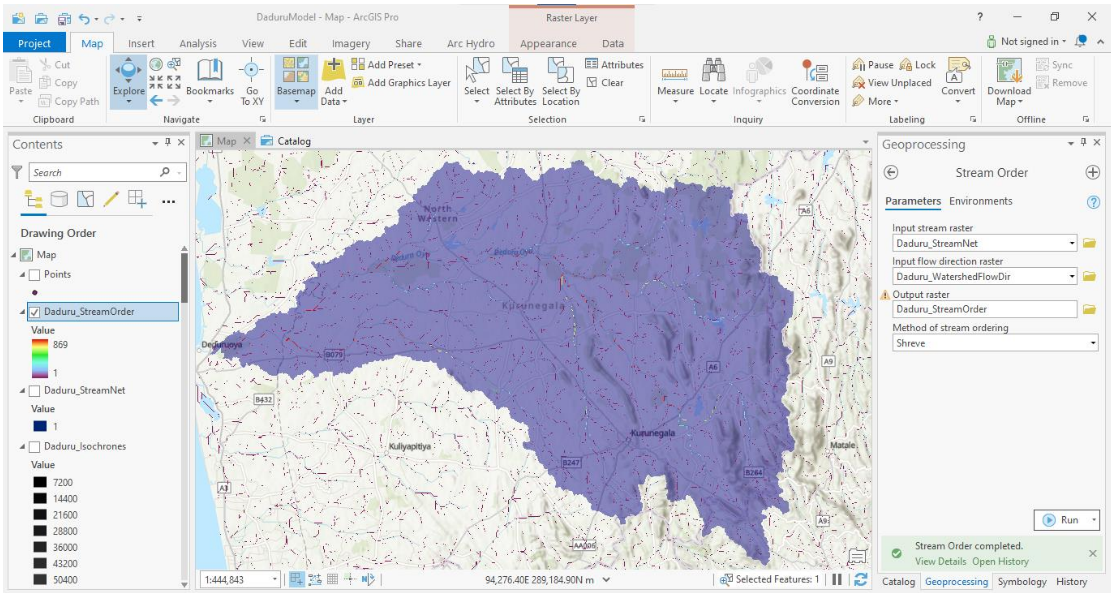


Figure 4.63: Stream order tools usage.

4.4.6.3 Stream links

It could use the ‘Stream Link’ tool to set unique values to each link in a raster linear network. This is particularly helpful as an input to the ‘Watershed’ tool, which allows to easily build watersheds based on stream junctions. It can also be used to link relevant attribute information to particular stream segments. Figure 4.64 shows how it works [45].

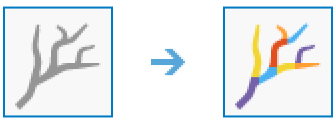


Figure 4.64: How stream link tool works [45].

The parts of a stream channel that connect two successive junctions, a junction and the outflow, or a junction and the drainage division, are referred to as links. The linkages in a stream channel are depicted in Figure 4.65.

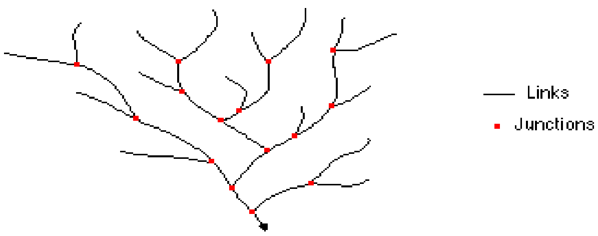


Figure 4.65: Links in a stream channel [45].

The input stream raster may be generated by thresholding the ‘Flow Accumulation’ tool results. On a ‘NoData’ backdrop, the stream raster linear network should be represented as values greater than or equal to one. The ‘Stream Link’ tool only accepts a D8 raster as an input flow direction raster. The ‘Flow Direction’ tool, with the default flow direction type D8, may be used to generate D8 flow directions. This program allows for parallel processing. Better performance may be obtained if the computer has several processors or processors with many cores, especially on bigger datasets [45]. Figure 4.66 illustrates the ‘Stream Link’ tool. In the final model this tool was not used since it does not need for the analysis.

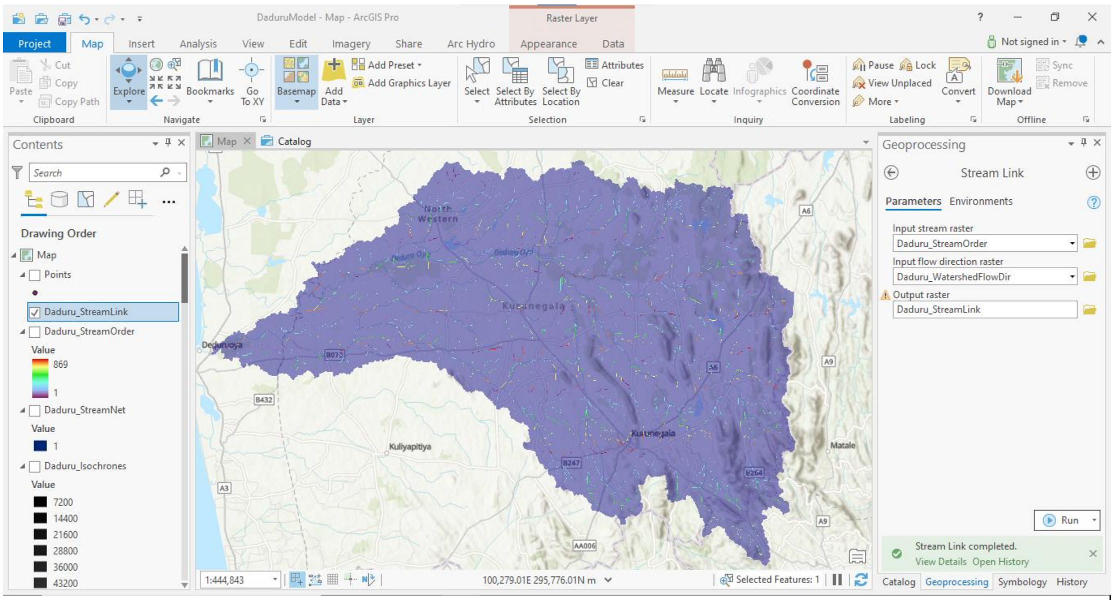


Figure 4.66: Stream link tool.

4.4.6.4 The vectorization of a raster stream network

The ‘Stream to Feature’ tool accurately converts a raster linear network to feature data. Figure 4.67 shows the model part representing the tool. On a ‘NoData’ backdrop, the input stream raster linear network should be represented as values greater than or equal

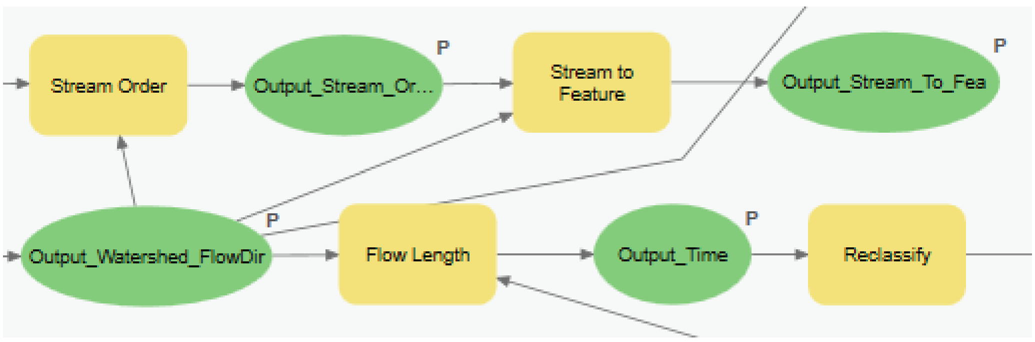


Figure 4.67: Model part for stream order and stream to feature tools.

to one. The ‘Flow Accumulation’ tool output may be used to generate a raster stream network by applying a threshold value to cells with a high accumulated flow. Cells with more than 1000 cells flowing into them, for example, are utilized to define the stream network. could use the ‘Con’ or ‘Set Null’ tool to construct a stream network raster in which flow accumulation values of 1000 or above are set to 1 and the remainder are put to the background (NoData).

The stream network that results may be utilized in ‘Stream Link’ and ‘Stream to Feature’ tools. Contiguous features with the same value, such as the results of the ‘Stream Order’ or ‘Stream Link’ tools, should exist. ‘Stream to Feature’ should not be used on a raster with a small number of neighbouring cells with the same value. The output characteristics will be oriented downstream [45]. How ‘Stream to Feature’ tool is used is given in figure 4.68.

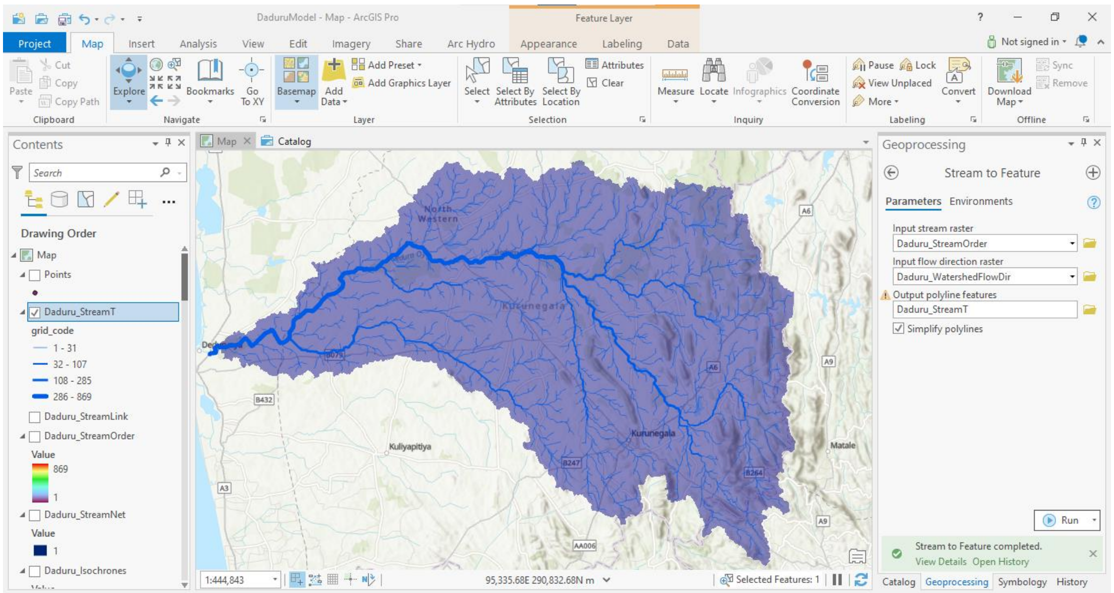


Figure 4.68: Stream to feature tool.

4.4.6.5 Creating flood depth and flood extent using HAND tool

In figure 4.69, HAND based flood depth and extent mapping tool is depicted. Flood depth is entered into the model using a variable so that the user can change it and see the effect.

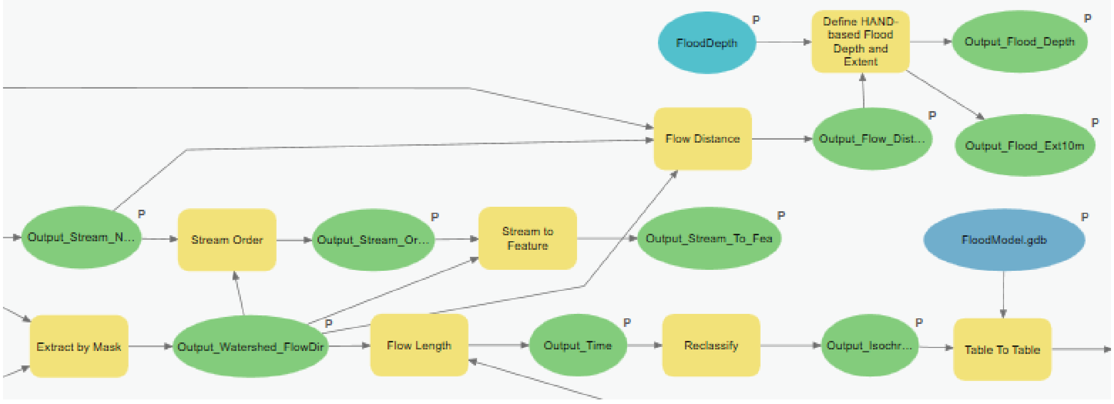


Figure 4.69: How to use HAND tool.

4.4.6.6 Flow distance

Calculate the vertical or horizontal downslope distance to streams using a single or multiple flow routes. For computing flow distance, D8, D-infinity, and MFD algorithms are supported. When there are numerous flow routes, the lowest, weighted mean, or maximum flow distance can be calculated. 'Height Above Nearest Drainage' is a term that is used in the calculation of Height Above Nearest Drainage (HAND). Flooding happens when the depth of the water exceeds HAND [50]. Figure 4.70 displays this scenario [42].

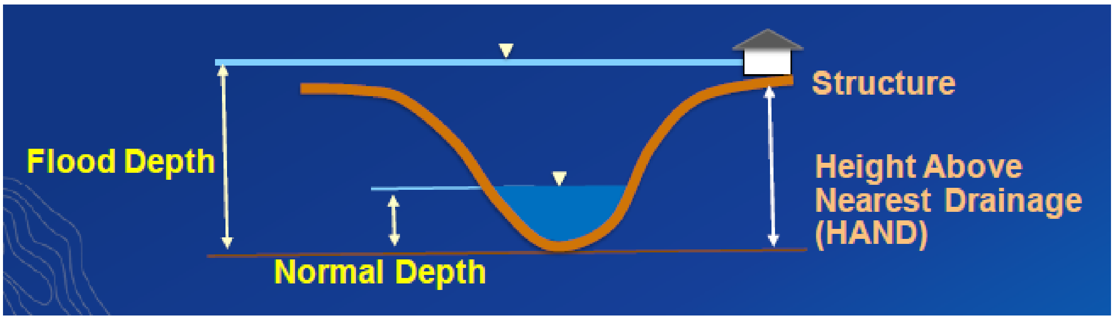


Figure 4.70: HAND concept. [42]

'Flow Distance' tool uses DEM, watershed flow direction and stream network as input raster data. Input flow direction type was selected as D8 since it has been the method throughout the project. This process in the flow distance tool is illustrated in figure 4.71.

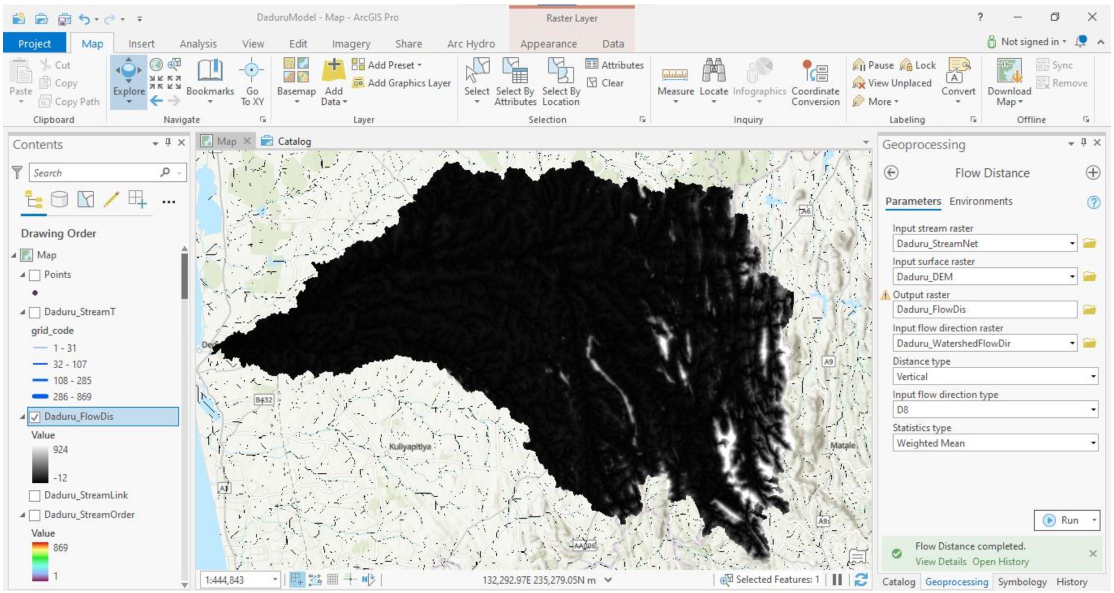


Figure 4.71: Flow distance tool usage.

Now the ‘Define Hand-based Flood Depth and Extent’ tool available in ‘ArcHydro Tools Pro’ -> ‘H & H modelling’ -> ‘Hand Processing’ toolbox could be used to get maps showing flood extent of Daduru Oya and the flood depth of Daduru Oya according to the flood depth the user input into the model. In the final model this value can change and could run the model to see the effect of the change. So, the authorities could decide on the cause of action according to the map, it clearly shows the area that will flood and the depth of the flood in any place in the watershed. Figure 4.72 depicts the flood extent map and figure 4.73 depicts the flood depth map for 4m depth.

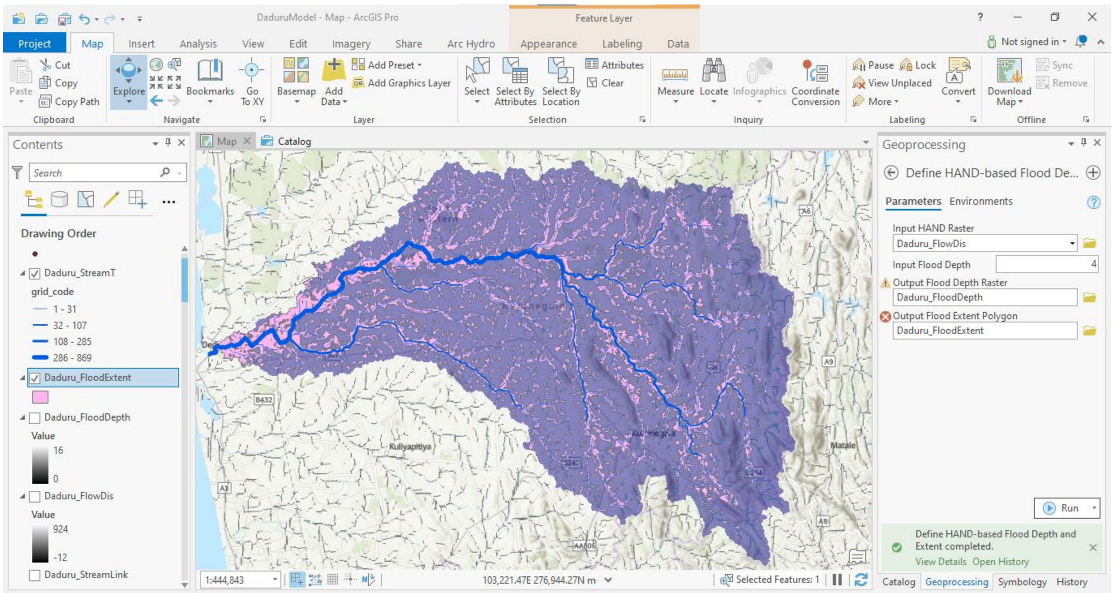


Figure 4.72: Flood Extent map of Daduru Oya for depth of 4m.

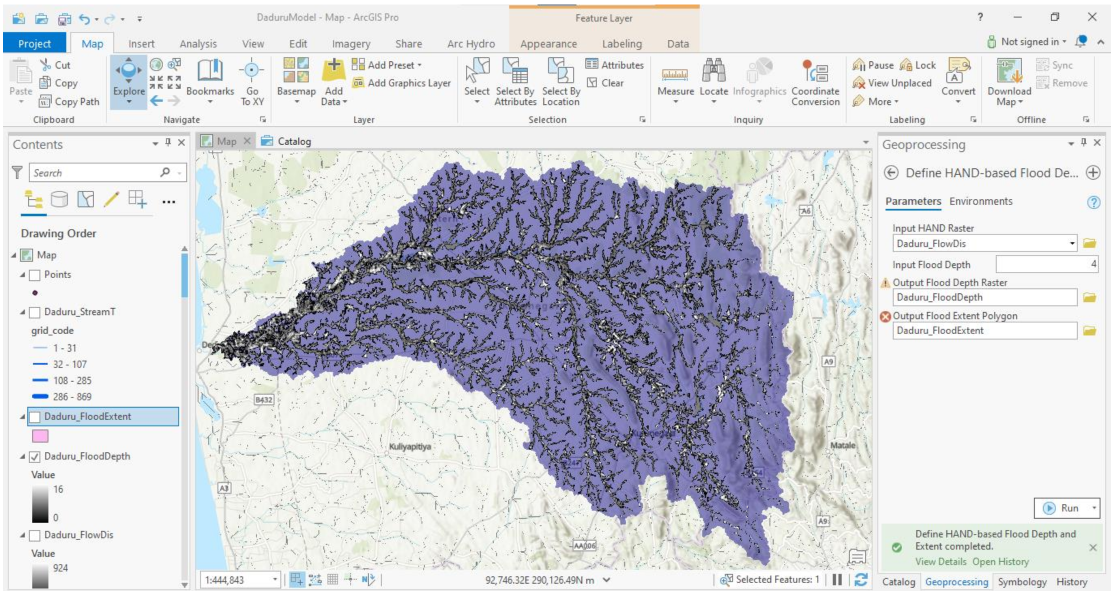


Figure 4.73: Flood Depth map of Daduru Oya for depth of 4m.

By clicking on a place in the map will give the relevant flood depth of that place as given in figure 4.74.

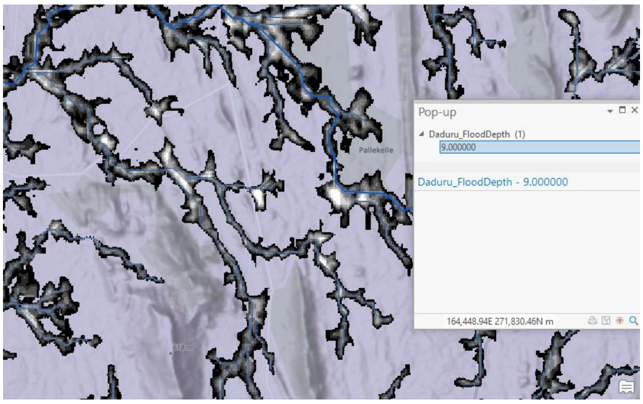


Figure 4.74: Flood depth of 9m near Pallekelle.

