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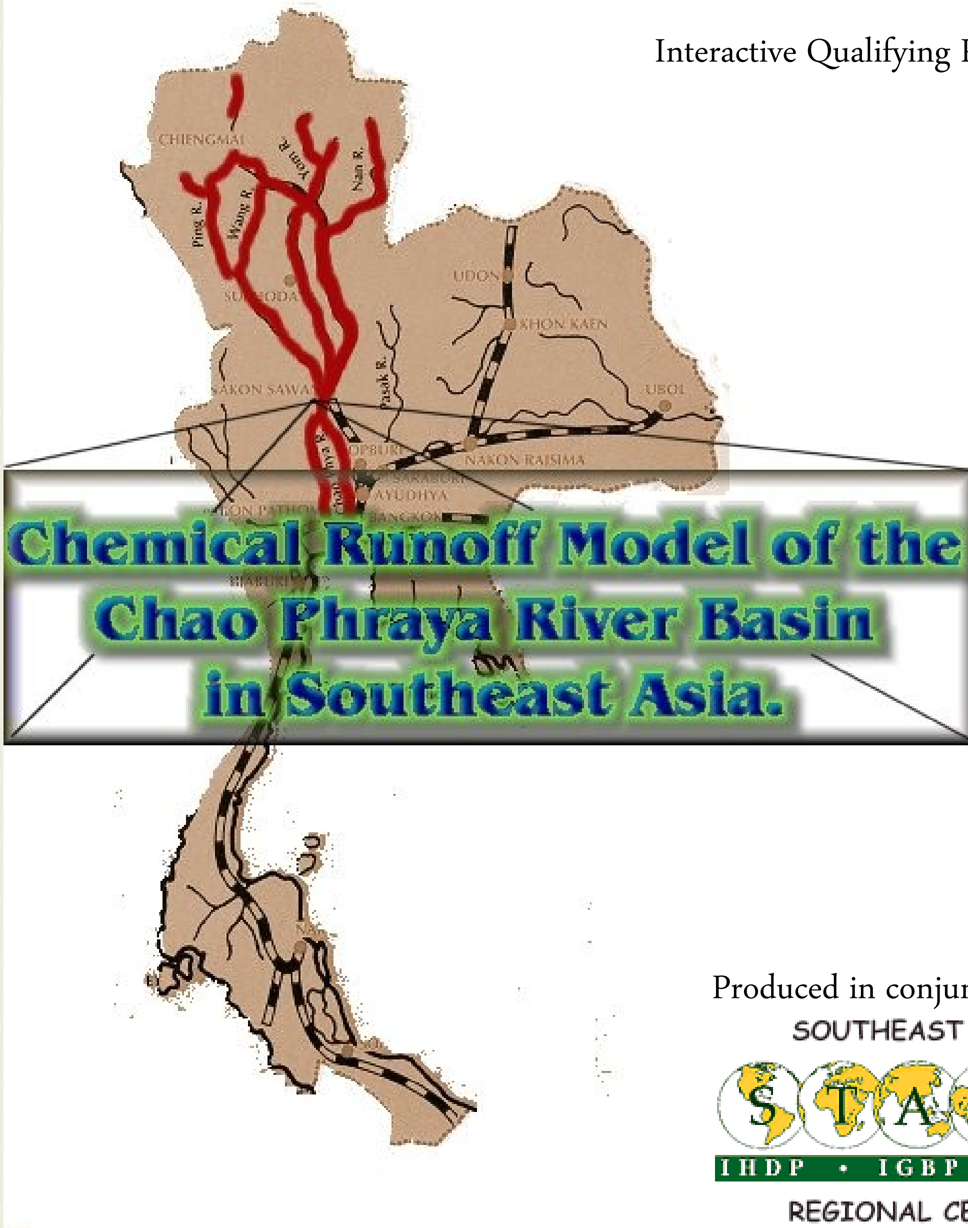
WPI

Interactive Qualifying Project



Chemical Runoff Model of the Chao Phraya River Basin in Southeast Asia.

Produced in conjunction with

SOUTHEAST ASIA START
IHDP • IGBP • WCRP
REGIONAL CENTRE

located at the Environmental Research Institute,

Chulalongkorn University

Bangkok, Thailand 2000

Project Number: KAL0002

Chemical Runoff Model of the Chao Phraya River Basin in Southeast Asia

An Interactive Qualifying Project Report

Submitted to the Faculty of

WORCESTER POLYTECHNIC INSTITUTE

In partial fulfillment of the requirements for the

Degree of Bachelor of Science

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THE CHAO PHRAYA RIVER BASIN TEAM 2000

Authorship

Each sentence has been reworded and worked countless times by all three members; each paragraph is composed of sentences from each author; and each section is an eclectic collection of paragraphs. Conclusively, we are only able to say that there is equal authorship throughout the paper.