4.5 Summary

In this chapter the model building process was discussed in detail step by step with illustrations for each step of the process as well as an explanation of the underlying theory and concepts with formulae when needed. The model validation process will be discussed in the next chapter.

Chapter 5

Evaluation

5.1 Introduction

When creating a model, the data and tools that are added and connected are automatically verified or reviewed to confirm that the data exists, is valid for usage with a tool, and that the tool parameter values are provided appropriately. It may manually assess the model after generating a model and modifying, moving, renaming, or deleting the data or tools in the model. Also, if all processes in the model have been performed and wish to run them again, it must verify the model.

In this chapter, flood inundation maps of Kelani River and Kalu Ganga was downloaded from the Irrigation department website for two flood events and compared with flood extent maps generated from the final model for those two rivers to evaluate the accuracy of the model. Since some data of Daduru Oya like velocity, time it takes water to travel from starting position of the river to pour point was not available and available data is also not in a suitable form or sufficient for analysis, it was decided to use this method for the evaluation of the model.

5.2 Evaluation of the Final Model

5.2.1 With Kelani river map

From the Irrigation department website, a flood inundation map for an actual flood event in May 2016 for Kelani river was downloaded (figure 5.1) [46] and compared with the predicted flood depth map from the model (figure 5.2). It could be seen that fairly similar results were obtained, and differences may be due to factors such as not considering soil and land use data in modelling due to simplification and time limits. In Appendix – D, all the diagrams for Kelani flood prediction modelling process is given.

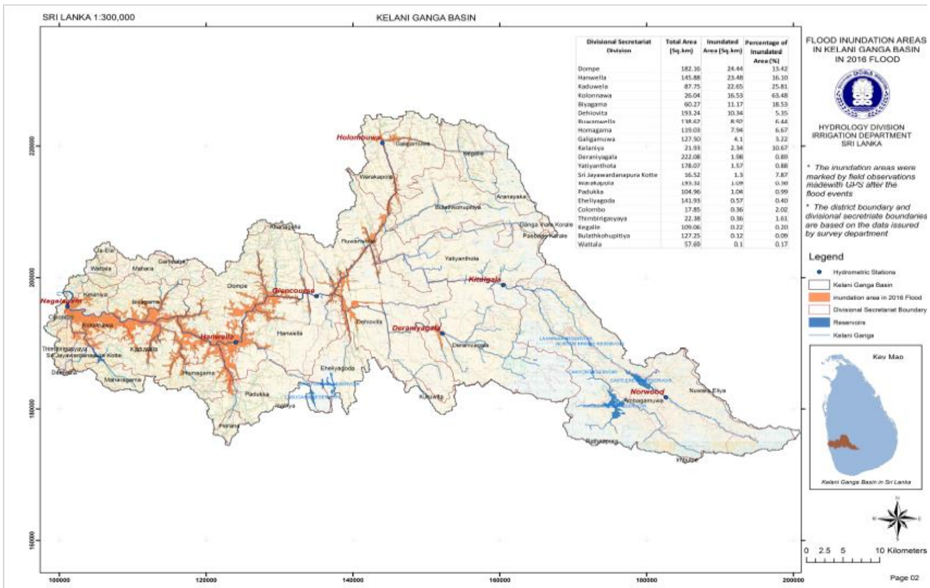


Figure 5.1: Observed flood event in Kelani River in May 2016. [46]

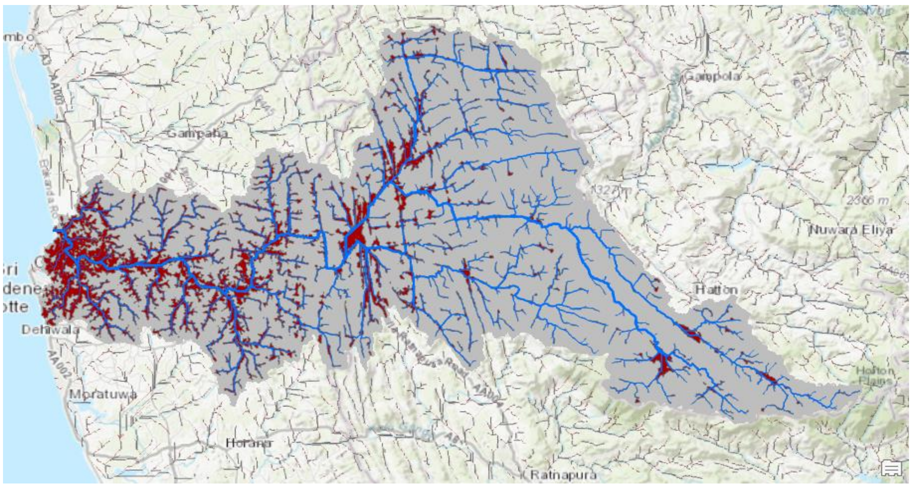


Figure 5.2: Predicted flood extent map using the model for Kelani River.

5.2.2 With Kalu Ganga(river) map and data

From the Irrigation department website, a flood inundation map for an actual flood event in year 2003 for Kalu Ganga was downloaded (figure 5.3) [47]and compared with the predicted flood depth map from the model (figure 5.4). It could be seen that fairly similar results were obtained, and differences may be due to factors such as not considering soil and land use data in modelling due to simplification and time limits. In Appendix – C, all the diagrams for Kalu flood prediction modelling process is given.

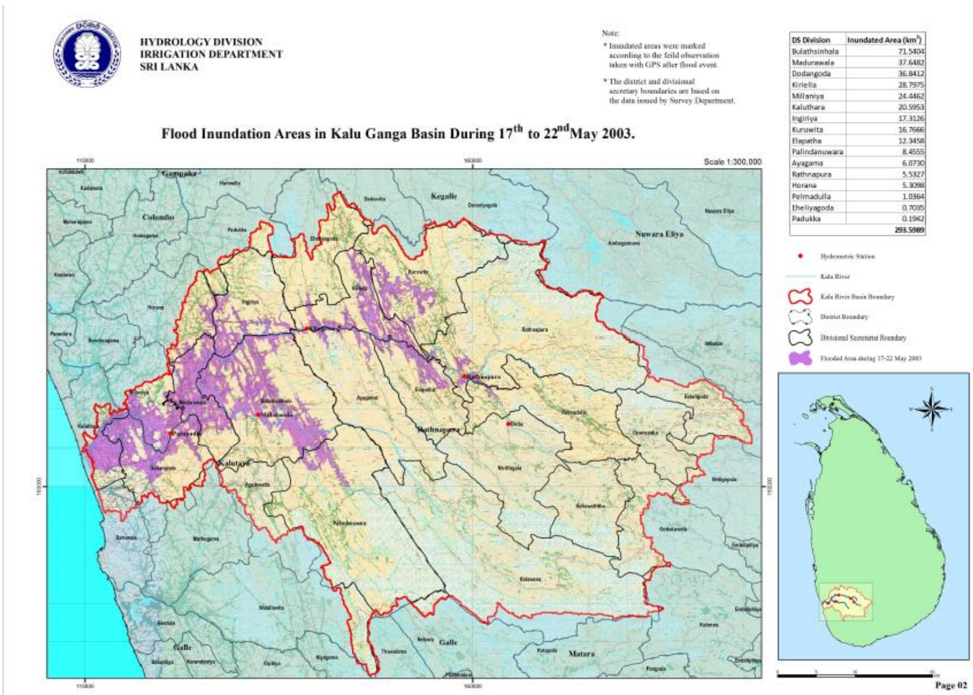


Figure 5.3: Observed flood inundation map for Kalu Ganga in year 2003. [47]

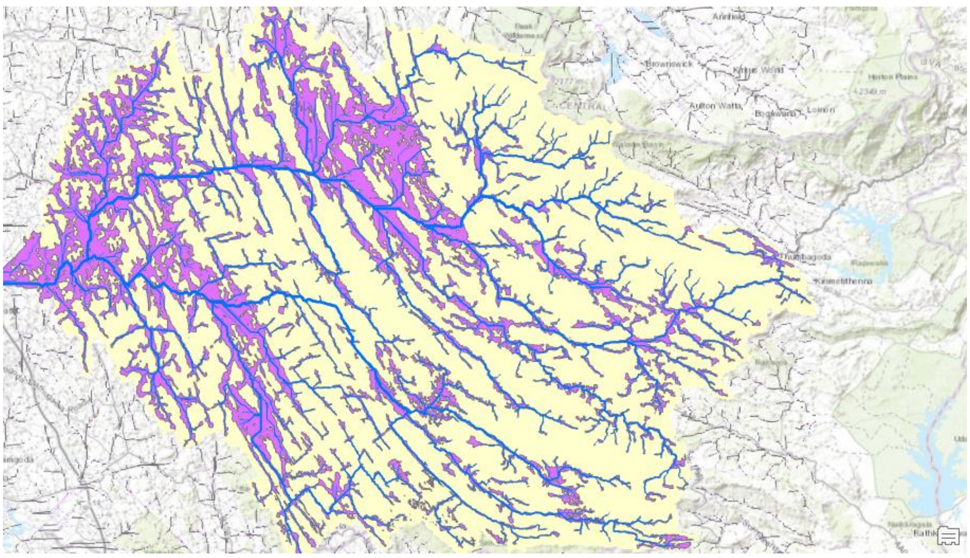


Figure 5.4: Predicted flood extent map using the model for Kalu Ganga.

In an observed flood event in year 2003 for Kalu Ganga the following flood levels in figure 5.5 were calculated [47].

Station	Highest Flood Level (m MSL)	Return Period yr	Other Critical Floods within the period with respective dates
Putupaula	6.09	10 - 25	6.15 (88/89), 6.55 (2007/08)
Millakanda	11.20	10 - 25	10.47(88/89), 12.35 (2007/08), 10.28 (2013/14)
Ellegawa	14.05	50	13.05 (88/89)
Ratnapura	23.59	10 - 25	24.78 (1988/89), 21.97 (93/94), 21.75 (2007/08)

Figure 5.5: May 2003 flood details of Kalu Ganga. [47]

From the model very similar results were obtained as shown in figure 5.6 for Putupaula, 5.7 for Millakanda, 5.8 for Ellagawa and 5.9 for Rathnapura.

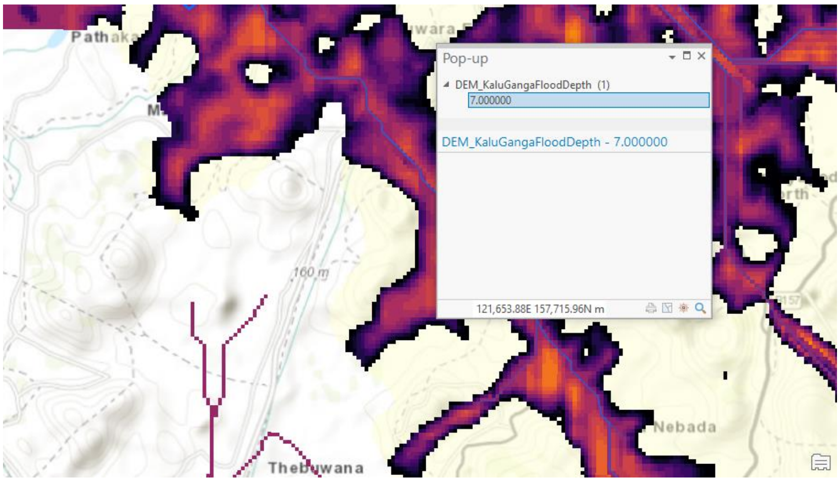


Figure 5.6: Putupaula flood depth from the model.

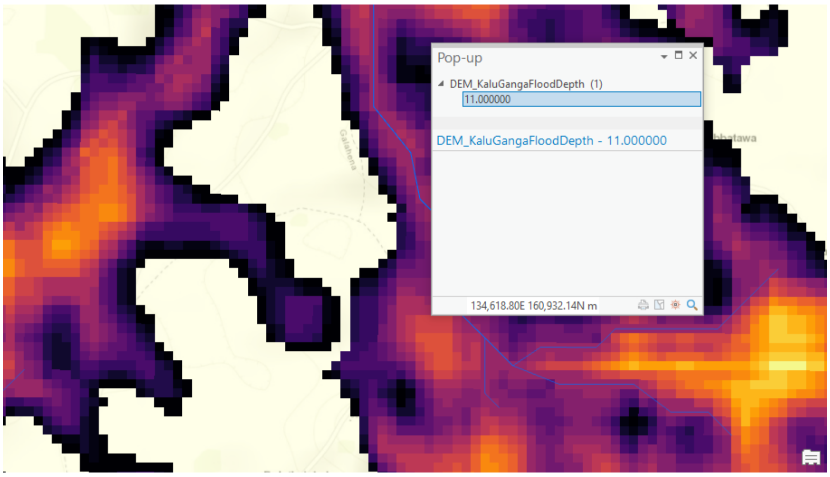


Figure 5.7: Millakanda flood depth from the model.

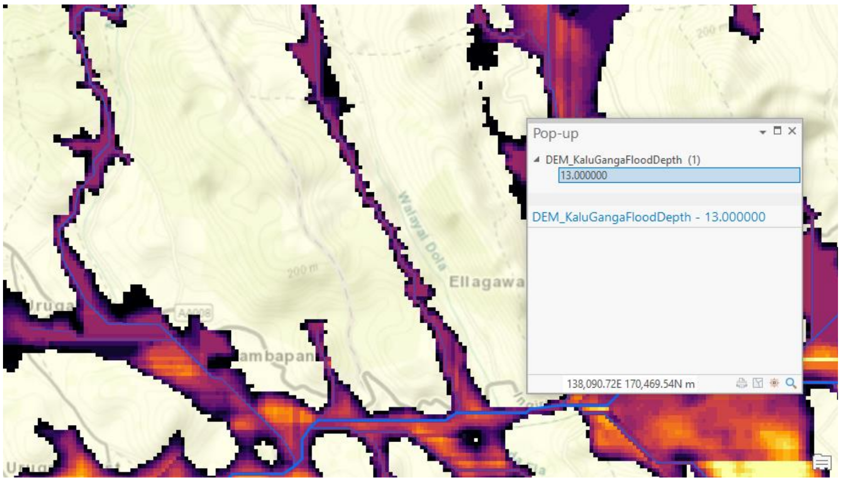


Figure 5.8: Ellagawa flood depth from the model.

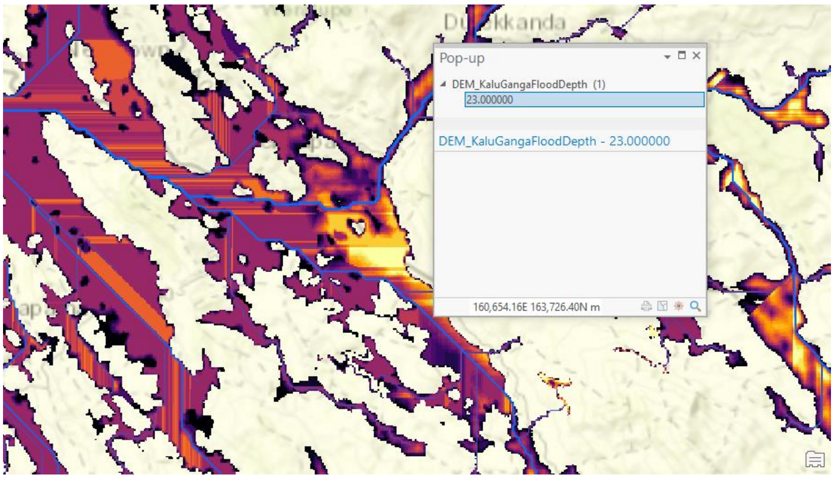


Figure 5.9: Rathnapura flood depth from the model.

5.3 Summary

From the results of the evaluation, it is clear that very similar results were obtained from the model compared to actual events. If the model is developed further, then more accurate results could be obtained. It will be discussed in the following chapter under future work.

Chapter 6

Conclusion and Future Work

6.1 Conclusion

The main objective of the project was to create a model tool using ArcGIS software to make the flood prediction process more efficient and effective. By creating a generalised model that could take any DEM data and a pour point feature class layer for the specific DEM that objective was achieved. Now it takes only few minutes to complete this task when it may have taken hours without the model and each time it had to be repeated for every DEM. And by giving significant values as variables, it could calibrate the model further and compare results very easily. It should only change the value of the variable and run the model to see the result of the change and model will only run from the place of the change. It makes the task easier and less time consuming. Because of the ‘Parse Path’ tool naming outputs have become very easy and saves a lot of time that should have spent on otherwise a less important tasks. And it also made saving so efficient because it automatically saves all the results to the file path of the DEM. Due to these factors, when it starts raining in upper catchment area could forecast due inundation area in minutes.

6.2 Challenges

Collecting Daduru Oya data have been a challenge because no hourly rainfall data was available and other data such as velocity of the river, how much time it takes to a drop of rain to reach pour point from the starting position of the river was not available.

6.3 Future Work

The model could be further developed to include factors such as soil, land use, evaporation, etc. to make it more accurate. Using ArcGIS City Engine, the model could further develop to make a 3D model of the watershed to show inundation area with buildings and other important developments and sites that will be flooded in a hypothetical situation to get a clear idea about places that will flood so it could take preventive action suitable for the scenario. And it could include HEC-RAS and HEC-HMS modelling to model with real-time data. Further an ArcGIS Dashboard could create to display data in online format, and it could use to give real-time flood forecasting by giving data through a server in real-time. And the possibility of including technologies available with ArcGIS such as machine learning, regression analysis and artificial intelligence could be explored to make the model more accurate and effective.

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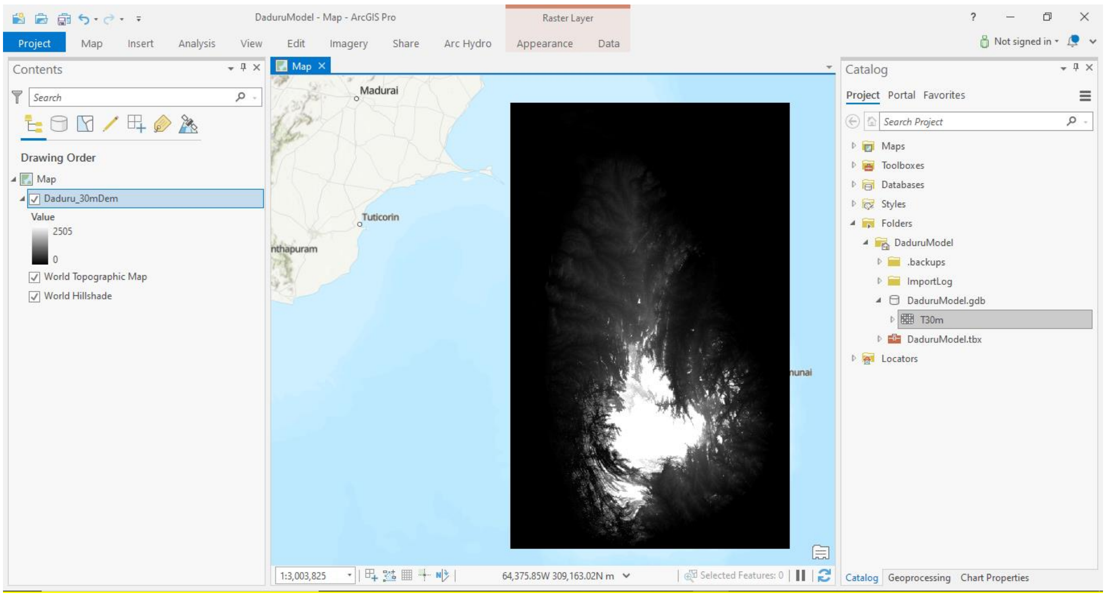
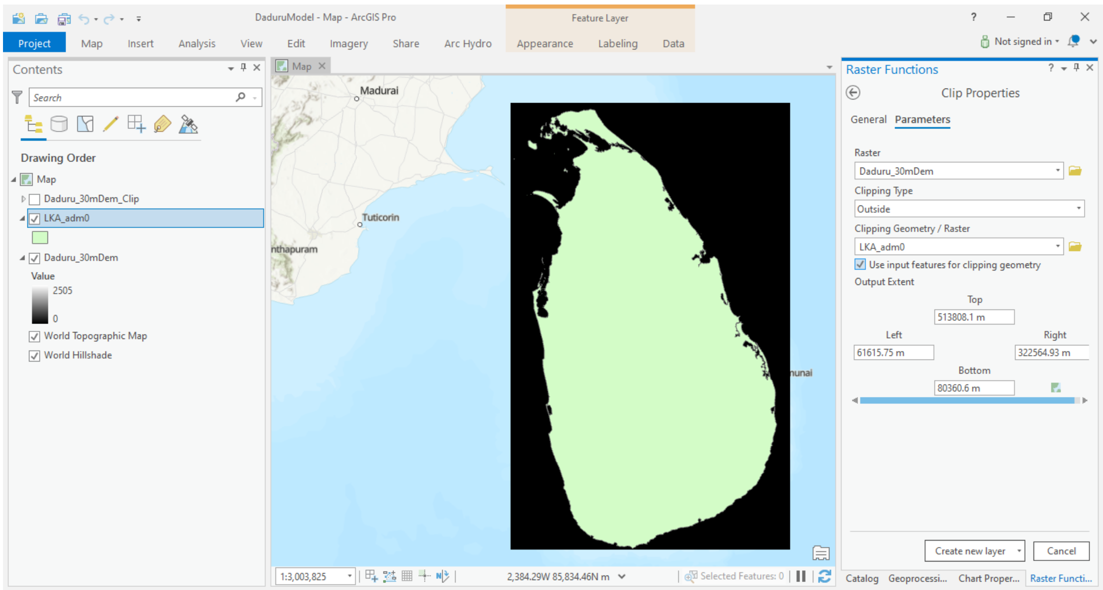
Appendix A – Getting DEM and Pour Point

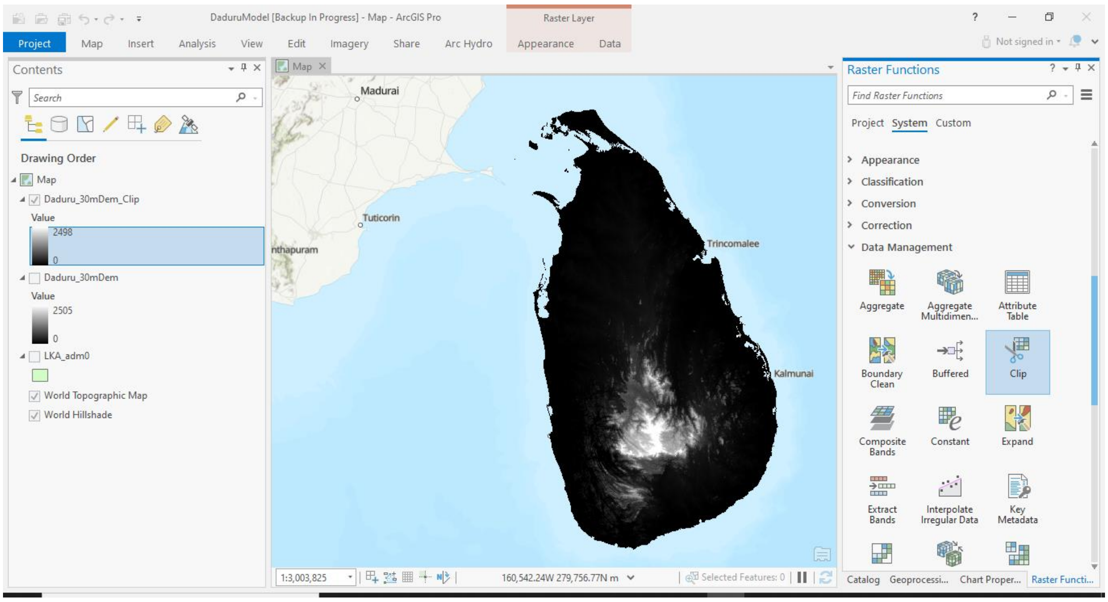
Adding DEM Data



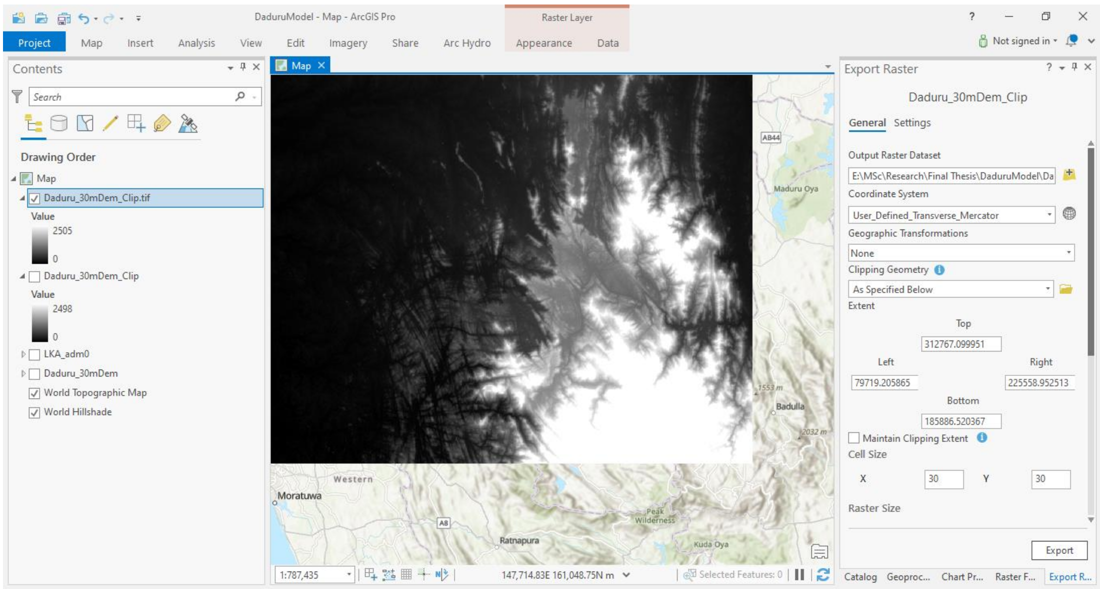
Using Raster Function Clip Tool



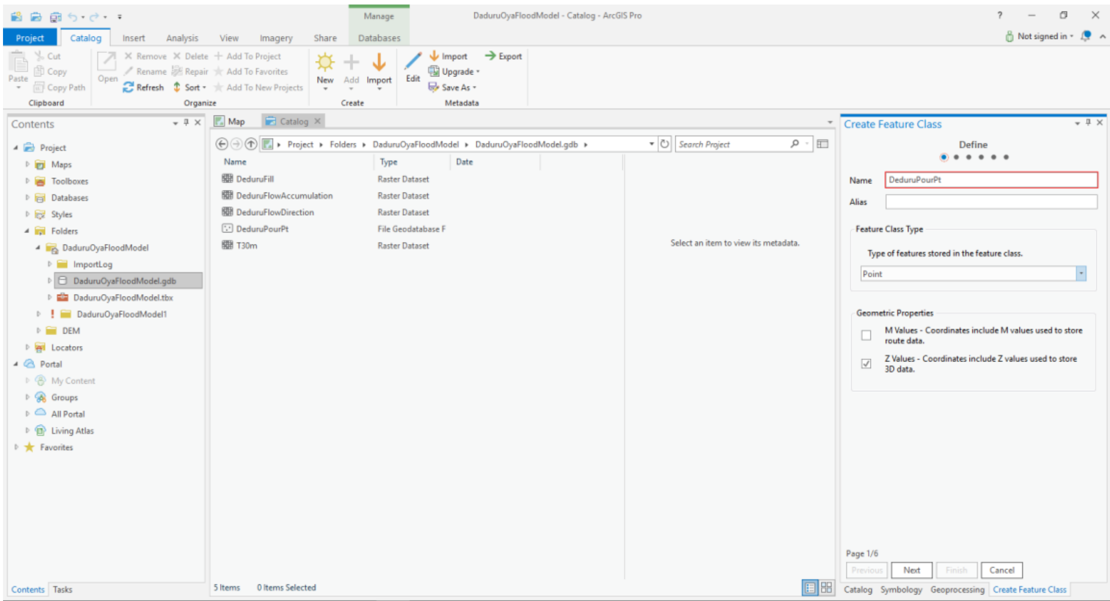
Clipped DEM



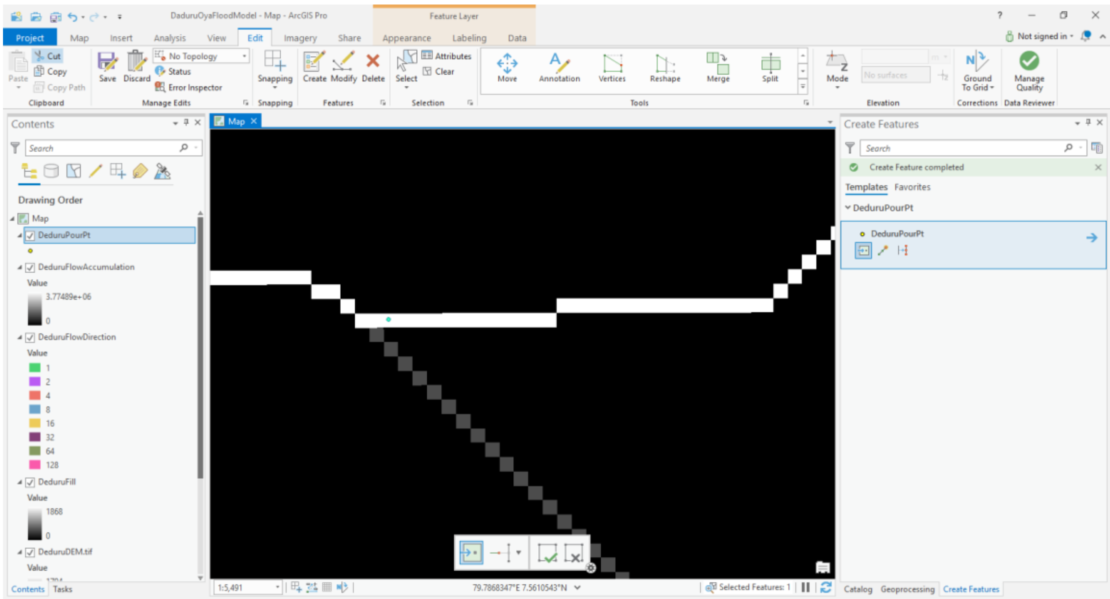
Clipping to Make a Smaller DEM



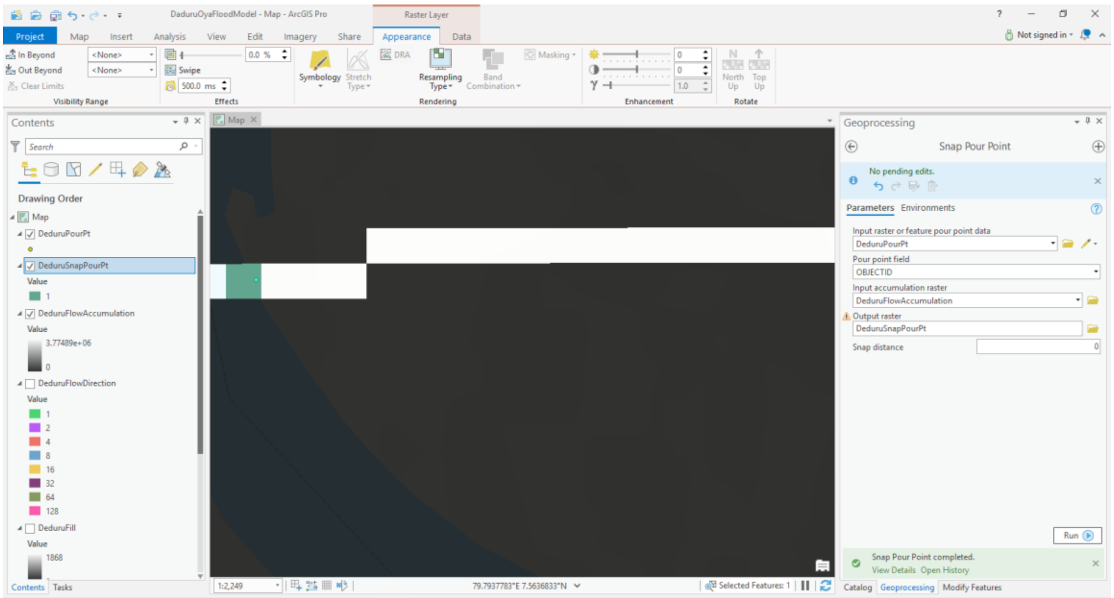
Create New Feature Class Pour Point



Create Feature



Snap Pour Point Tool



Appendix B - Reclassification Table

```
FROM_,TO,OUT,MAPPING
0.000000000000000,7200.000000000000000,7200,ValueToValue
7200.000000000000000,14400.000000000000000,14400,ValueToValue
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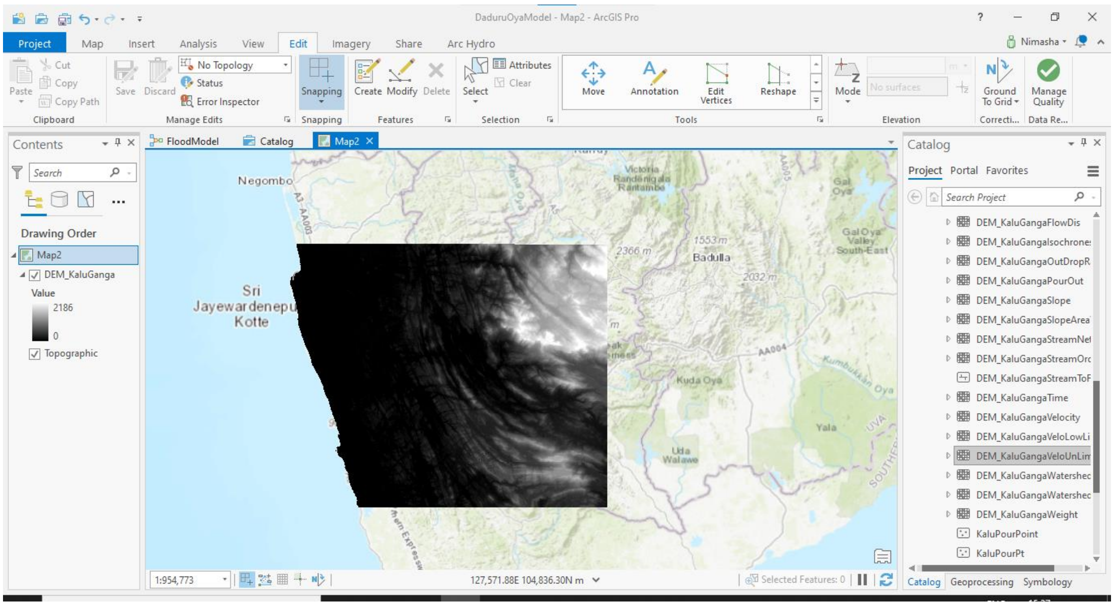
Appendix C - Kalu Ganga

DEM



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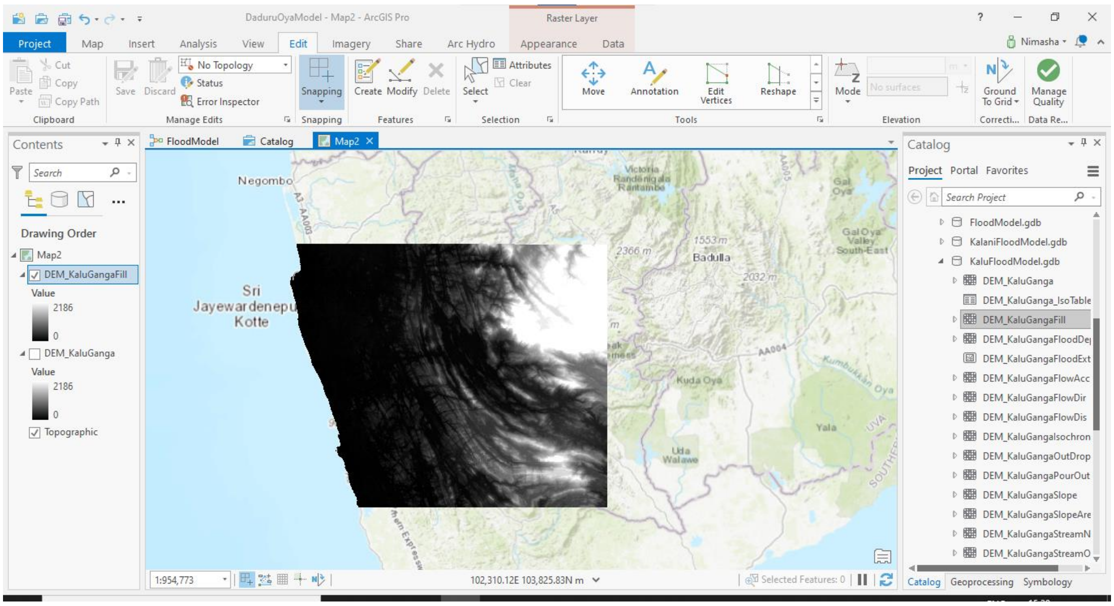
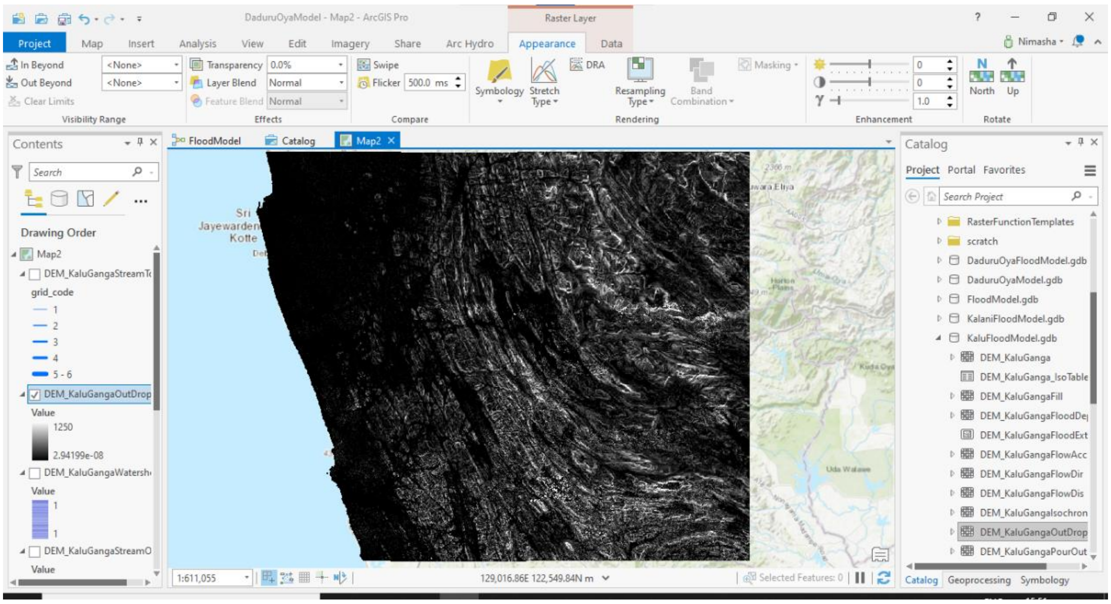
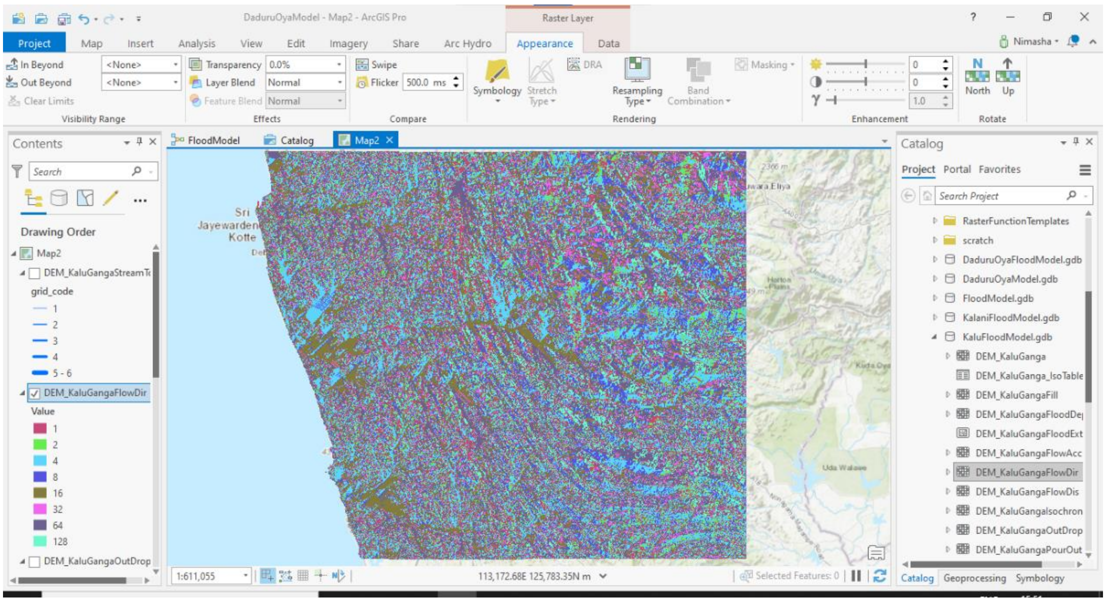


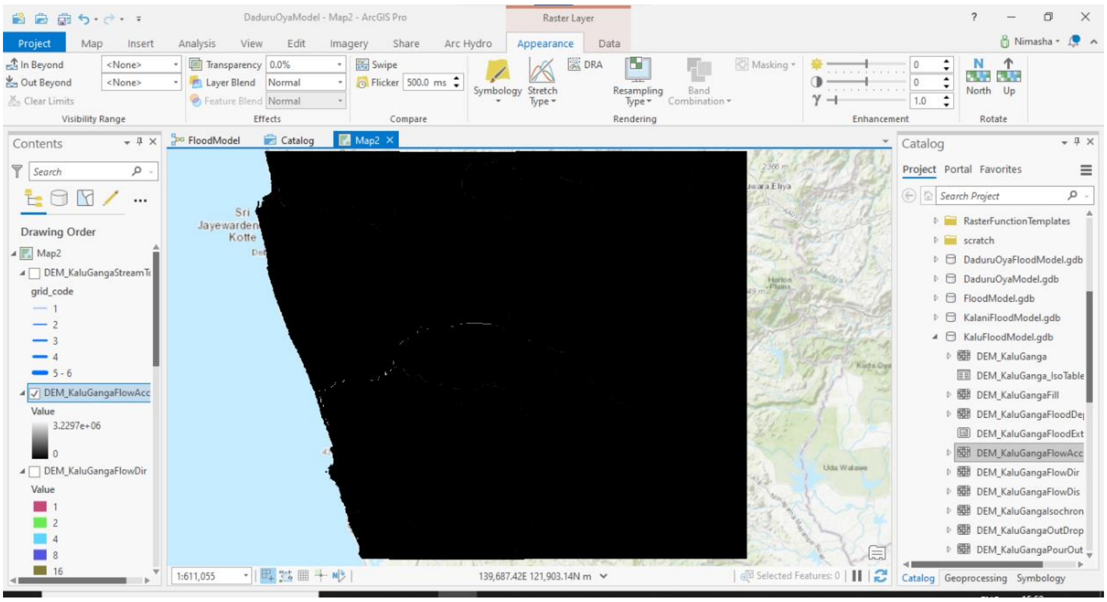
Drop Raster



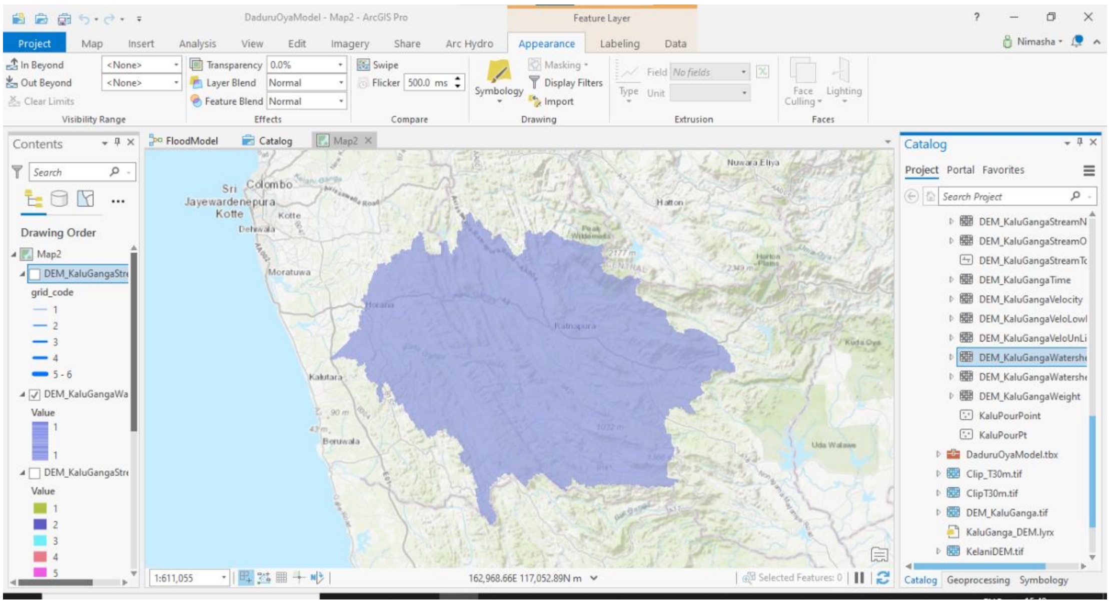
Flow Direction



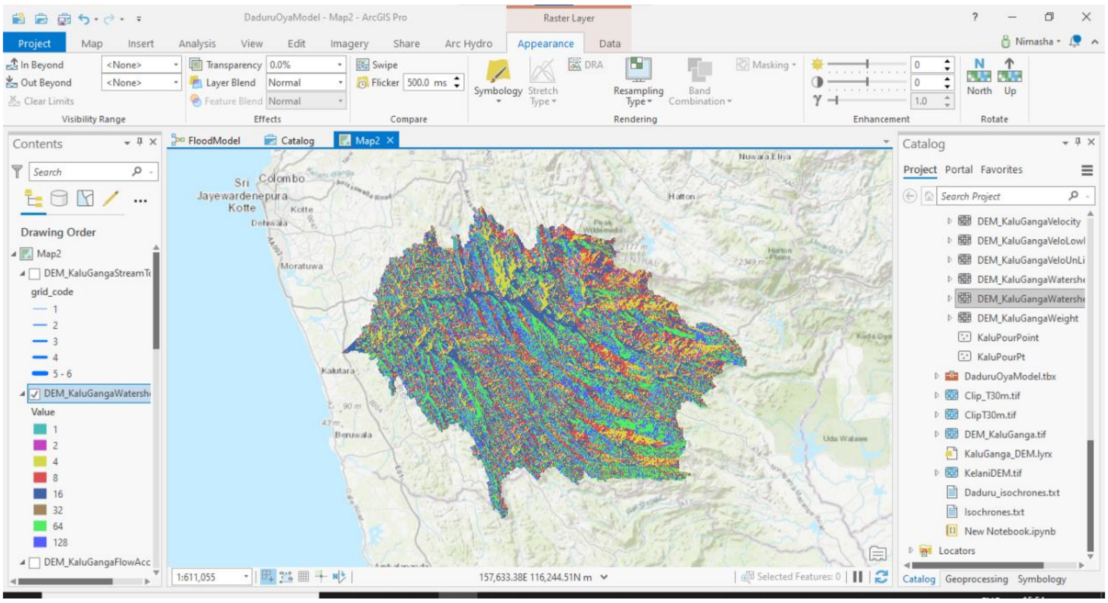
Flow Accumulation



Watershed



Watershed Flow Direction