Abstract

Scientists have become increasingly more aware of the toll that the industrial use of rivers has on wildlife and human cultures. With the advent of Geographic Information Systems, there has been a new and detailed understanding of how both introduced pollutants and natural attributes in the environment change the life cycles of plants and animals. This project, completed at the Southeast Asia Systems for Analysis, Research, and Training Regional Center, in Bangkok, Thailand, created a more focused and accessible model of the Chao Phraya River Basin. The two goals of this project are to create a model which will show correlations between human use of the river and its pollutant concentrations, and to make our model more available to the scientific community.

Executive Summary

Thailand is a developing nation with a growing population which has resulted in a steadily increasing pollution problem. The cause of this pollution increase is the accelerating factory production levels and the developing of new environmentally unfriendly technologies. The ecosystem in and around the Chao Phraya River is severely impacted by this, which is harmful to all surrounding life. The need for healthy aquatic life can be directly seen when humans consume fish containing pollutants from the river, or indirectly when fishing industries crash because of fish scarcity. All organisms in the Chao Phraya River Basin feel the result of a polluted and poorly functioning river system. The river's pollution levels have increased a great deal during the last 20 years, and this degradation of the river has its effects on the people.

Scientists have a powerful tool which enables them to make simplified models of water and land environments. This computer technology is called Geographic Information Systems (GIS). It allows researchers to create basic models of chemical and water properties of rivers, lakes, and oceans.

This project's ultimate goal was to make a model of the pollution in the Chao Phraya River Basin. It was completed at the Southeast Asia System for Analysis, Research, and Training Regional Center, (SEA START RC), which is a non-profit organization committed to monitoring the environment. SEA START RC gathers data about the environment and human interactions affecting it.

Using SEA START's precollected data, we prepared and built a model called NAGA 2.1 to predict the chemical changes for one year in the Chao Phraya River Basin. Comparing the results of NAGA 2.1 to the latest sampled data, we correlated possible cause-and-effect relationships between humans and the environment through a map in ArcView. This map

visually displayed the concentration of pH, BOD, COD, and alkalinity in different portions of the river.

This was the first SEA START model to analyze chemical pollution changes in the environment. We were pleased to find that several of the predictions were corroborated by the actual data even though the model is still in its pre-development stage.

This project increased our awareness of the pollution problem of the Chao Phraya River, and an understanding of modeling techniques used to display this data. Our model incorporated only a select number of pollution indicators, so an expansion of it can be performed. The expansion of this project has the potential to become a countrywide model of pollution of rivers in all of Thailand. In essence, this project is a small step to analyze worldwide pollution problems.

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Chapter 1: Introduction

Introduction

In this age of rapid technological advancements and population growth, humans are beginning to severely impact their environment as shown by the adverse effects that can be seen in plants and animals. This is only one sign that the natural habitat and intricate food webs are crumbling. Until recently, these indicating effects had gone unnoticed.

Industries have affected Thailand's river basins by overfishing, damming, and polluting. Thailand is a developing nation whose population has been increasing drastically. As with any country, pollution levels have also steadily risen [Cummings, 1997]. Pollutants have been discharged directly into rivers, or carried in storm runoff making their way to streams and lakes. These contaminants directly affect one or many organisms in the aquatic systems dramatically changing their life cycles. Each species is intricately connected in a cycle of predator and prey, relying on other organisms for food. When one animal or plant becomes unable to uphold its commitment, each organism within that system experiences a negative effect.

This project focused on specific pollutants in the Chao Phraya River and their effects on the people who rely on it. The Chao Phraya River flows down the middle of Thailand, through Bangkok and into the Gulf of Thailand. Fourteen million people in the Central Plains of Thailand rely on the Chao Phraya River for a variety of reasons. The farming regions depend on the river to flood during the yearly rainy season and bring nutrients to their fields. Fishermen depend on the fish in the river for their income. The inhabitants of Bangkok rely on the river for transportation, entertainment, and electricity.

As cities grow, so do the wastes generated, and with these increases there is a greater demand for its disposal. The Chao Phraya River has been an easy means for this waste disposal for many years. In some regions, it is common practice for waste to be piped or dumped directly into the water. If these practices continue, the river will no longer be able to support aquatic life.

For our project we built a model of how pollutants affect the Chao Phraya River Basin and the life within it, using Geographic Information Systems (GIS) computer programs, ArcInfo and ArcView. This model will give a clearer understanding to the problems that face Thais and the Chao Phraya River. This project will be performed at the SEA START Regional Center and will involve testing water clarity by measuring the river's Chemical Oxygen Demand, Biochemical Oxygen Demand, pH, and alkalinity. A trip to the Chao Phraya River was taken to obtain data so a comparison could be made between the model's predictions and averaged chemical data from previous years. By understanding trends in chemical concentrations from year to year we were able to offer insight into the seriousness of the pollution.