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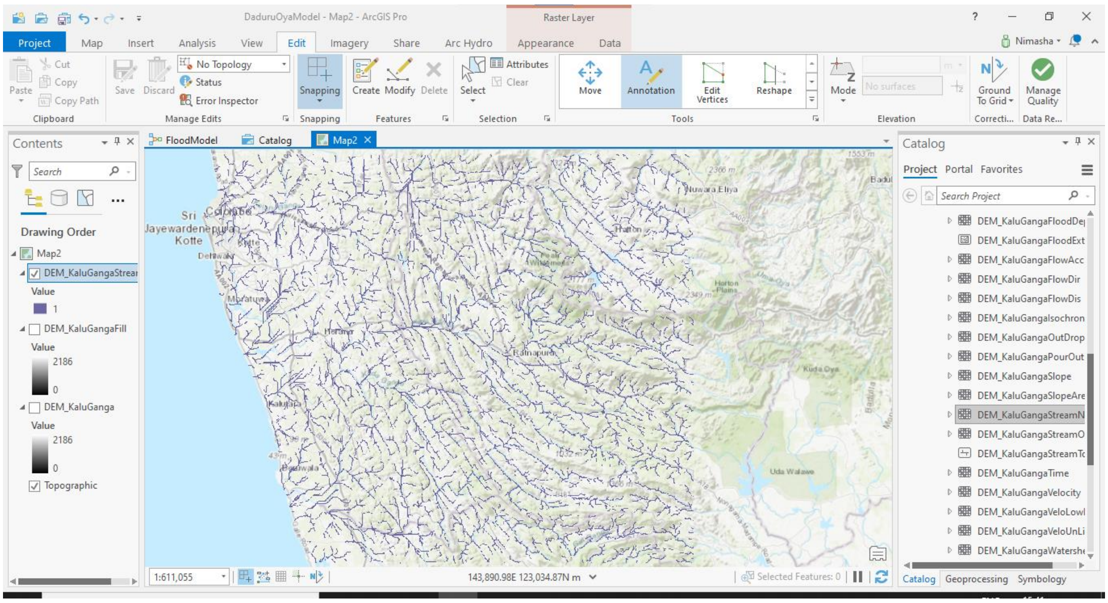
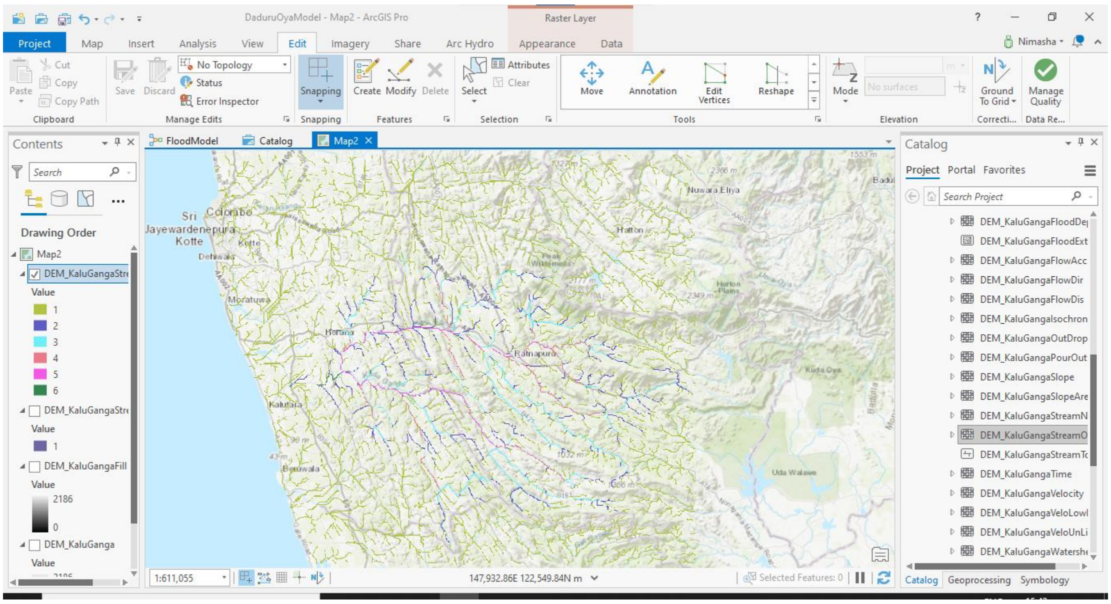
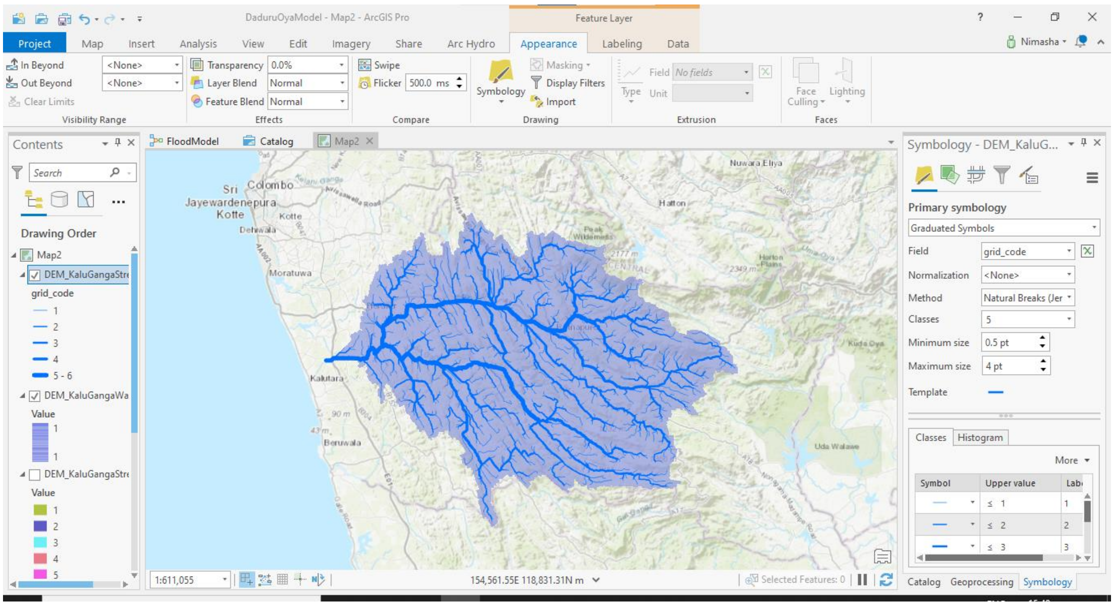


Stream Order



Stream to Feature



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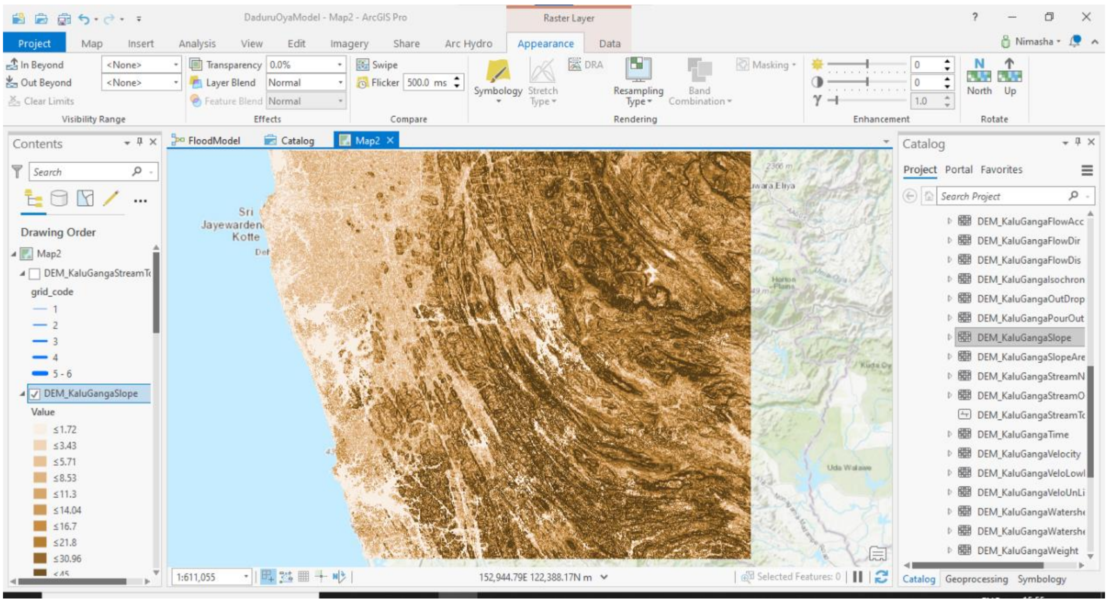

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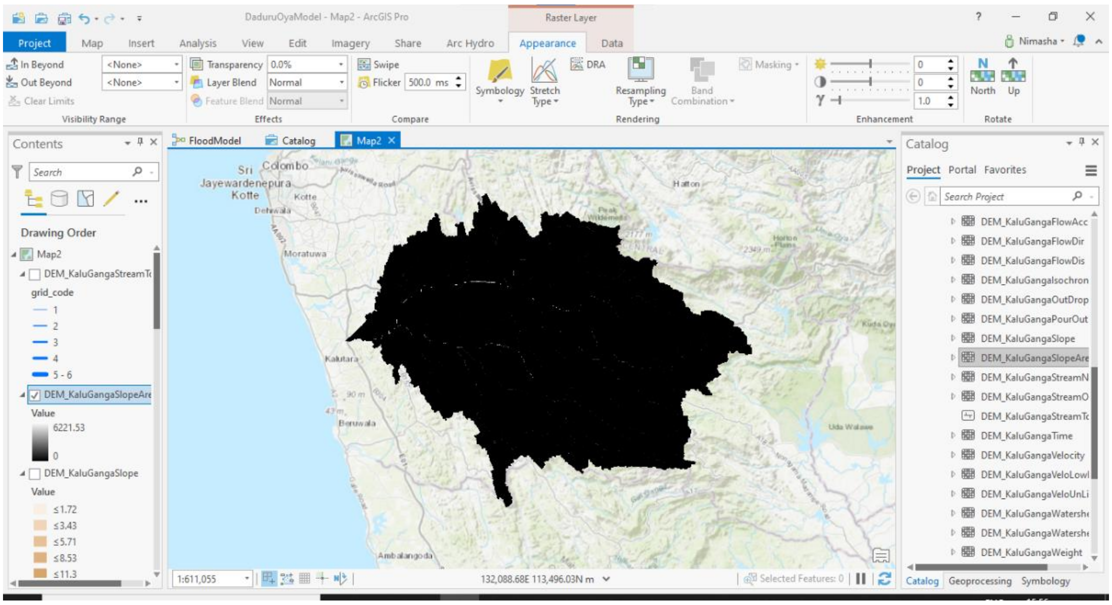
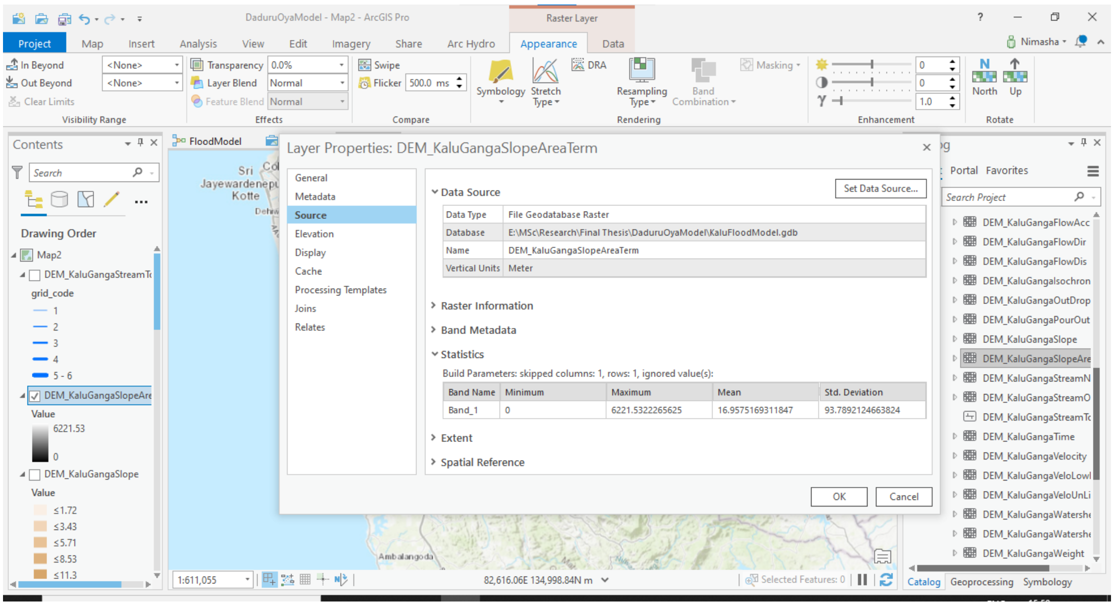


Statistics of Slope Area Term



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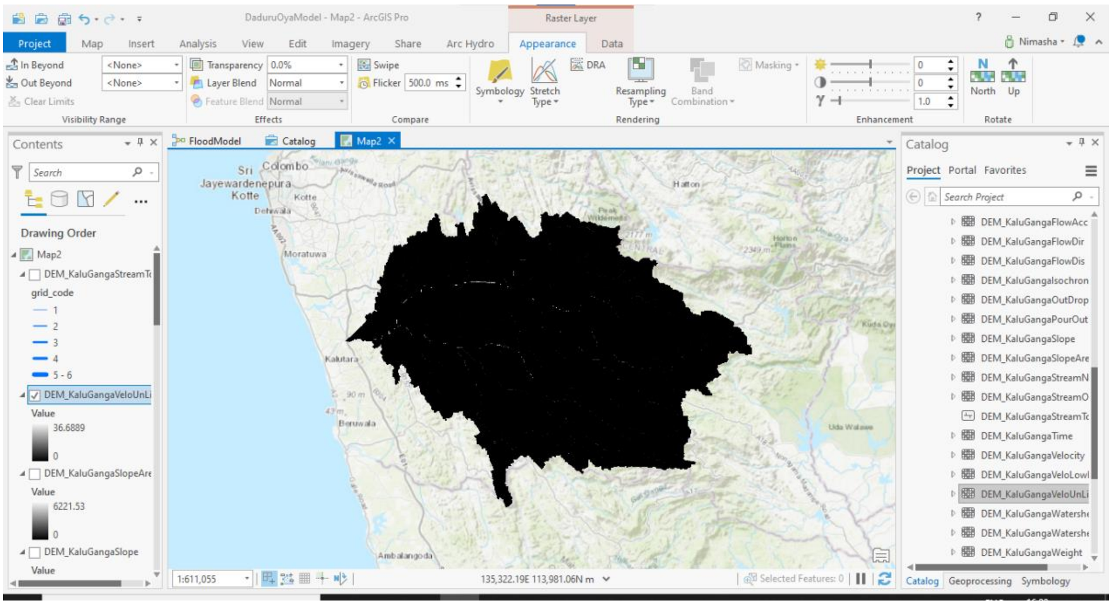
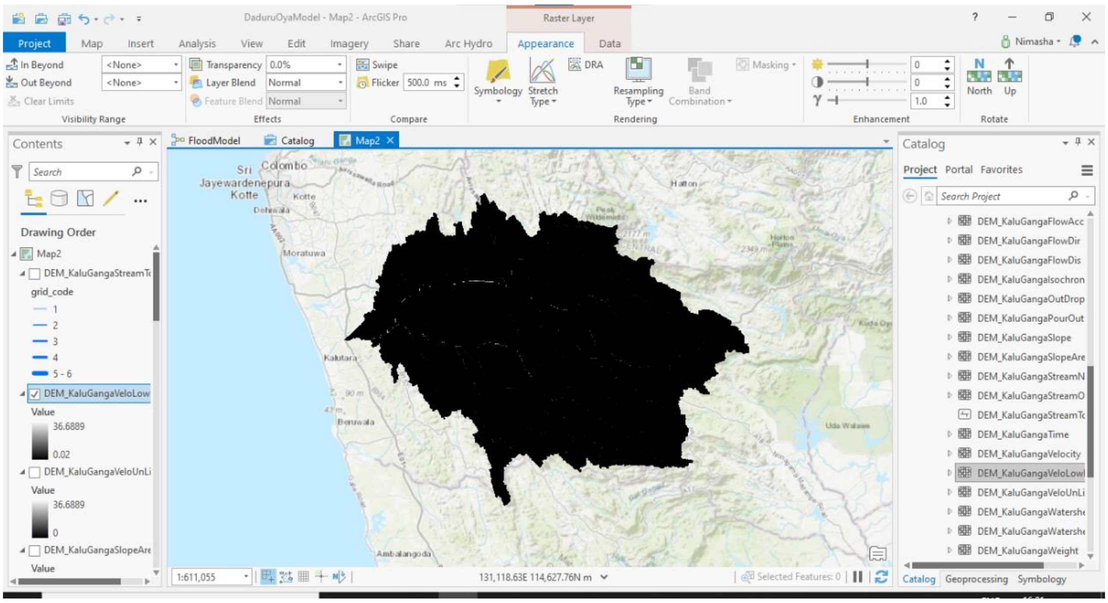
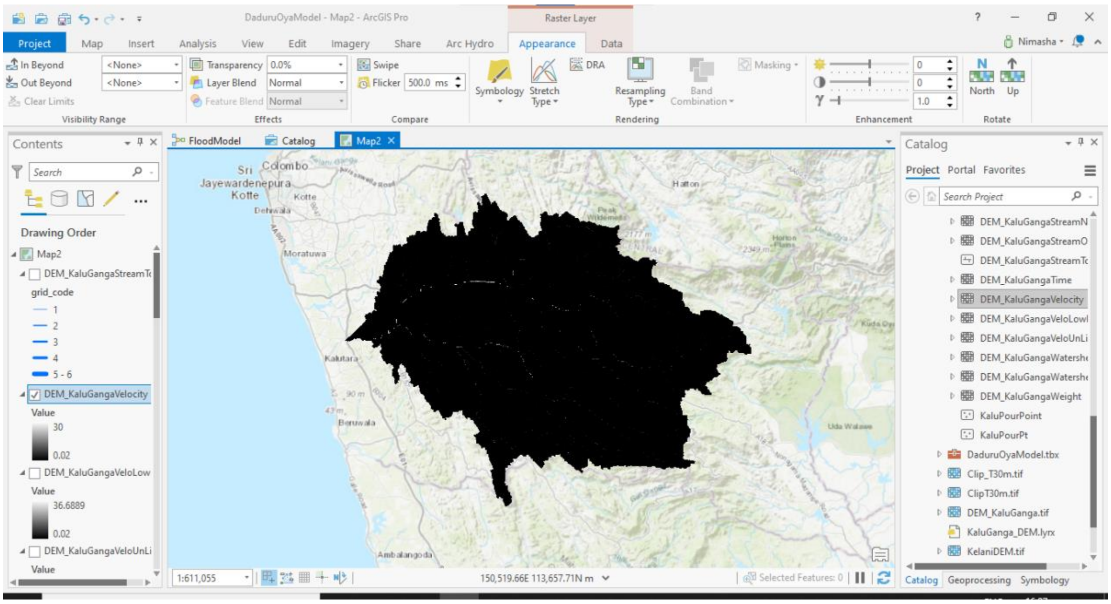


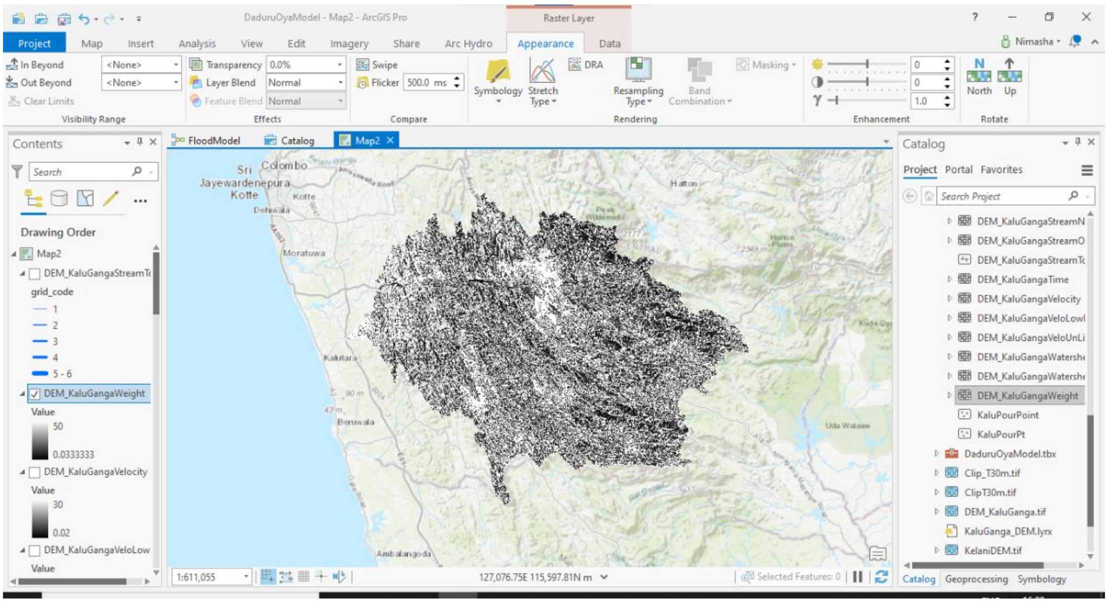
Velocity lower limited



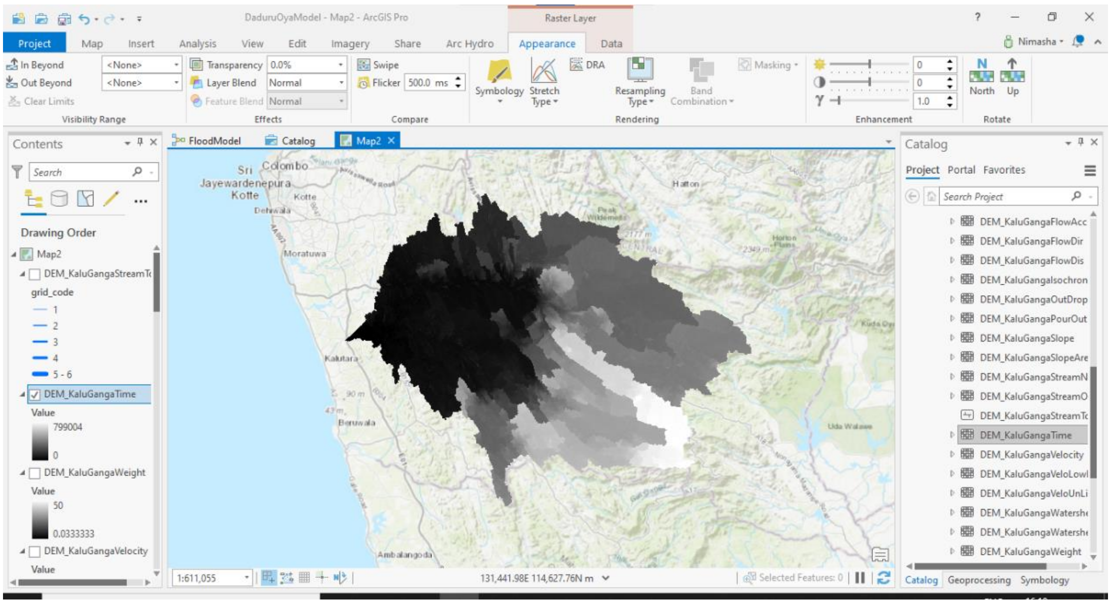
Velocity



Weight



Time



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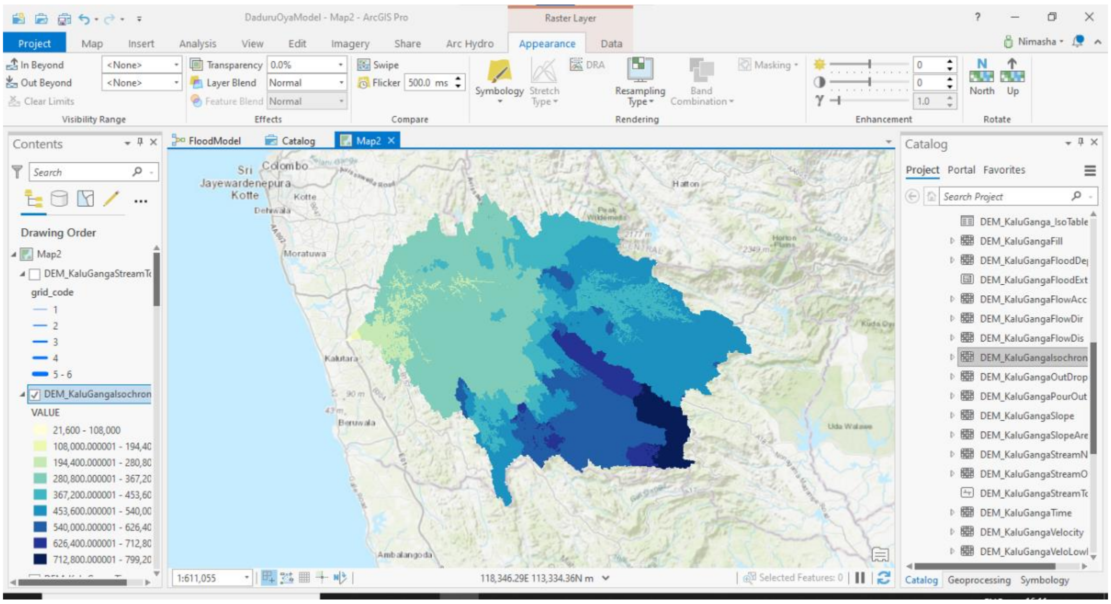

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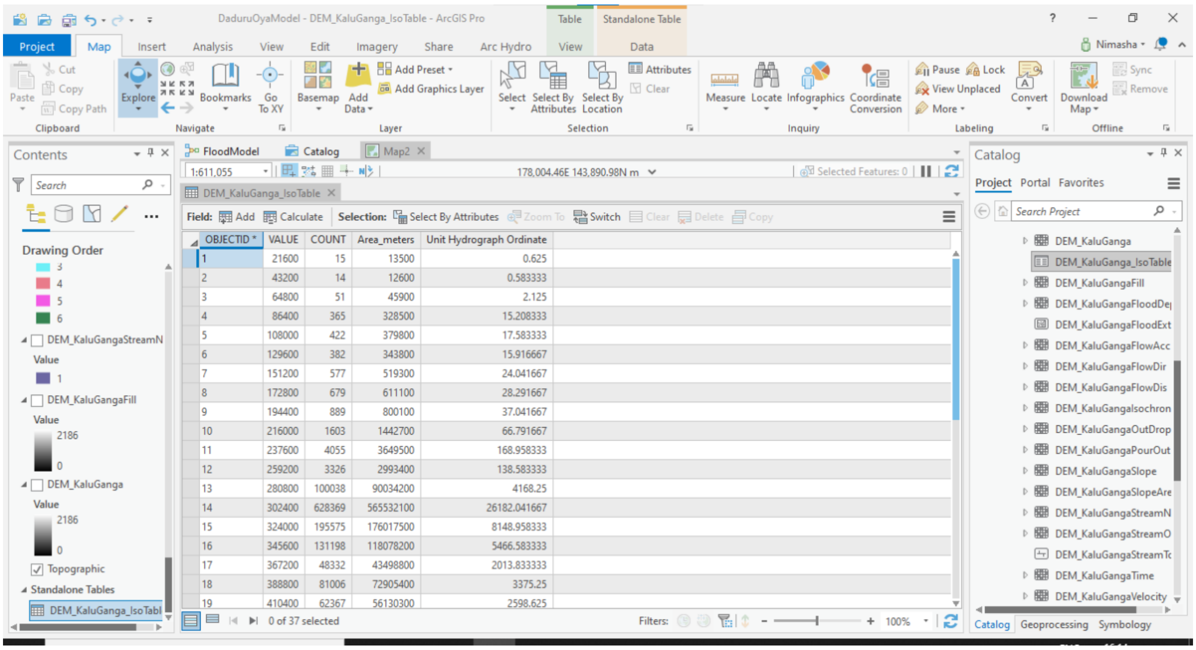

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10	216000	1603	1442700	66.791667
11	237600	4055	3649500	168.958333
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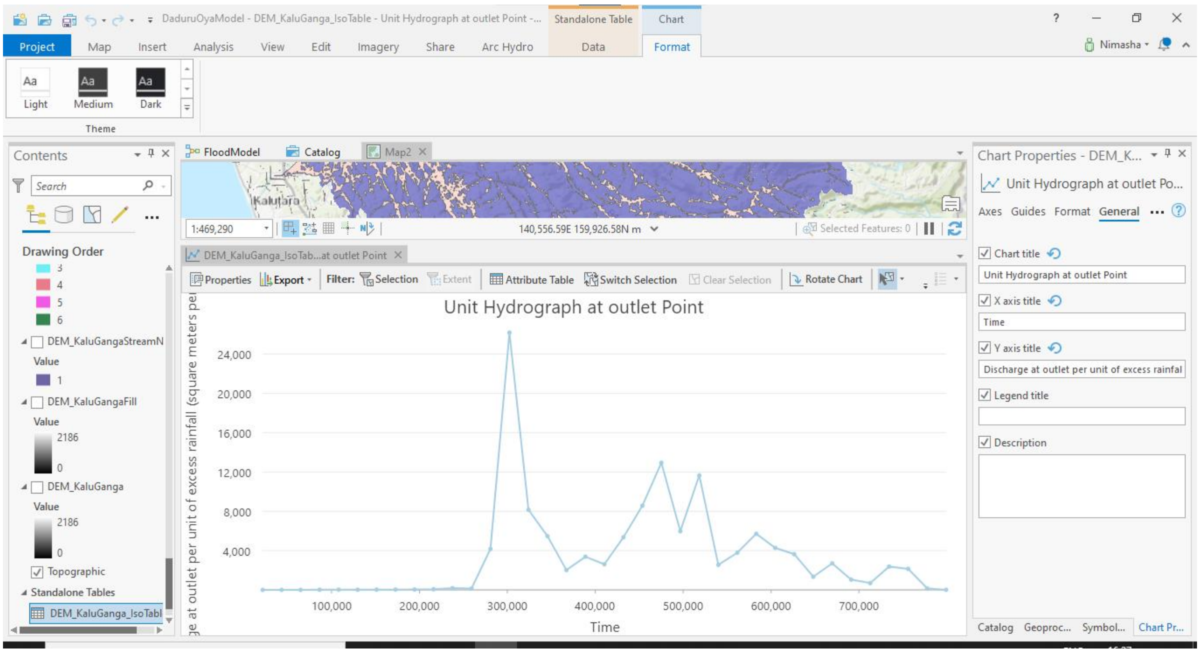
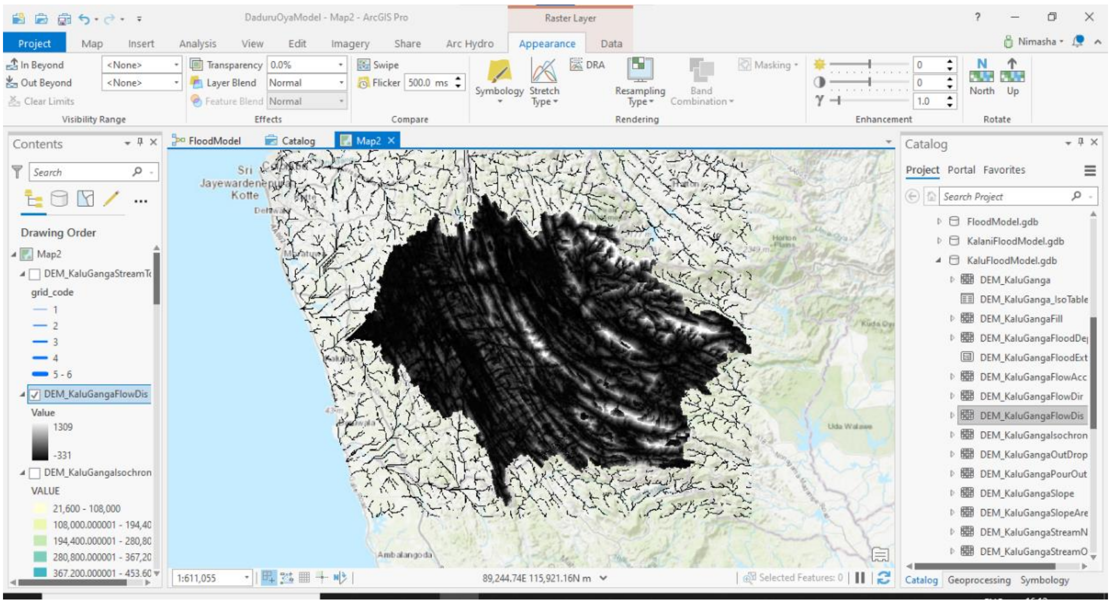
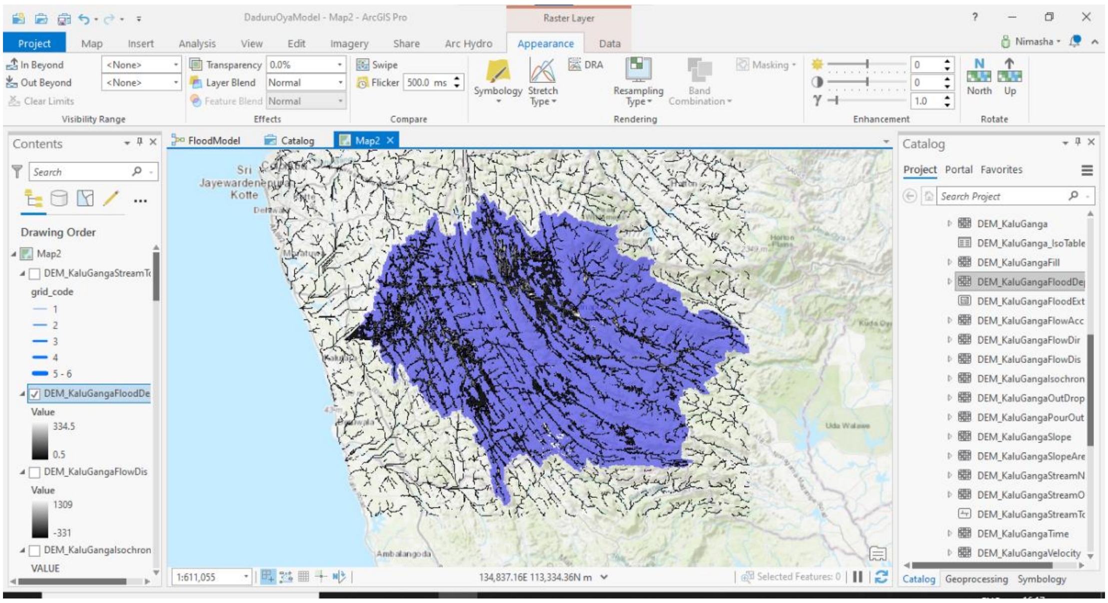
Unit Hydrograph



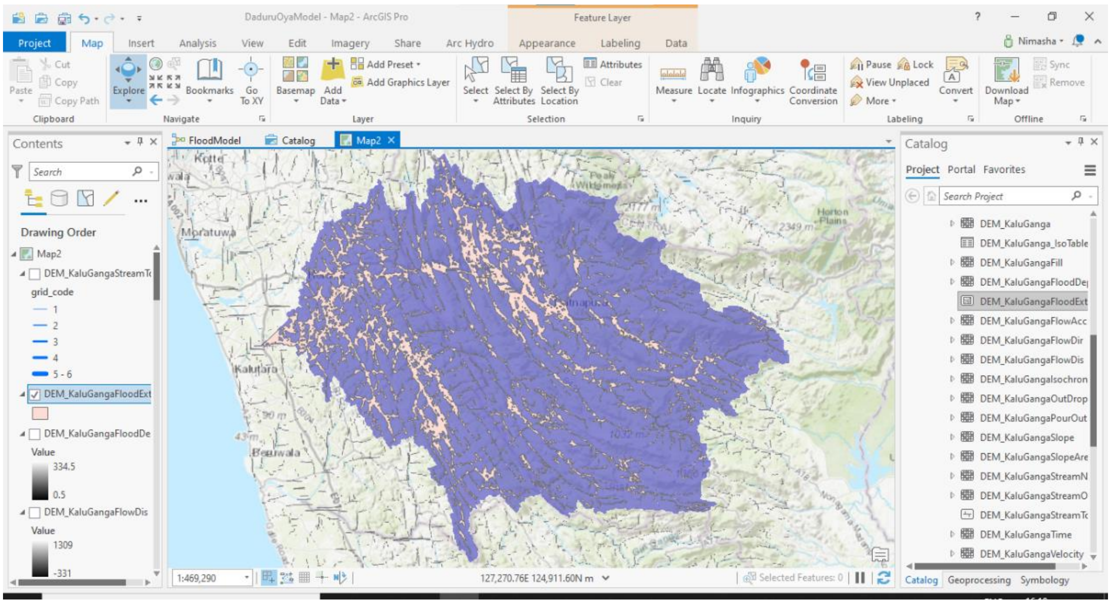
Flow Distance



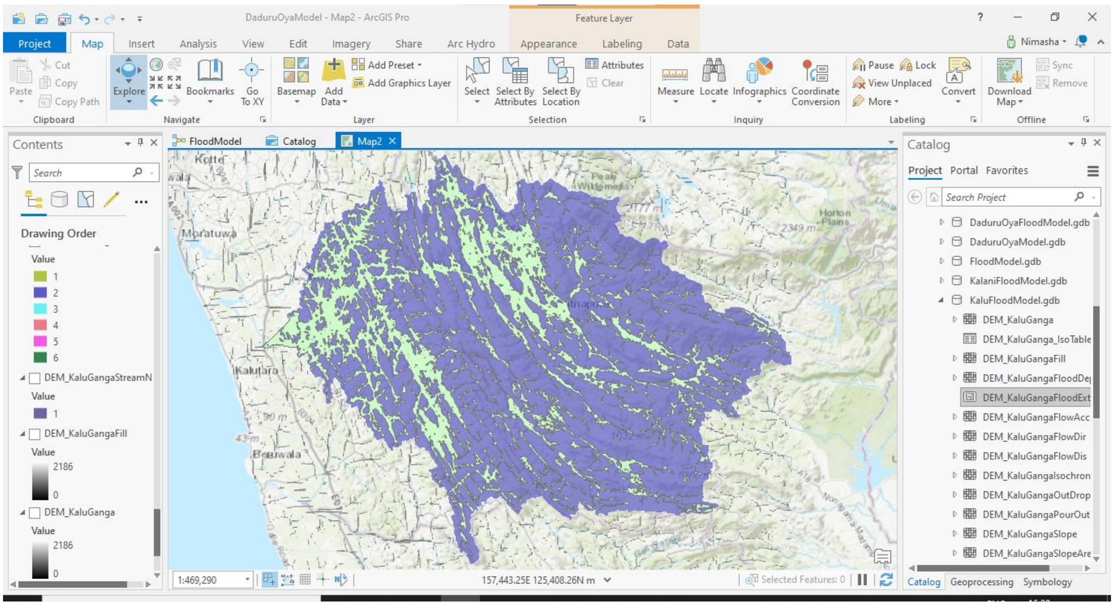
Flood Depth at 3.5m



Flood Extent at 3.5m

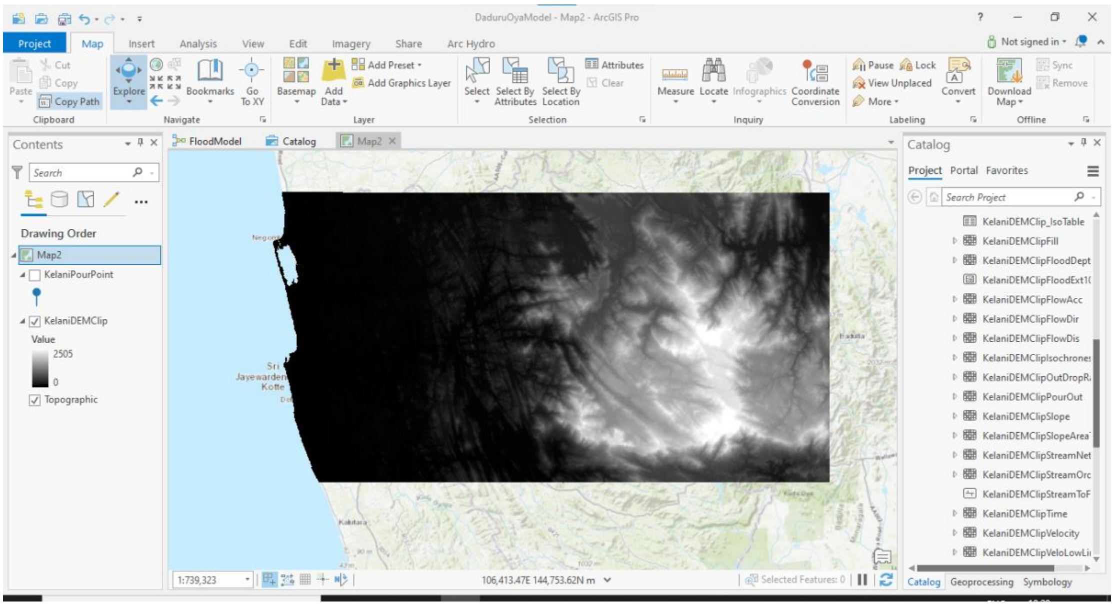


Flood Extent at 10m



Appendix D - Kelani Ganga

DEM



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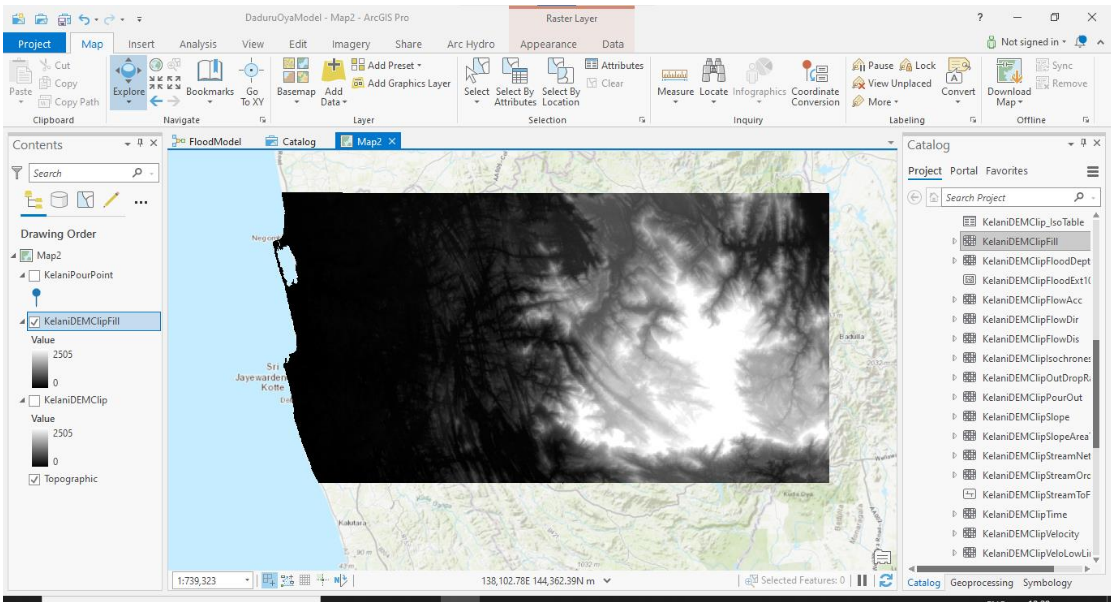

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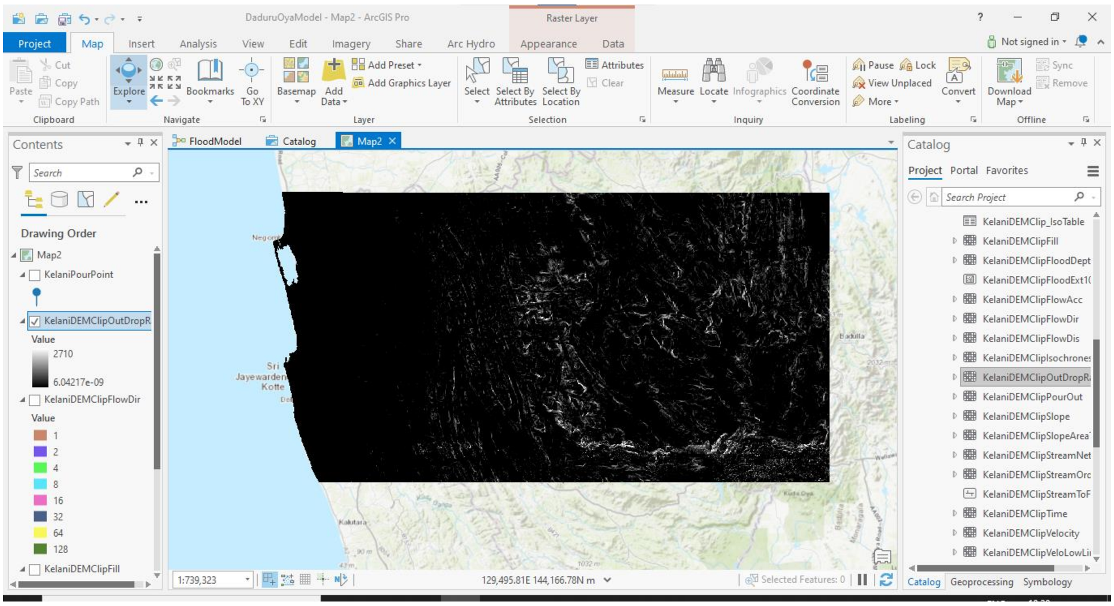
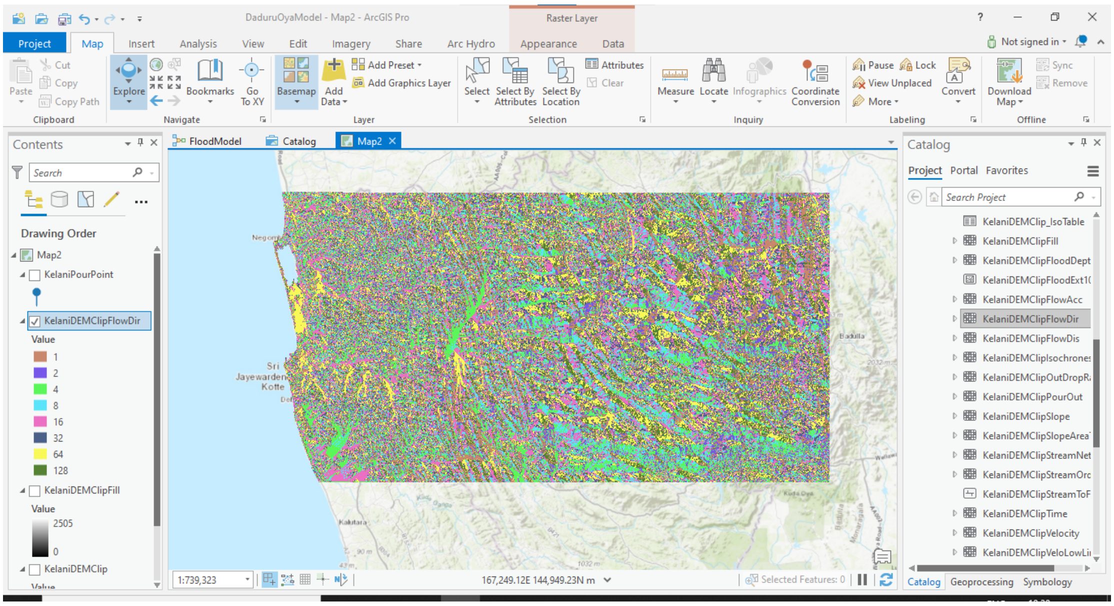
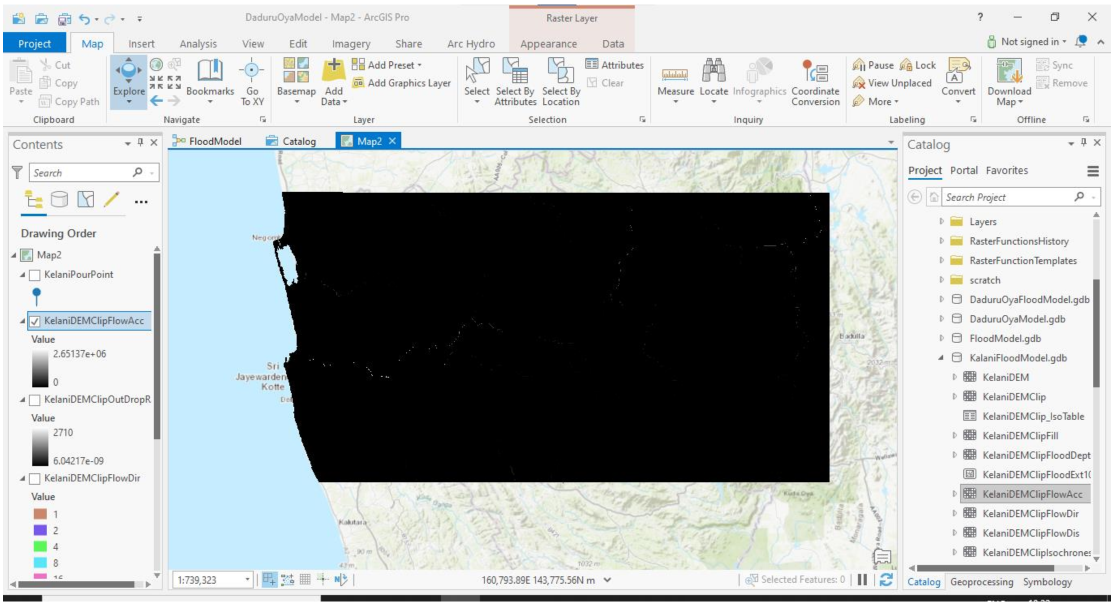


Flow Direction



Flow Accumulation



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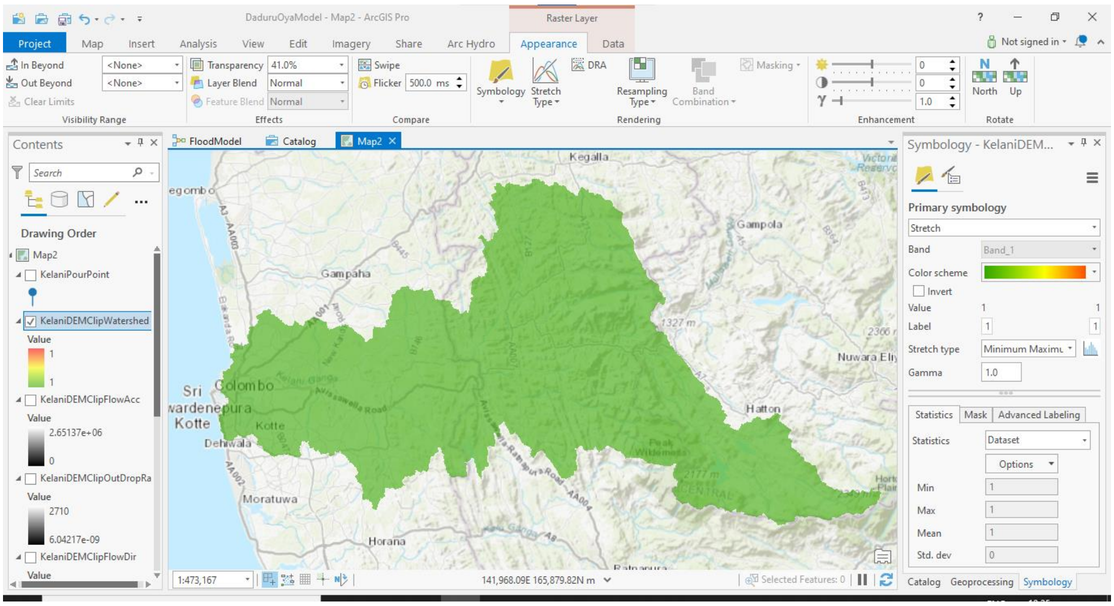

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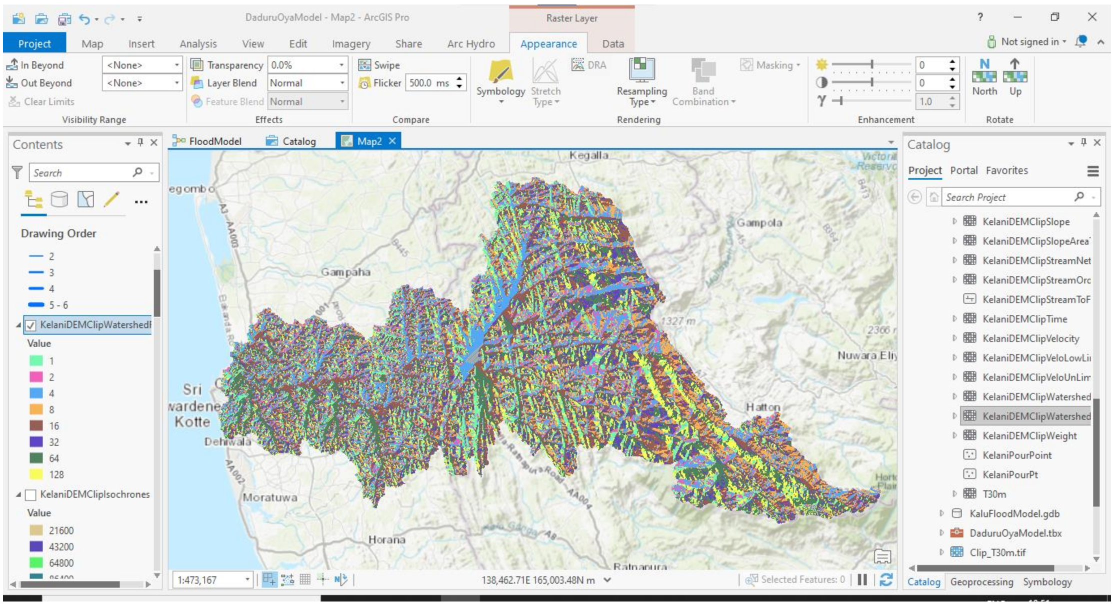

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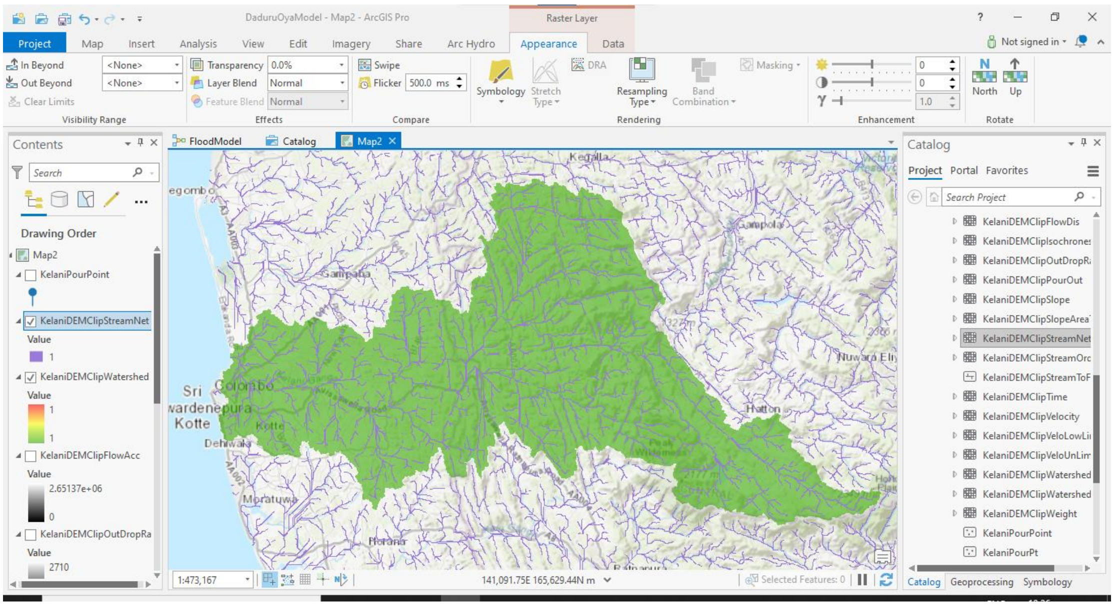

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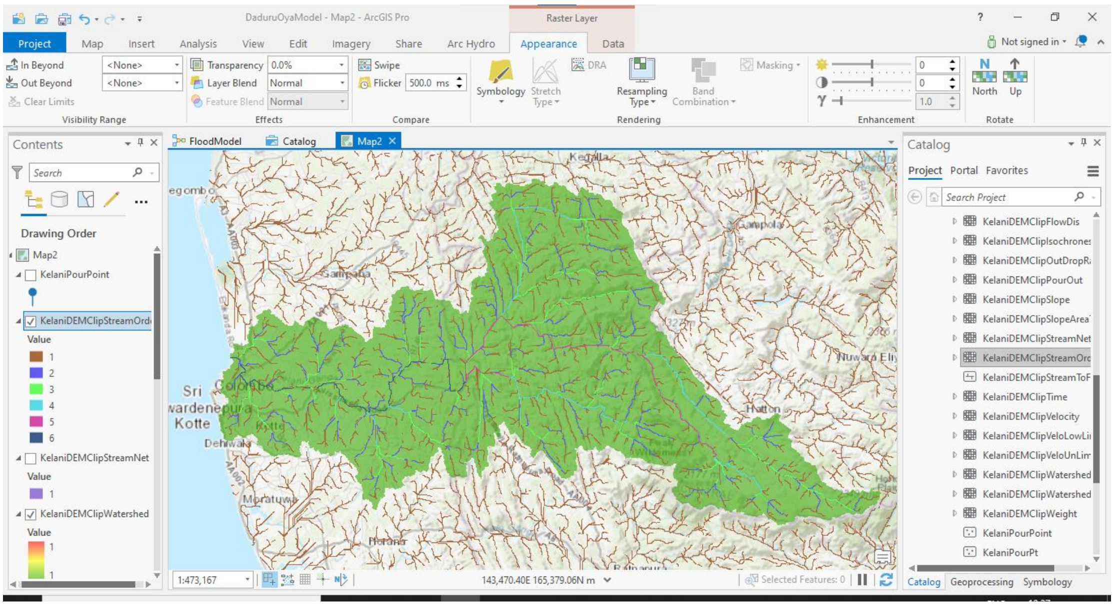
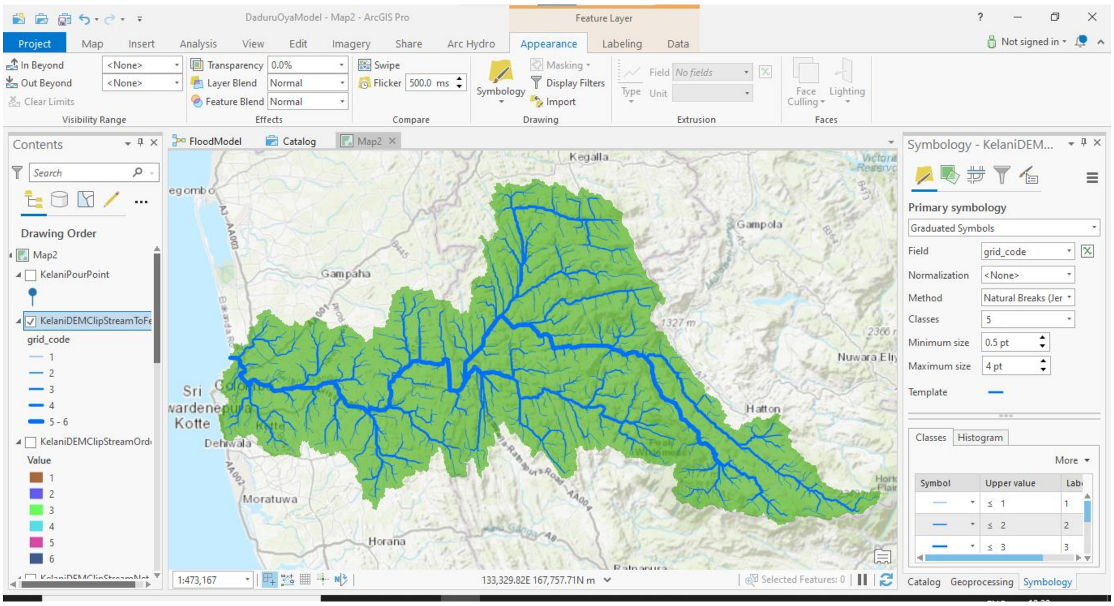


Stream to Feature