Chapter 2:
Literature Review

Literature Review

This chapter contains background information on the Chao Phraya River, water hydrology, river basins, human impact on rivers, Geographic Information Systems, and pollutants that affect the river. The Chao Phraya River is Thailand's most valuable river; its cleanliness, and ecological health will shape the welfare and economy of the generation to come.

2.1 Chao Phraya River

The Chao Phraya River runs the length of Thailand, flowing through Bangkok, and then emptying into the Gulf of Thailand. It is formed by the confluence of the Nan and Ping rivers at Nakhon Swan. Its basin is the largest and most important geographical landmass, occupying thirty-five percent of Thailand. It supplies water to nine rice farming regions, fish for food, and fertile soil for farming from the yearly flooding.

Three regions common to all rivers are the upper reach, the middle reach, and the lower reach. The upper reach of the Chao Phraya River lies in the mountainous regions of Northern Thailand. The river runs through the well-forested mountains and to the valleys, which are sites for rice farming. The middle reach is flatter, composed of a flood plain bordered by foothills. A *floodplain* is a depressed belt between ten to twenty kilometers in width that runs adjacent to the river. The belt gives a clear visual representation of how far the river floods each year during the monsoon season. The lower reach is where the river is the widest, yet the slowest. This part of the river is where the densest population of Thailand lives; it is also the most industrialized area. The river delta is located at the end of the lower reach where the river flows into the Gulf of Thailand [Takaya, 1987].

Literature Review

Water cycling in the Chao Phraya River follows two paths, one through the rice paddies and the other through the industrial regions. In the northern region, the river is used to irrigate rice, cassava, and other crops. The water is either removed directly from the river or from reservoirs. The water is cycled through the rice paddies and into the ground through percolation. In the southern regions the water is withdrawn directly for municipal and industrial use. The water is then returned downstream, however the chemical composition is largely altered [Richey, 1998].

Figure 2.1: Chao Phraya River at Saphan Taksin in Bangkok

The Chao Phraya River is highly polluted and each year it becomes worse. The lower reach, which is the most industrialized, has a very high level of domestic waste. There are high concentrations of *coliform* bacteria, which feed on human and animal waste. The middle reach is much less industrialized and therefore less polluted. However, there is a relatively high level of domestic waste, but the concentrations of coliform bacteria are much lower. The upper region, which consists primarily of rice paddies, has the lowest level of domestic waste but twice as much coliform bacteria as the middle region. Excess fertilizer is carried to the river as runoff. Once there, coliform bacteria begins to flourish. In all regions, waste is readily disposed of into the river with little thought about the possible consequences. Not only is the river affected where waste is dumped into it, but for miles downstream [Snidvongs, 1996].

2.2 Human Factors Influencing River Basins

Rivers are the link between the precipitation that falls in the river basin area and the ocean where water is evaporated. Rivers provide water for vegetation and allow for dense forest and intricate food chains in areas where there are no large bodies of water. River Basins have developed complex ecological structures where life would not have been possible. Rivers have also enabled cities to be formed inland and have provided humans with mechanical and hydroelectric power, food, and an easy way to dispose of the waste generated in cites.

2.2.1 The Development of Cities

Throughout history, cities have always flourished along rivers. The Nile, the Ganges, the Euphrates, and the Tigris rivers are early civilizations with natural geographic protection from enemies, while still allowing access to the ocean. Rivers also provide an efficient mode of transportation. Exporting often developed on rivers so that goods could easily be taken by ship down the river to the ocean and then off to otherwise unreachable consumers.

2.2.2 The Industrial Revolution

The Industrial Revolution was a change from individual manual labor to a production of goods using mills and factories. The Industrial Revolution occurred in most countries around the 1800's. A common occurrence of the Industrial Revolution was the birth or growth of cities on rivers. Rivers provided an easily harnessed source of power for many mills and factories. The cities grew, economies boomed, and people flocked there for jobs and the excitement of city life.

2.2.3 An Increase in Waste

As the population of cities grew, the amount of waste that was dumped into the rivers also grew. The rate of dumped waste into the rivers increased as fast or faster than the rate at which people and factories occupied the banks of the river. With an increased population being subjected to waste, people began to understand that the waste needed to be removed.