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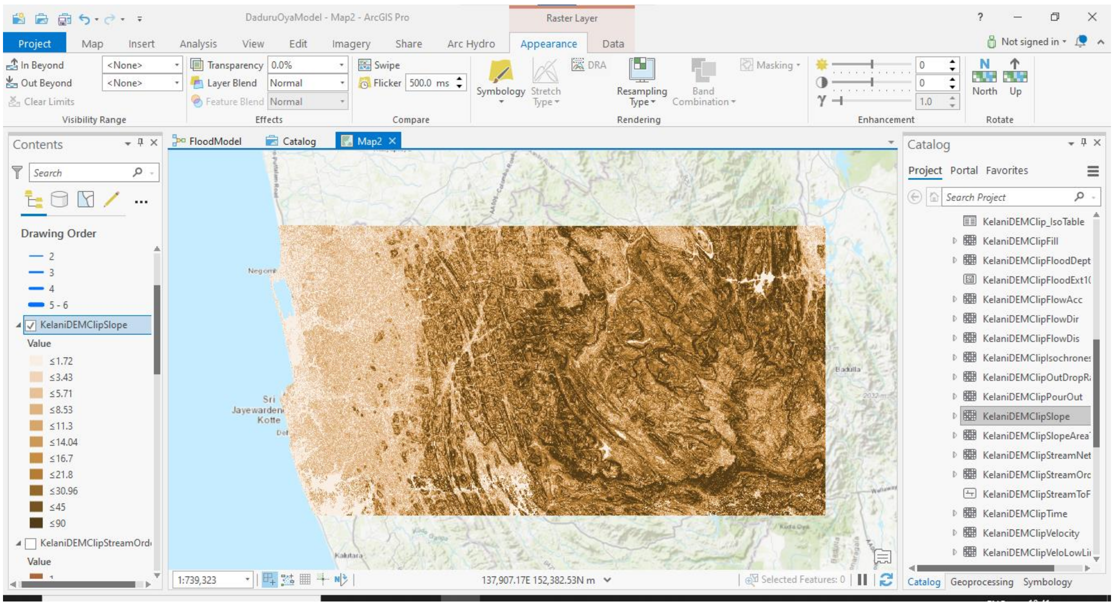

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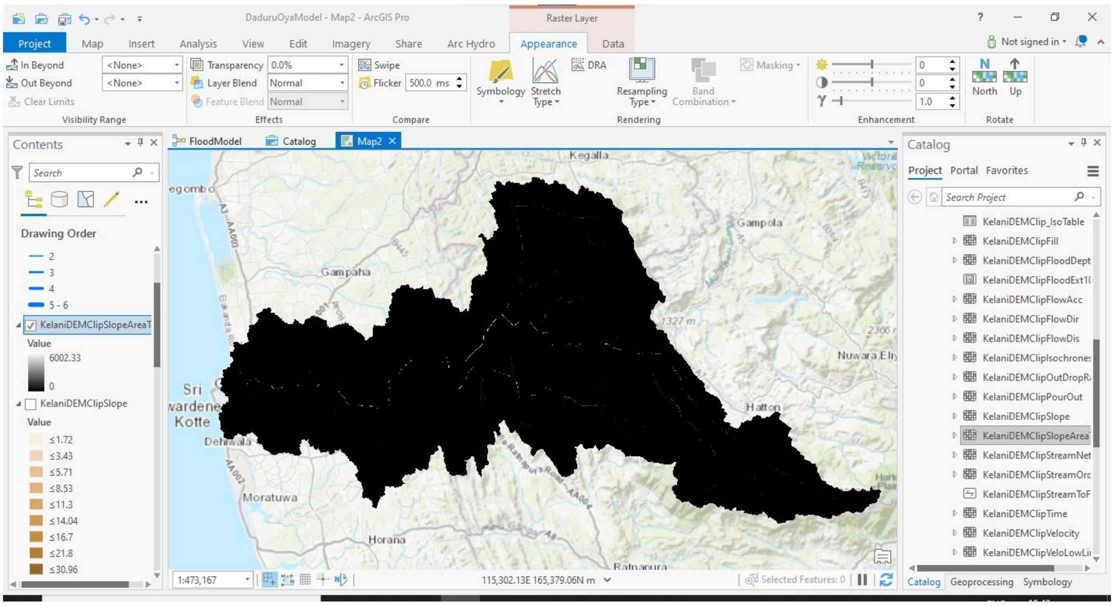
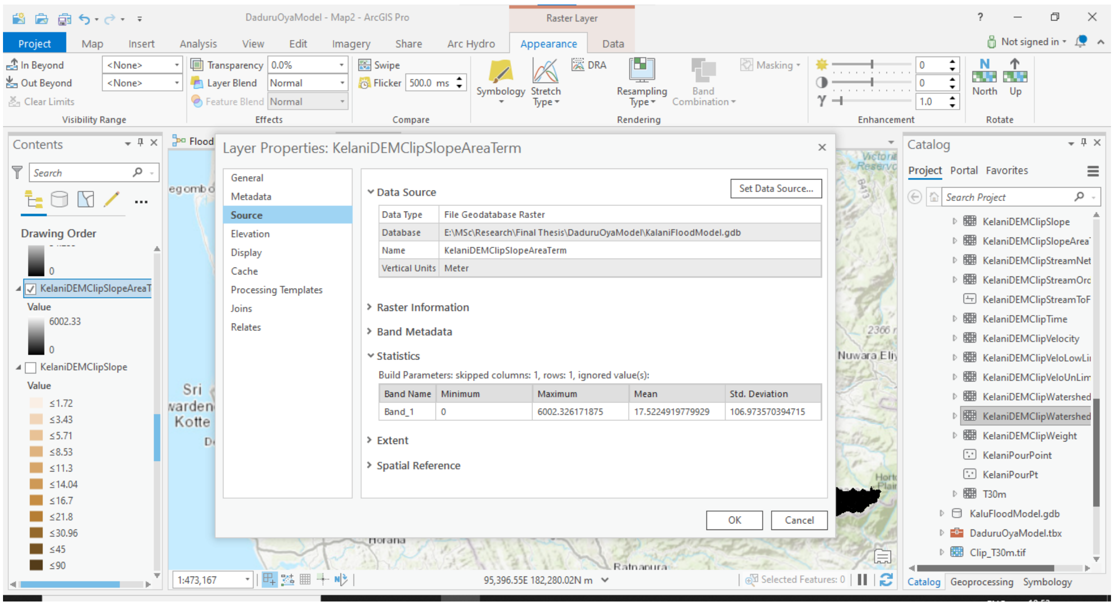
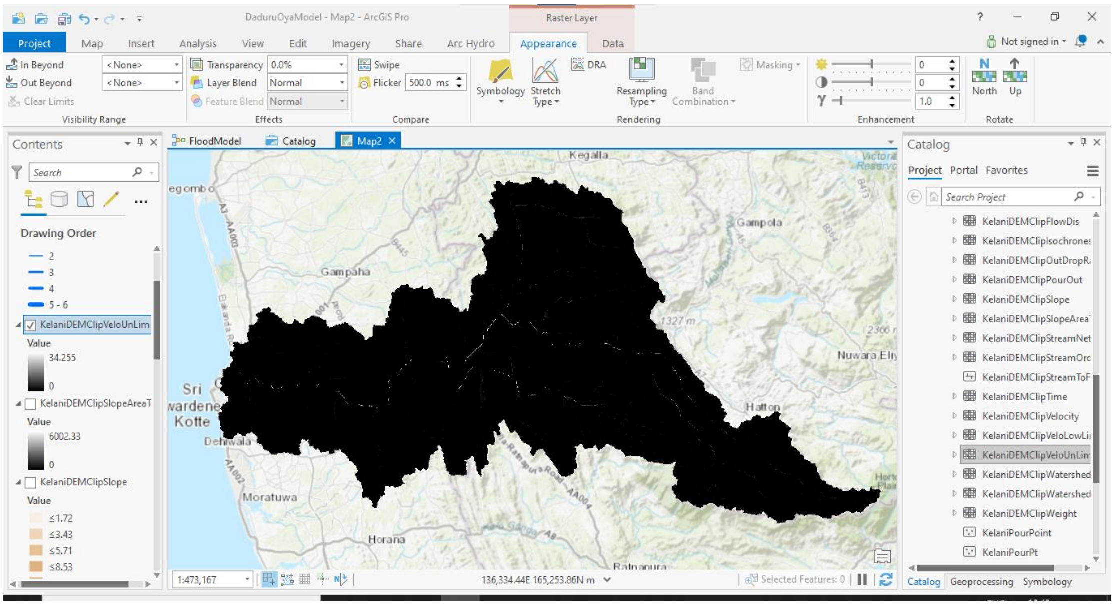


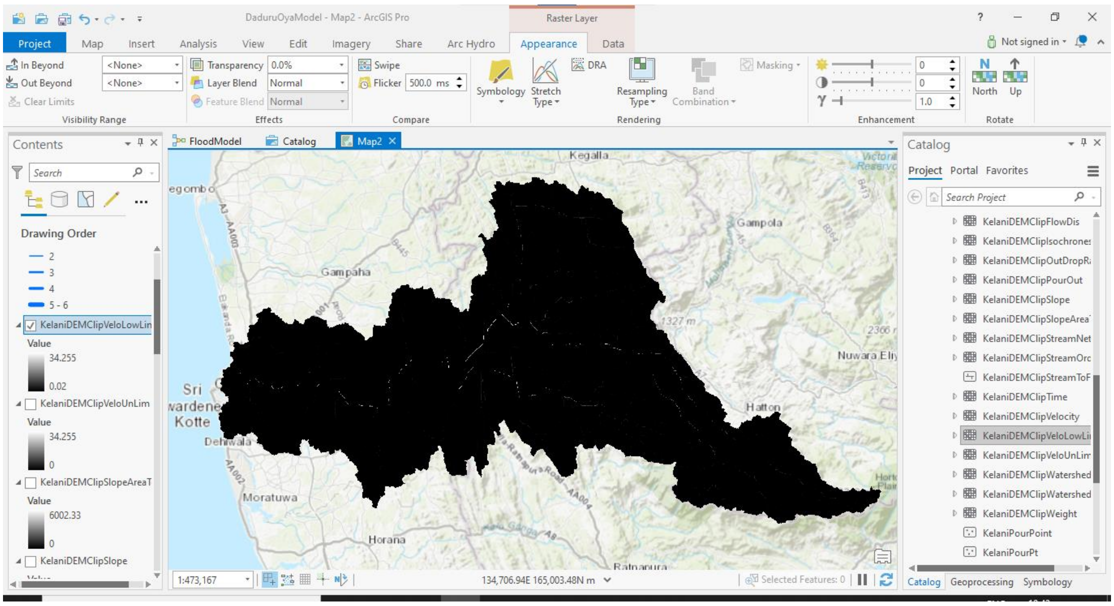
Statistics of Slope Area Term



Velocity Unlimited



Velocity Lower Limited



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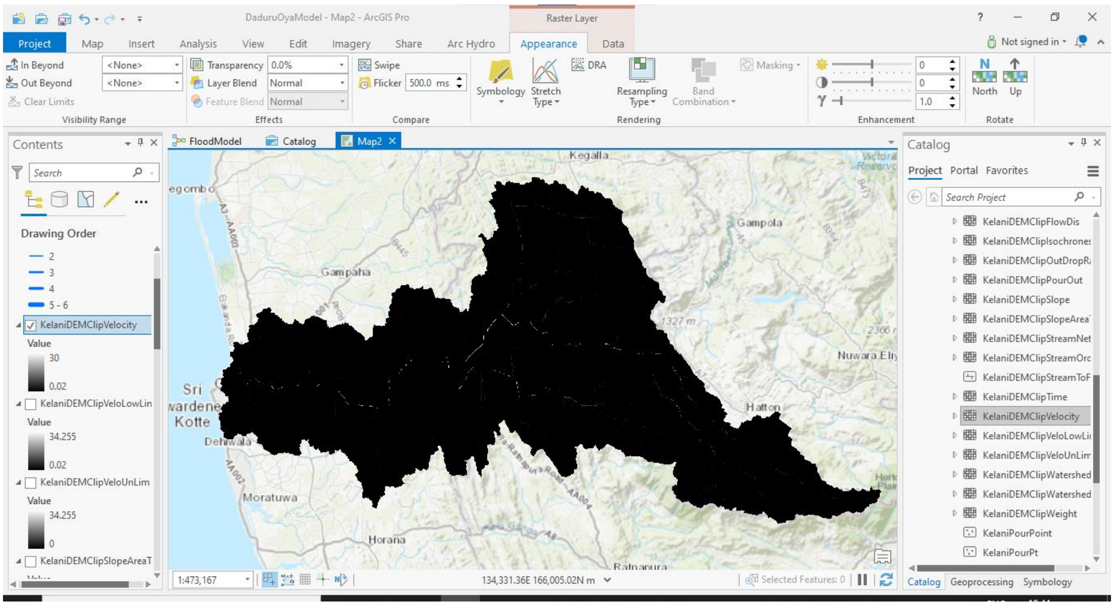

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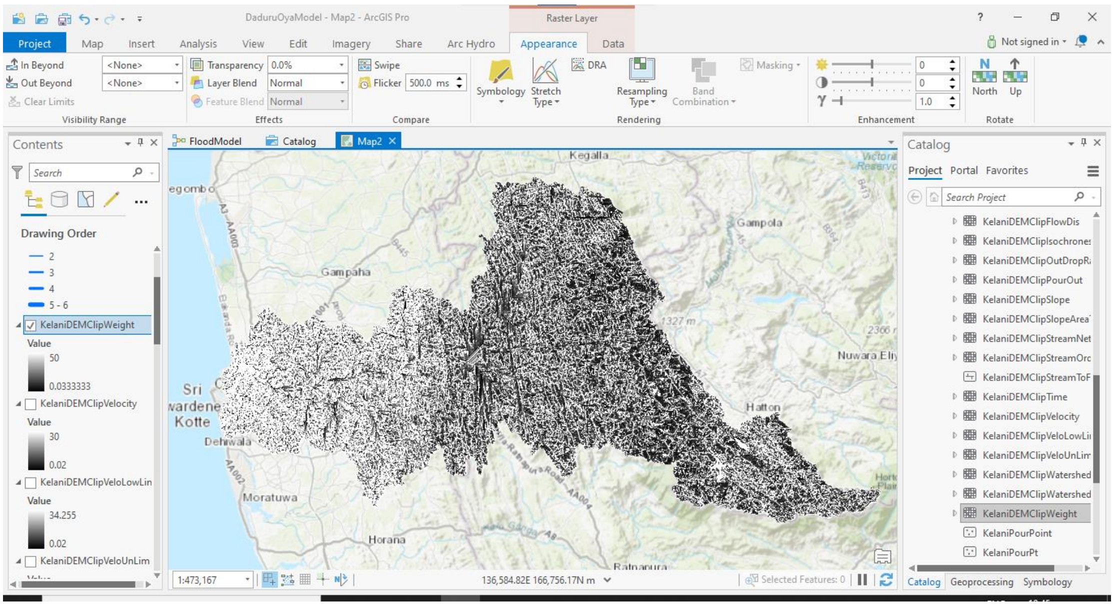

DaduruOyaModel - Map2 - ArcGIS Pro
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Insert
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Edit
Imagery
Share
Arc Hydro
Appearance
Data
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In Beyond
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Transparency
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Effects
Swipe
Flicker
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Compare
Symbology
Stretch Type
DRA
Resampling Type
Band Combination
Masking
Rendering