Figure 2.2: Waste from pipes flowing into the Chao Phraya River

Rivers were the easy solution; much, if not all, sewage was piped and trash was dumped directly into the river. Where it was carried was no longer the city's concern. Rivers have a natural ability to absorb some pollution and waste; however, effects became more and more noticeable. To make matters worse, as technology increased, so did the number of industries that were using even more exotic chemicals and heavy metals in their production methods. These pollutants often made their way down the rivers to the next city, town, or village.

2.2.4 Fertilizers

Farmers in Thailand have been forced to over farm their land in order to meet the current demand for rice in both Thailand and countries abroad. Often farmers grow their crops along the river because these fields are more easily irrigated. There they can control when the crops receive water and how much. The soil is over farmed if farmers do not allow sufficient time for the natural nutrients to return. The easiest way for a farmer to allow nutrients to return is to avoid planting on the same field every season. Without an idle year for a field, the farmers need to use more fertilizer in order to maintain healthy crops because there is a lack of nutrients in the soil.

Figure 2.3: Applying Fertilizers

Fertilizer is composed of nitrogen, phosphorous and potassium which are vital elements for plants. These chemicals are the major elements that plants need to bloom, reproduce, and grow healthier. However, if the fields are too close to the river, excess fertilizer is channeled into the river as runoff.

High concentrations of these chemicals promote exponential algae growth that suffocates other plants and turn the entire top layer of water green. This is called the *eutrophication* process. This thick, green film covers the river preventing sunlight from reaching the algae on the lower layers. These lower level algae then die and bacteria use oxygen to decompose them. This process may extract all of the dissolved oxygen in the water preventing other organisms from using it and downstream animals asphyxiate and die. There is a 7000 square mile dead zone where the Mississippi River meets the Gulf of Mexico in which no aquatic animal can thrive. This is caused by fertilizers being washed down from the cornfields along the Mississippi River ["Fertilizer Washing into the Gulf of Mexico Causing Dead Zone," 1999].

2.3 Aquatic Life and Pollution

Two indicators of water quality are the amount of dissolved oxygen and the pH of the water. A low water quality is due to a low dissolved oxygen concentration and a pH value that is not close to neutral. Chemical Oxygen Demand and Biochemical Oxygen Demand affect the dissolved oxygen concentrations while pH and alkalinity are measures of the hydrogen ion concentrations.

2.3.1 Dissolved Oxygen

Dissolved oxygen is the volume of oxygen contained in water. It is measured in milligrams per liter (mg/L) and is a major determiner of whether a body of water is suitable for aquatic life. Dissolved oxygen enters water in two ways, photosynthesis, and molecular transfer across the water-air surface. Plants and algae photosynthesize to make simple sugars ($C_6 H_{12} O_6$) from water ($H_2 O$), carbon dioxide (CO_2), and sunlight. Photosynthesis is defined by the following equation:

$$6CO_2 + 6H_2O \leftrightarrow C_6H_{12}O_6 + 6O_2 \quad \textbf{[Eq. 2.1]}$$

Molecular transfer occurs along the water-air surface, when oxygen permeates the water and raises the dissolved oxygen concentration. Moving water has a greater potential for a higher dissolved oxygen concentration. This occurs because water that is rich in oxygen near the surface is constantly cycled toward the bottom of the body of water, which is lower in dissolved oxygen. Bodies of water that are stagnant experience a decrease in dissolved oxygen with an increase in depth. This is because the water on the bottom does not reach the top where it could absorb oxygen. Sunlight intensity decreases proportionally with an increase in depth, which inhibits photosynthesis. Oxygen solubility is directly proportional to temperature, pressure on the water and salinity. Therefore, as temperature, pressure and salinity decreases, the oxygen solubility increases.

2.3.2 Chemical Oxygen Demand

Chemical oxygen demand (COD) is a measure of the amount of oxygen needed for chemicals in a solution to reach their most stable state. Some molecules are volatile when they are not bonded to other molecules. When they are in this state they explosively react when introduced to molecules that rapidly form bonds. Other molecules form bonds much more slowly.

Most COD's are introduced as a result of chemical runoff from manufacturing plants along a river, lake, or ocean. When a pollutant causing a COD is introduced to an ecological system it begins to bond with the oxygen dissolved in the water. This begins to suffocate all of the animal life in the water. After much of the oxygen needed has been absorbed, the water in the river reaches a low oxygen point. Natural processes slowly begin to replenish the dissolved oxygen concentration of the water. COD has no given range for how long it takes to the water to return to its natural dissolved oxygen concentration. It is dependent on the kind of chemicals that are introduced. If a chemical is very reactive with oxygen and there is turbulence in the lower levels of the water, the water can almost instantaneously become devoid of oxygen. Then it has the capability to naturally oxygenate quickly. However if the river is a smoothly flowing water mass and the reactant added slowly bonds with oxygen, more time is needed before the chemical satisfies its oxygen demand, and the river may have no oxygen for many miles down stream.

2.3.3 Biochemical Oxygen Demand

Within the category of chemical oxygen demand is the subcategory of biochemical oxygen demand. Biochemical Oxygen Demand (BOD) is a measure of the amount of dissolved oxygen needed to completely break down an organic compound. The most common of these organic compounds are human or animal wastes. This demand is the allocation of oxygen to organic matter (carbon, hydrogen and oxygen compounds) in order to break it down into carbon dioxide and water. The amount of dissolved oxygen needed in a system is measured by the amount of oxygen consumed in a sample that is kept in the dark at 20°C over a specific time [Davis, 1998].

When there is a sewage effluent entering a river that has a high BOD, a large concentration of oxygen is required to break down the organic matter. There are two major problems associated with a high BOD. First, there are only a few organisms that can break down waste in high BOD. Therefore, only these organisms flourish and multiply. They multiply well beyond the ability of their predators to eat them. This offsets the food chain and can wreak ecological havoc. Worse is the fact that the waste needs oxygen to be broken down. In all bodies of water there is a certain amount of dissolved oxygen; this enables the animals to live in the water. This oxygen is produced in the water by photosynthesizing organisms and by the movement of the water itself. Waste that is deposited into a river is usually in the decomposing phase. In the decomposing phase, the sewage absorbs oxygen from the surroundings to break down into a simpler compound. A stream or river that does not flow through a metropolitan area has an average dissolved oxygen content of eight parts per million. As soon as waste is added, this quantity begins to decrease and can drop as low as zero. At this level, the only organisms that can survive are worms, midge and mosquito larvae. Thus, as sewage is pumped into a river, it creates a dead zone downstream. The length of the dead zone is the average distance the water travels in five days. Five days is the amount of time a BOD needs to absorb all the oxygen, break down, and then leave the water so that it may begin to return to its original oxygen concentration [Davis, 1998].

2.3.4 PH

PH stands for "potential for hydrogen" and is the negative log of the amount of Hydrogen (H^+) ions. The pH scale is a scale that runs from zero, which is the most acidic, to fourteen, which is the most basic. Fluids that are neutral have a pH of seven. Pure water is composed of two hydrogen atoms and one oxygen atom. Often, one of the two bonds breaks forming two different molecules. These two new molecules are hydroxide (OH^-) ions and hydrogen (H^+) ions.

The amount of Hydrogen increases exponentially as the pH value decreases. When different chemicals are introduced, or the chemical concentration is altered, the pH of the system can be altered. Without buffers or some alkalinity in the environment, the system would become unable to support life [Logan, 2000].

2.3.5 Alkalinity

Alkalinity is a measure of a liquid's ability to neutralize acid, or a measure of all possible bases in a solution. It is a sum of all substances that are able to bond to free H^+ ions and increase the pH level. Alkalinity is important in natural aquatic systems. When the photosynthesis cycle occurs, weak acid is a by-product that is released into the water by plants. The natural alkalinity present neutralizes this acid so that the water can return to a healthier pH level. Without this neutralizing agent, life would not be possible in rivers and lakes. Alkalinity in surface water is usually a result of the presence of carbonate, bicarbonate, and hydroxide. These chemicals are able to bond to free H^+ ions so that the pH of a lake or river does not drop to lethal levels ["Water Quality Parameters," 2000].

2.4 Effects of River Pollution on Humans

Pollutants in aquatic systems affect all life directly or indirectly in that given region. Chemicals introduced by humans not only affect the animals in the rivers and oceans but also the societies that rely on these bodies of water for food. Pollution concentrations increase as more humans settle along the river.

2.4.1 Bioaccumulation

When a pollutant enters the water at a specific concentration, it is absorbed in the plants and small organisms. These concentrations may be too small to harm aquatic life or humans. However, when a larger fish eats that plant in large quantities the concentrations increase in the fish. *Bioaccumulation* occurs when a pollutant increases in an organism to concentrations much higher than its surrounding environment. Most often this bioaccumulation occurs in animals that ingest large quantities of plants and organisms each day. These animals are often at the top of the food chain. However, the animals do not die as a result of this chemical being stored in their fat and muscle, but rather live until they are caught for food by humans. These chemicals are then ingested by humans causing cellular damage and sickness.

The effects of inorganic pollutants that enter an aquatic system are compounded by certain environmental conditions. *Biopersistence* is the term used to describe pollutants that do not deteriorate easily and remain in the environment for years. The longer these pollutants stay in the system, the more aquatic life will experience their negative effects. *Bioamplification* is the term used to describe that more complex animals have more genes so they are more likely to experience interference in their chromosomal signaling. Therefore, a whale or a human is much more likely to be affected by a pollutant than a protozoa or an amoeba. *Biogeneration* is the term used to describe that some pollutants can be passed from one generation to the next. Mammals can pass down pollutants to their offspring. In some mammals, up to thirty percent of the mother's pollutants can be passed to her offspring through milk or the placental barrier, ["Dolphins Studied for Pollution's Impact," 1999].