Enhancement
North
Up
Rotate
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FloodModel
Catalog
Map2
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Moratuwa
Horana
Nuwara Eliy
Hatton
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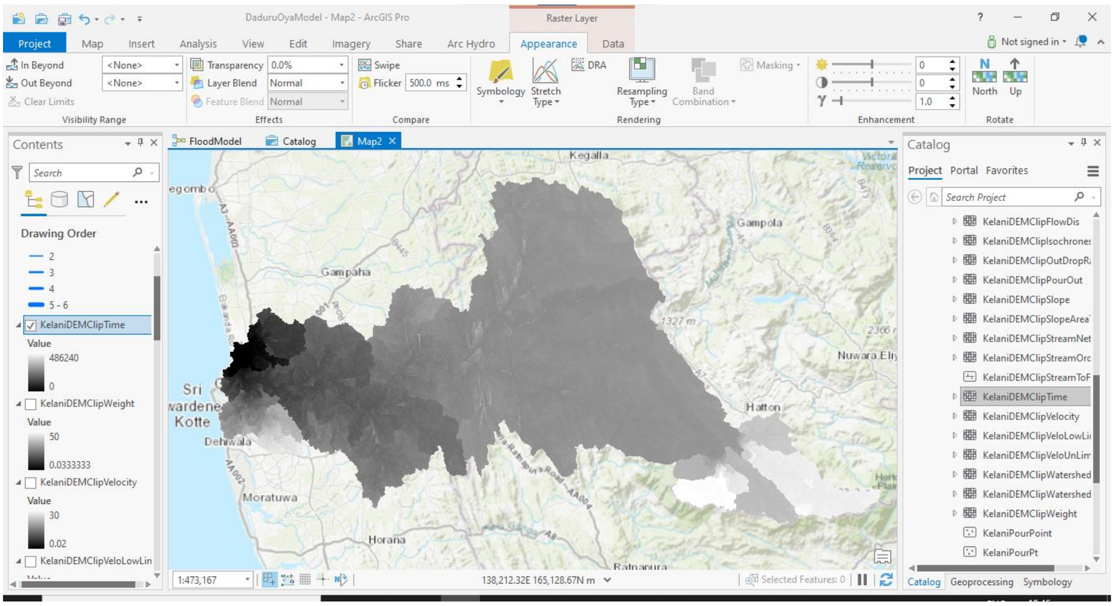

DaduruOyaModel - Map2 - ArcGIS Pro
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Catalog
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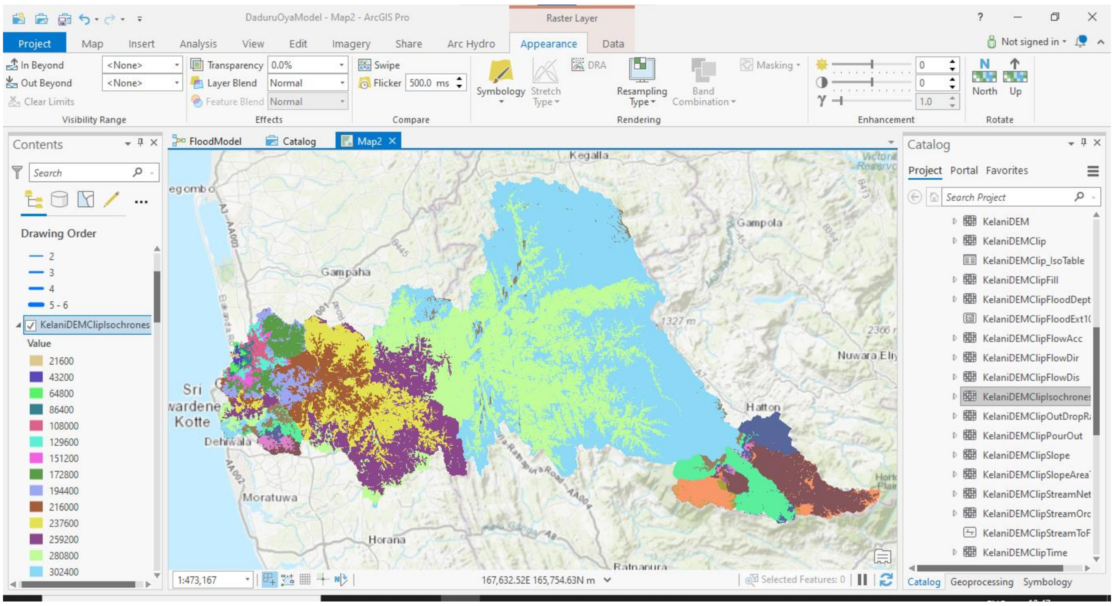
Symbology

Isochrones



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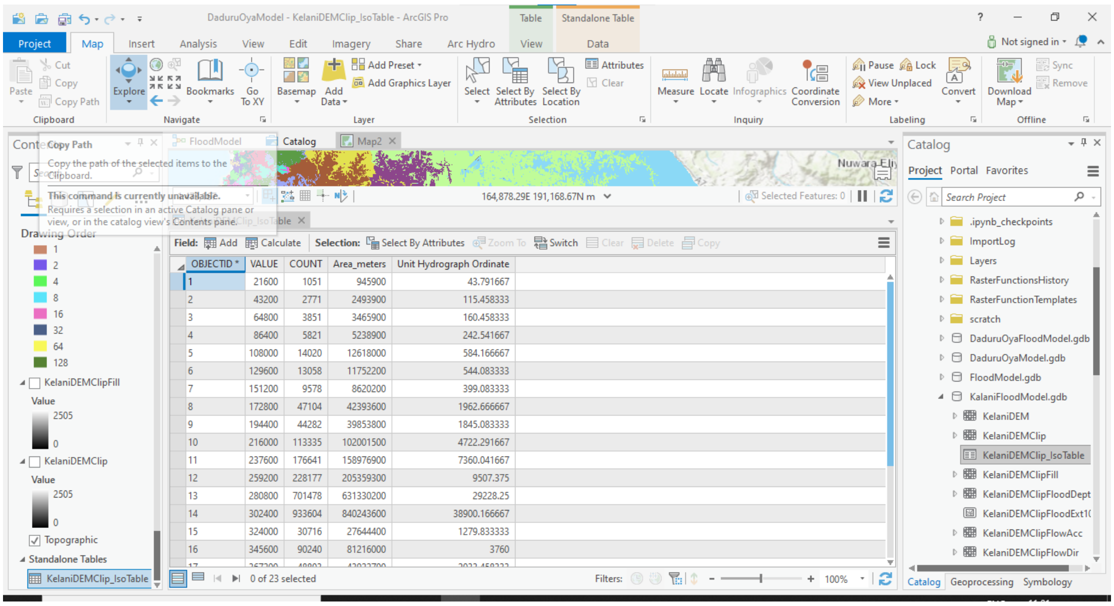

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6	129600	13058	11752200	544.083333
7	151200	9578	8620200	399.083333
8	172800	47104	42393600	1962.666667
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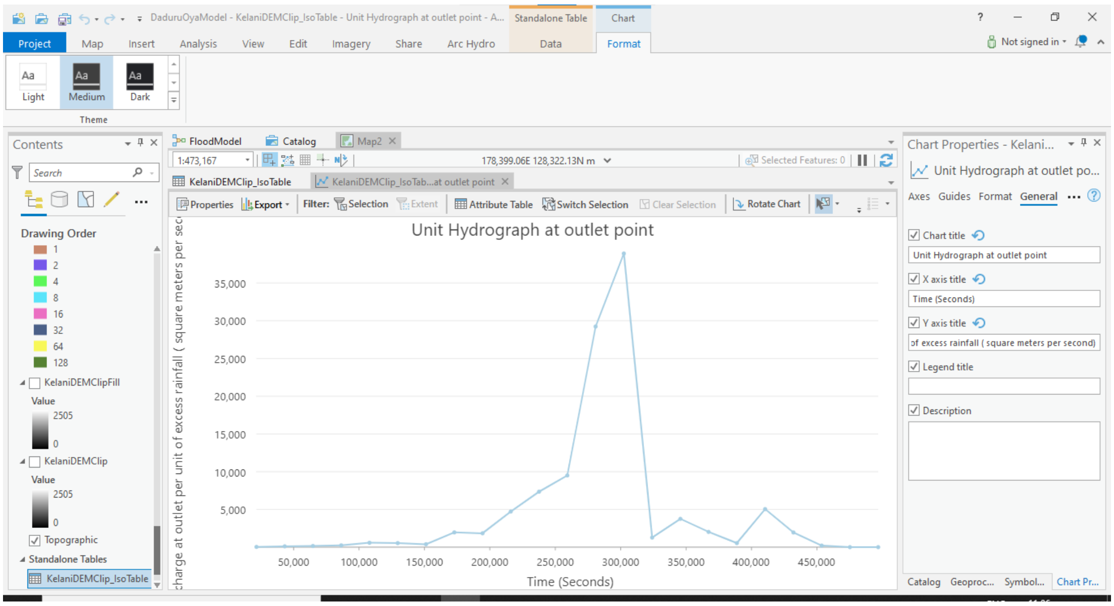
Unit Hydrograph



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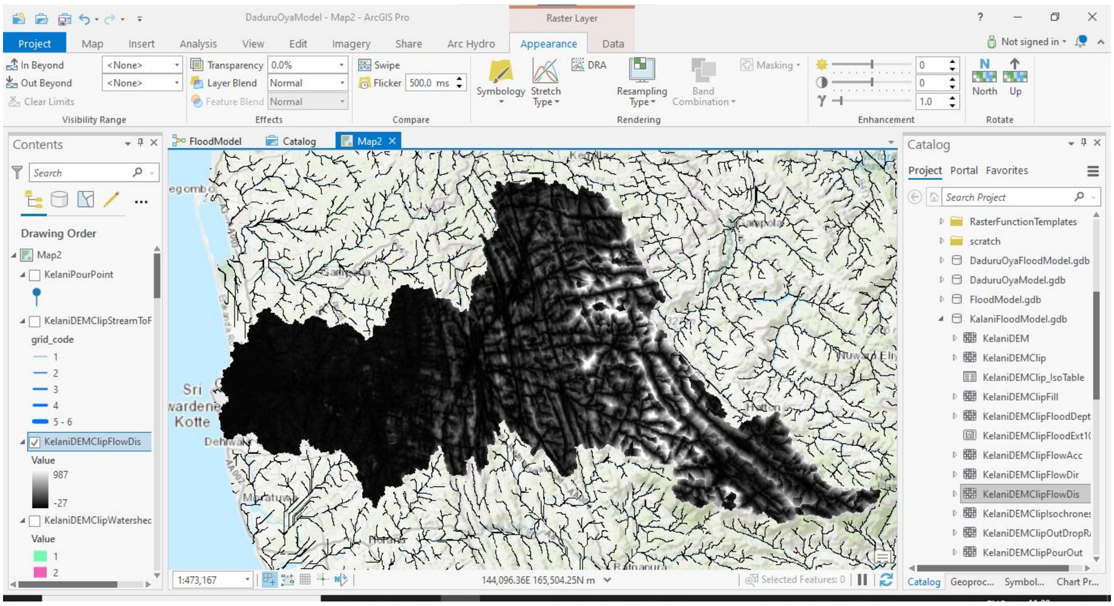
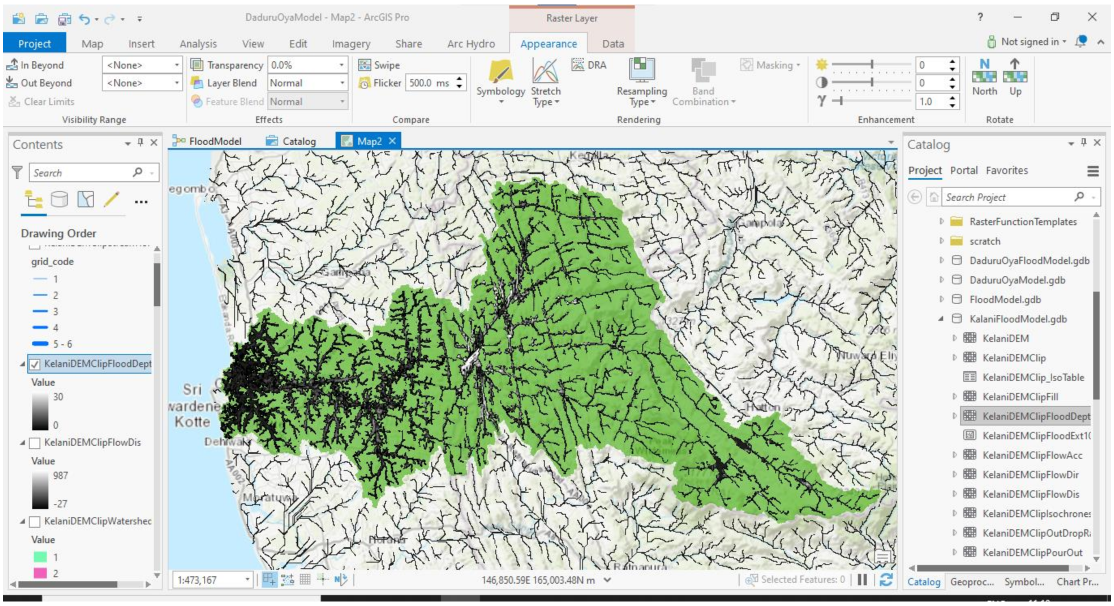
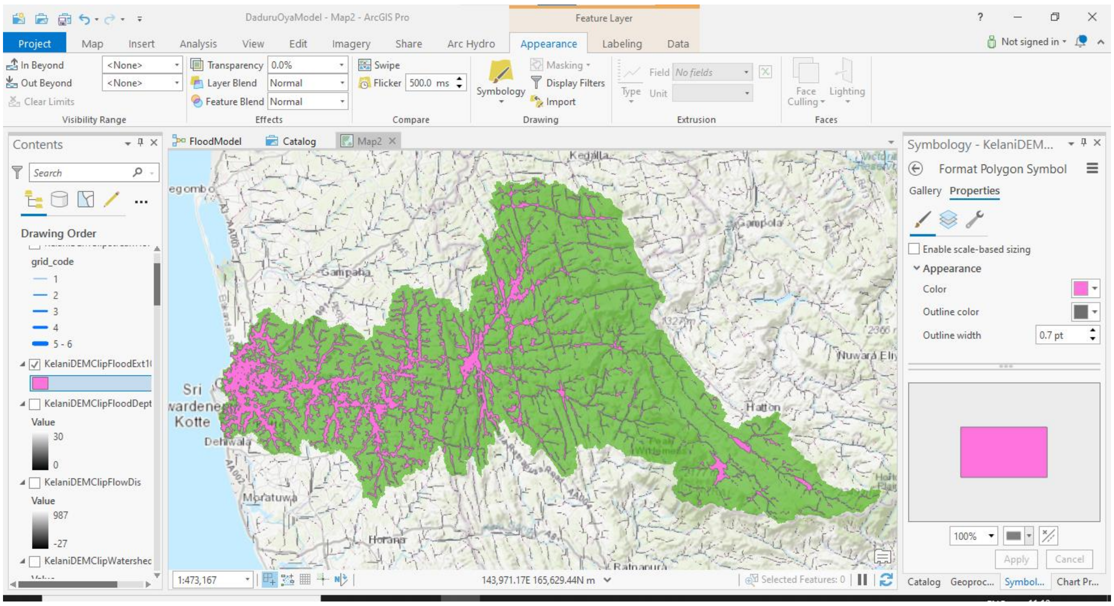


Flood Depth at 10m



Flood Extent at 10m



Appendix E - Python Code of the Model