2.4.2 Use of Polluted Water

Some of Thailand's rural population relies on water that has been contaminated by pollution. In many villages and communities water is drawn from streams or wells that lie within the water table of the Chao Phraya River. Drinking water quality is largely determined by where the water originates, how the water is transported, and the level of treatment. In Northern and rural Thailand much of the water is poorly transported from contaminated areas with little or no treatment. However, even before the water is collected it has a concentration of pollutants higher than acceptable standards.

Many of these inorganic and organic chemicals that enter the water have been linked to chronic disease. There is a link between stomach and liver cancer and polluted water. In rural China liver and stomach cancers are the leading cause of cancerous deaths ["China's Health and Environment," 1999].

When farmers use polluted river water to irrigate their fields their crops become contaminated with dangerous chemicals and biological contaminants. Some crops have the ability to absorb these chemicals and heavy metals. They can be deposited in the seeds or flowers. These are the parts of the plant that are most often eaten by humans. There have been studies showing links between cancer rates, birth defects and even death with populations that consume crops that have been irrigated with contaminated water ["China's Health and Environment," 1999].

2.5 SEA START

Southeast Asia System for Analysis, Research, and Training Regional Center, (SEA START) is located at the Environmental Research Institute of Chulalongkorn University. SEA

START is a non-profit regional organization, and one part of The Southeast Asia Regional Committee for START (SARCS) committee. The START organizations focus on the interaction of humans and the environment, especially how humans affect and are affected by global changes.

The collection of START organizations are a global network of multi-disciplinary regional centers. These centers include: the Pan-African Center, the Southeast Asia Center, the South Asia Center, the Temperate East Asia Center, the Mediterranean Center, and the Oceania Center. They also provide a framework to support policy development using their research for scientific assessments. It is an organization that synthesizes models with their data, and is active in the development of new policies. Projects similar to ours are: “Land Use/ Cover Change” [LUCC, 1999], and “Integrated Regional Model of River Basins in South East Asia”, a 1999 WPI IQP ["SEA START”, 1999].

2.5.1 SEA START Land Use/Cover Change (LUCC) project

LUCC is an organization that performs analysis on land uses and cover change. Their projects in Southeast Asia were proposed by SEA START. LUCC is currently working on four projects in South East Asia: one in Indonesia, one in Malaysia, one in the Philippines, and one in Thailand. LUCC performs regional land cover analysis, management for global and regional data availability, and socio-economic regional land use modeling. The project in Thailand modeled a watershed and the surrounding geographical features. It studied the villages in the watershed to determine how humans were affecting the water’s purity. They performed a field study to acquire additional information on physical and cultural conditions of the area.

LUCC showed which human actions have a negative effect on the river. All of the values assigned to human variables directly correlated with the changes in the natural land covers. Population density had the greatest effect on the surrounding environment. The data also showed that not only does urbanization impact the river, but also that removing the natural vegetation for agriculture has lasting effects. These changes cause a decrease in land quality and an increase in sedimentation and chemical build up in the river. These changes have a compounding effect. They cause the nutrients in the soil to decrease, which leads to a loss of vegetation and then soil erosion. These are only the short-term damages. Ultimately climate and temperature changes are possible long-term effects ["SEA START," 1999].

2.5.2 SEA START Integrated Regional Model of River Basins in Southeast Asia

SEA START also proposed the integrated regional model of river basins in South East Asia. This project is considered an integrated regional model because the major objective is to engage scientists, policy makers, students, and ultimately the industrial/manufacturing sector to contribute to the solution of the pollution problem in Thailand's rivers. This project was designed to test water drainage and absorption of the soil. Some human statistics that were pertinent to their research include population size, growth rate, density, age, occupation, and education. This project analyzed the hydraulic pathways, biogeochemical indicators, and human impact on the river to help describe how chemicals are transported from the lands' surface to the river basin. This project mapped water flow in the watershed of the Mekong River to determine if humans had any impact on it. This model was named NAGA after an Indian word for a mythical giant serpent widely regarded in Southeast Asia as the guardian of water resource. This project resulted in a better understanding of the hydrological pathways in a northern region of Thailand, called Isan [Kowalik et al, 1999].

2.6 Geographic Information Systems

Geographical Information System (GIS) is a program that can use collected data to model a geographical area. There are three programs, ArcView, ArcInfo, and Surfer that are designed specifically for geographical analysis. These programs predict the value of selected variables in the geographical area being analyzed. Using GIS models to make predictions based on collected data is useful for many things, some of which are disease control, population growth, and pollution dispersion mapping.

GIS maps can analyze events on the earth and contain many *features* of one geographical area. One *layer* in the map represents one feature; the feature is an input of collected data, images, or manual drawings. Some examples of features are rainfall, elevation, river runoff, and streets. Because a map has several layers, many features can be analyzed together. Inputs to the model are made, and GIS then calculates results which are called predictions. These predictions need to be tested with actual data to confirm their accuracy. Once the model seems to accurately represent the geographic area that is being studied, it can be used. Small groups of completed models can be gathered to form databases in GIS. GIS databases can be used to obtain general background information on an area, modify data from pre-existing geographical databases, solve design issues, and sample and test modeling.

GIS plots data on a X/Y coordinate system. The data are stored in tables, which are either imported from outside data files or entered manually. The entries in tables may be constants or variables. *GIS scripts* can be used to manipulate the data presentation. For example, GIS scripts can be written to import population distributions in a given city and graphically represent concentration with different colors.

2.6.1 GIS Plotting Methods

GIS can display maps by using two methods: the Polygon method or the Raster method. ArcInfo uses only the polygon representation whereas ArcView uses both the polygon and the raster method

The Polygon Method consists of polygons shaped by vectors, which enclose areas on the map. Each vector contains a magnitude and a direction. The initial and final X/Y coordinates determine the vectors. The data inside the polygon represents one variable from the table. The advantage of the polygon method is that it runs quickly and does not occupy much memory space. The disadvantage is that it is less accurate and produces maps of lower quality.

The Raster Method selects pixels, or points, on the map. Each pixel is represented by its X/Y coordinate. Similar to the polygon method, the pixel can represent any one variable from the table of data. The advantage of the Raster method is that it has higher quality maps and is more accurate. The disadvantages are that it is time consuming to process the information and it occupies a larger memory space than the polygon method.