```
# -*- coding: utf-8 -*-
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Generated by ArcGIS ModelBuilder on : 2021-08-06 16:17:58
"""
import arcpy
from arcpy.sa import *
from sys import argv

def fn(y):
      x=arcpy.GetRasterProperties_management(y, "MEAN")
      z = x.getOutput(0)
      return z


def FloodModel(Output_Filled_DEM=fr"{Path}\{Name}Fill",
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      Output_Watershed=fr"{Path}\{Name}Watershed",
      Output_Velocity_Unlimited=fr"{Path}\{Name}VeloUnLim",
      Output_Stream_Network=fr"{Path}\{Name}StreamNet",
      Output_Watershed_FlowDir=fr"{Path}\{Name}WatershedFlowDir
      ", LowerLimit=0.02,
      Output_Velocity_LowLimited=fr"{Path}\{Name}VeloLowLim",
      Output_Stream_Order=fr"{Path}\{Name}StreamOrder",
      UpperLimit=30, Output_Time=fr"{Path}\{Name}Time",
      Output_Velocity=fr"{Path}\{Name}Velocity",
      Output_Weight=fr"{Path}\{Name}Weight",
      Output_Isochrones=fr"{Path}\{Name}Isochrones",
      Output_Stream_To_Fea=fr"{Path}\{Name}StreamToFea",
      Output_Flow_Distance=fr"{Path}\{Name}FlowDis",
      Output_Flood_Ext10m=fr"{Path}\{Name}FloodExt10m",
      Output_Flood_Depth=fr"{Path}\{Name}FloodDepth",
      FloodModel_gdb=f"{Path}",
      Output_Drop_Ras=fr"{Path}\{Name}OutDropRas",
      FloodModel_KelaniPourPt_Points_="FloodModel KelaniPourPt
      (Points)", DEM="E:\\MSc\\Research\\Final
```

```
    Thesis\\DaduruOyaModel\\KalaniFloodModel.gdb\\KelaniDEMCl
    ip", SnapDistance=60):  # FloodModel

# To allow overwriting outputs change overwriteOutput option
to True.
    arcpy.env.overwriteOutput = False

# Check out any necessary licenses.
    arcpy.CheckOutExtension("spatial")
    arcpy.CheckOutExtension("3D")
    arcpy.CheckOutExtension("ImageAnalyst")
    arcpy.ImportToolbox(r"c:\program
     files\arcgis\pro\Resources\ArcToolbox\toolboxes\Arc_Hydro
     _Tools_Pro.tbx")

# Model Environment settings with
arcpy.EnvManager(outputCoordinateSystem="PROJCS['WGS_1984_Web_
Mercator_Auxiliary_Sphere',GEOGCS['GCS_WGS_1984',DATUM['D_WGS_
1984',SPHEROID['WGS_1984',6378137.0,298.257223563]],PRIMEM['Gr
eenwich',0.0],UNIT['Degree',0.0174532925199433]],PROJECTION['M
ercator_Auxiliary_Sphere'],PARAMETER['False_Easting',0.0],PARA
METER['False_Northing',0.0],PARAMETER['Central_Meridian',0.0],
PARAMETER['Standard_Parallel_1',0.0],PARAMETER['Auxiliary_Sphe
re_Type',0.0],UNIT['Meter',1.0]]",

scratchWorkspace=r"E:\MSc\Research\Final
Thesis\DaduruOyaModel\FloodModel.gdb",

workspace=r"E:\MSc\Research\Final
Thesis\DaduruOyaModel\FloodModel.gdb"):

KelaniPourPoint = "E:\\MSc\\Research\\Final
Thesis\\DaduruOyaModel\\KalaniFloodModel.gdb\\KelaniPourPoint"

FloodDepth = 3

KaluPourPt = "KaluPourPt"

Pour_Pt = "DaduruPourPoint"

Snap_Pour_Point_Input_raster_or_feature_pour_point_data_Points
_ = "Snap Pour Point Input raster or feature pour point data
(Points)"
```

```
# Process: Fill Sinks (Fill Sinks) (archydropro)
        arcpy.archydropro.FillSinks(Input_DEM_Raster=DEM,
        Output_Hydro_DEM_Raster=Output_Filled_DEM,
        Fill_Threshold=None,
        Input_Deranged_Polygon_Feature_Class="",
        Use_IsSink_Field="ISSINK_NO")

# Process: Flow Direction (Flow Direction) (sa)
        Flow_Direction = Output_Flow_Direction
        Output_Flow_Direction =
        arcpy.sa.FlowDirection(in_surface_raster=Output_Filled
        _DEM, force_flow="NORMAL",
        out_drop_raster=Output_Drop_Ras,
        flow_direction_type="D8")
        Output_Flow_Direction.save(Flow_Direction)
        Output_Drop_Ras = arcpy.Raster(Output_Drop_Ras)

# Process: Flow Accumulation (Flow Accumulation) (sa)
        Flow_Accumulation = Output_Flow_Accumulation
        Output_Flow_Accumulation =
        arcpy.sa.FlowAccumulation(in_flow_direction_raster=Out
        put_Flow_Direction, in_weight_raster="",
        data_type="FLOAT", flow_direction_type="D8")
        Output_Flow_Accumulation.save(Flow_Accumulation)

# Process: Snap Pour Point (Snap Pour Point) (sa)
        Snap_Pour_Point = Output_Snap_PourOut
        with arcpy.EnvManager(snapRaster="Daduru_DEM"):
        Output_Snap_PourOut =
        arcpy.sa.SnapPourPoint(in_pour_point_data=KelaniPourPo
        int, in_accumulation_raster=Output_Flow_Accumulation,
        snap_distance=SnapDistance,
        pour_point_field="OBJECTID")
        Output_Snap_PourOut.save(Snap_Pour_Point)

# Process: Watershed (Watershed) (sa)
        Watershed = Output_Watershed
        Output_Watershed =
        arcpy.sa.Watershed(in_flow_direction_raster=Output_Flo
        w_Direction, in_pour_point_data=Output_Snap_PourOut,
        pour_point_field="VALUE")

        Output_Watershed.save(Watershed)
```

```
# Process: Extract by Mask (Extract by Mask) (sa)
        Extract_by_Mask = Output_Watershed_FlowDir
        Output_Watershed_FlowDir =
        arcpy.sa.ExtractByMask(in_raster=Output_Flow_Direction
        , in_mask_data=Output_Watershed)
        Output_Watershed_FlowDir.save(Extract_by_Mask)

# Process: Slope (Slope) (sa)
        Slope = Output_Slope
        Output_Slope = arcpy.sa.Slope(in_raster=DEM,
        output_measurement="PERCENT_RISE", z_factor=1,
        method="PLANAR", z_unit="METER")
        Output_Slope.save(Slope)

# Process: Raster Calculator (Raster Calculator) (sa)
        Raster_Calculator = Output_SlopeAreaTerm
        with arcpy.EnvManager(mask=r"%Path%\%Name%Watershed"):
        Output_SlopeAreaTerm = SquareRoot(Output_Slope) *
        SquareRoot(Output_Flow_Accumulation)
        Output_SlopeAreaTerm.save(Raster_Calculator)

# Process: Calculate Value (Calculate Value) ()
        if Output_SlopeAreaTerm:
            Value = fn("Output_SlopeAreaTerm")

# Process: Raster Calculator (2) (Raster Calculator) (sa)
        Raster_Calculator_2_ = Output_Velocity_Unlimited
        if Output_SlopeAreaTerm:
           with arcpy.EnvManager(mask="%Output_Watershed%"):
           Output_Velocity_Unlimited =  0.1 *
           (Output_SlopeAreaTerm/Value)
           Output_Velocity_Unlimited.save(Raster_Calculator_2_)

# Process: Con (Con) (sa)
        Con = Output_Velocity_LowLimited
        if Output_SlopeAreaTerm:
           Output_Velocity_LowLimited =
           arcpy.sa.Con(in_conditional_raster=Output_Velocity_U
           nlimited,
           in_true_raster_or_constant=Output_Velocity_Unlimited
           , in_false_raster_or_constant=LowerLimit,
           where_clause=f"VALUE >= {LowerLimit}")
           Output_Velocity_LowLimited.save(Con)
```

```
# Process: Con (2) (Con) (sa)
        Con_2_ = Output_Velocity
        if Output_SlopeAreaTerm:
           Output_Velocity =
           arcpy.sa.Con(in_conditional_raster=Output_Velocity_L
           owLimited,
           in_true_raster_or_constant=Output_Velocity_LowLimite
           d, in_false_raster_or_constant=UpperLimit,
           where_clause=f"VALUE < {UpperLimit}")
           Output_Velocity.save(Con_2_)

# Process: Raster Calculator (3) (Raster Calculator) (sa)
        Raster_Calculator_3_ = Output_Weight
        if Output_SlopeAreaTerm:
            Output_Weight = 1/ Output_Velocity
            Output_Weight.save(Raster_Calculator_3_)

# Process: Flow Length (Flow Length) (sa)
        Flow_Length = Output_Time
        if Output_SlopeAreaTerm:
           Output_Time =
           arcpy.sa.FlowLength(in_flow_direction_raster=Output_
           Watershed_FlowDir,
           direction_measurement="DOWNSTREAM",
           in_weight_raster=Output_Weight)
           Output_Time.save(Flow_Length)

# Process: Reclassify (Reclassify) (sa)
        Reclassify = Output_Isochrones
        if Output_SlopeAreaTerm:
            Output_Isochrones =
arcpy.sa.Reclassify(in_raster=Output_Time,
reclass_field="VALUE", remap="0 21600 21600;21600 43200
43200;43200 64800 64800;64800 86400 86400;86400 108000
108000;108000 129600 129600;129600 151200 151200;151200 172800
172800;172800 194400 194400;194400 216000 216000;216000 237600
237600;237600 259200 259200;259200 280800 280800;280800 302400
302400;302400 324000 324000;324000 345600 345600;345600 367200
367200;367200 388800 388800;388800 410400 410400;410400 432000
432000;432000 453600 453600;453600 475200 475200;475200 496800
496800;496800 518400 518400;518400 540000 540000;540000 561600
561600;561600 583200 583200;583200 604800 604800;604800 626400
626400;626400 648000 648000;648000 669600 669600;669600 691200
```

```
691200;691200 712800 712800;712800 734400 734400;734400 756000
756000;756000 777600 777600;777600 799200 799200;799200 820800
820800;820800 842400 842400;842400 864000 864000;864000 885600
885600;885600 907200 907200;907200 928800 928800;928800 950400
950400;950400 972000 972000;972000 993600 993600;993600
1015200 1015200;1015200 1036800 1036800",
missing_values="DATA")
            Output_Isochrones.save(Reclassify)

# Process: Table To Table (Table To Table) (conversion)
        if Output_SlopeAreaTerm:
            Output_IsoTable =
arcpy.conversion.TableToTable(in_rows=Output_Isochrones,
out_path=FloodModel_gdb, out_name=f"{Name}_IsoTable",
where_clause="", field_mapping=fr"VALUE \"VALUE\" false true
true 0 Long 0 0,First,#,{Path}\{Name}Isochrones,VALUE,-1,-
1;COUNT \"COUNT\" false true true 0 Long 0
0,First,#,{Path}\{Name}Isochrones,COUNT,-1,-1",
config_keyword="")[0]

# Process: Add Field (Add Field) (management)
        if Output_SlopeAreaTerm:
            Output_IsoTable_2_ =
arcpy.management.AddField(in_table=Output_IsoTable,
field_name="Area_meters", field_type="DOUBLE",
field_precision=None, field_scale=None, field_length=None,
field_alias="", field_is_nullable="NULLABLE",
field_is_required="NON_REQUIRED", field_domain="")[0]

# Process: Calculate Field (Calculate Field) (management)
        if Output_SlopeAreaTerm:
            Output_IsoTable_3_ =
arcpy.management.CalculateField(in_table=Output_IsoTable_2_,
field="Area_meters", expression="!Count! * 30 * 30",
expression_type="PYTHON3", code_block="",
field_type="TEXT")[0]

# Process: Add Field (2) (Add Field) (management)
        if Output_SlopeAreaTerm:
            Output_IsoTable_4_ =
arcpy.management.AddField(in_table=Output_IsoTable_2_,
field_name="UH_ordinate", field_type="DOUBLE",
field_precision=None, field_scale=None, field_length=None,
```

```
field_alias="Unit Hydrograph Ordinate",
field_is_nullable="NULLABLE",
field_is_required="NON_REQUIRED", field_domain="")[0]

# Process: Calculate Field (2) (Calculate Field) (management)
        if Output_SlopeAreaTerm:
            Output_IsoTable_5_ =
arcpy.management.CalculateField(in_table=Output_IsoTable_4_,
field="UH_ordinate", expression="!Area_meters! / 21600",
expression_type="PYTHON3", code_block="",
field_type="TEXT")[0]

# Process: Raster Calculator (4) (Raster Calculator) (sa)
        Raster_Calculator_4_ = Output_Stream_Network
        Output_Stream_Network =
        Con(Output_Flow_Accumulation>1000, 1)
        Output_Stream_Network.save(Raster_Calculator_4_)

# Process: Stream Order (Stream Order) (sa)
        Stream_Order = Output_Stream_Order
        Output_Stream_Order =
        arcpy.sa.StreamOrder(in_stream_raster=Output_Stream_Ne
        twork,
        in_flow_direction_raster=Output_Watershed_FlowDir,
        order_method="STRAHLER")
        Output_Stream_Order.save(Stream_Order)

# Process: Stream to Feature (Stream to Feature) (sa)

arcpy.sa.StreamToFeature(in_stream_raster=Output_Stream_Order,
in_flow_direction_raster=Output_Watershed_FlowDir,
out_polyline_features=Output_Stream_To_Fea,
simplify="SIMPLIFY")

# Process: Flow Distance (Flow Distance) (sa)
        Flow_Distance = Output_Flow_Distance
        Output_Flow_Distance =
arcpy.sa.FlowDistance(in_stream_raster=Output_Stream_Network,
in_surface_raster=DEM,
in_flow_direction_raster=Output_Watershed_FlowDir,
distance_type="VERTICAL", flow_direction_type="D8",
statistics_type="MINIMUM")
        Output_Flow_Distance.save(Flow_Distance)
```

```
# Process: Define HAND-based Flood Depth and Extent (Define
HAND-based Flood Depth and Extent) (archydropro)

arcpy.archydropro.DefineHANDbasedflooddepthandextent(Input_HAN
D_Raster=Output_Flow_Distance, Input_Flood_Depth=FloodDepth,
Output_Flood_Depth_Raster=Output_Flood_Depth,
Output_Flood_Extent_Polygon=Output_Flood_Ext10m)
        Output_Flood_Depth = arcpy.Raster(Output_Flood_Depth)

# Process: Parse Path (Parse Path) (mb)
        Path, Name, Extension, Workspace_Name =
arcpy.mb.ParsePathExt(in_data_element=DEM,
format="NOT_FORMAT")

        return Output_IsoTable, Output_IsoTable_2_,
Output_IsoTable_3_, Output_IsoTable_4_, Output_IsoTable_5_

if __name__ == '__main__':
    FloodModel(*argv[1:])
```

Appendix F - PRISMA Statement