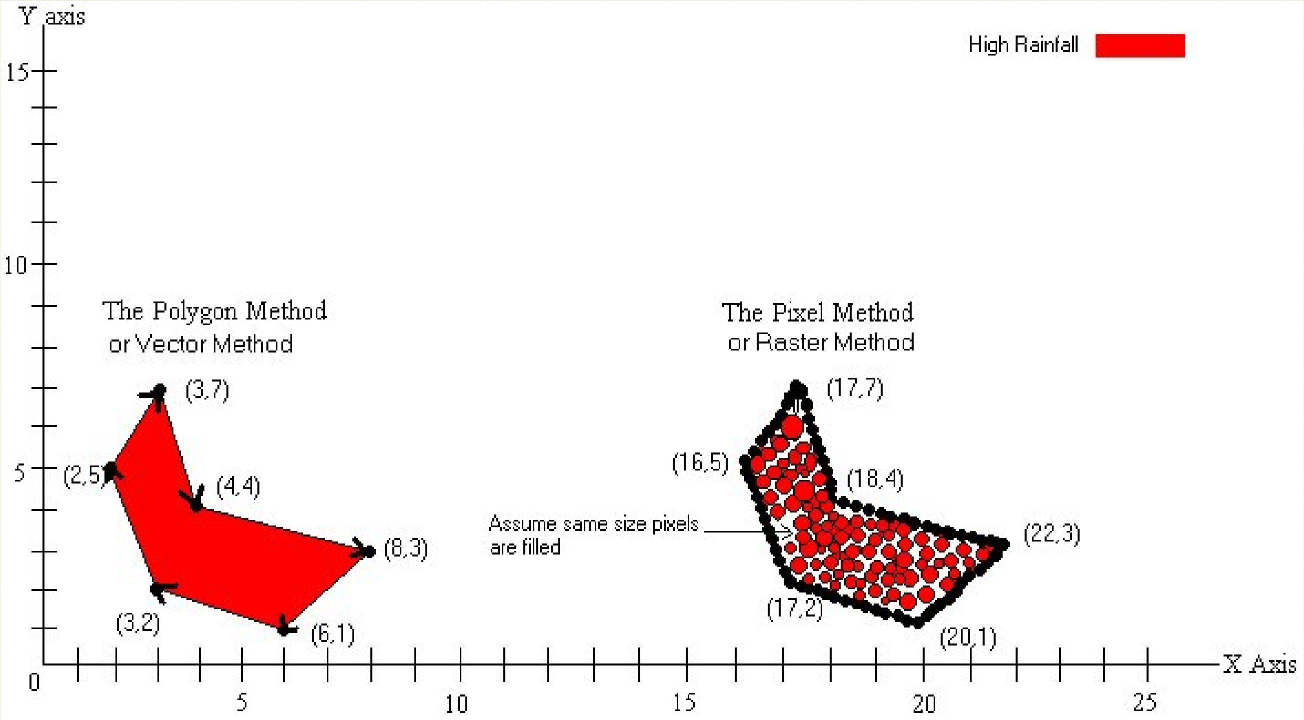


Figure 2.4: Comparison of the Pixel and Polygon Method in GIS

The difference between both methods is displayed in Figure 2.4. One polygon would represent one variable from the table of data. The Raster method has the same representation, but with pixels instead of vectors. The pixels are points on the map. Both methods can be used in maps to cover the same geographical features. The Raster method has noticeably finer detail. The GIS programs can convert back and forth between the two methods with little to no loss of information.

2.6.2 ArcInfo

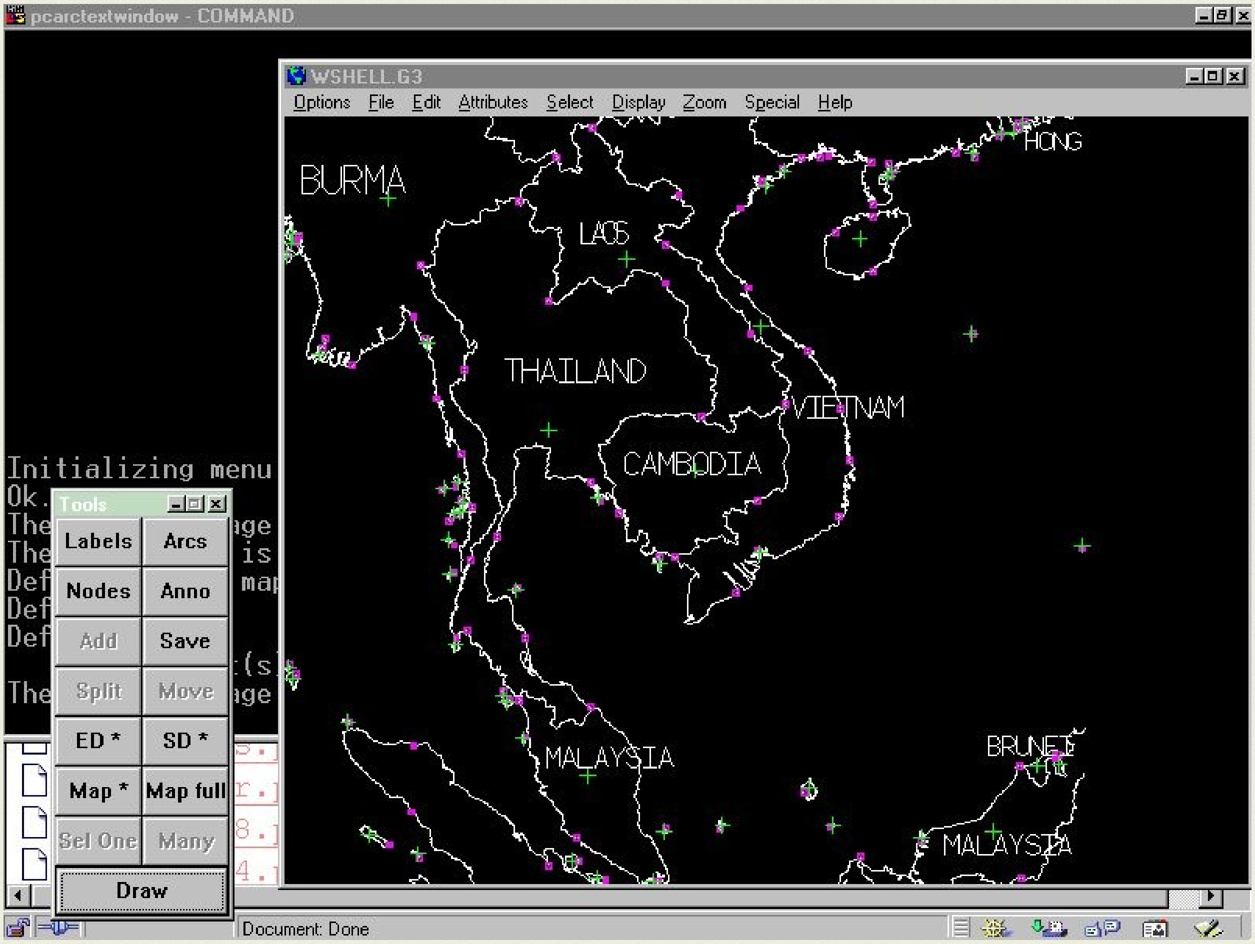


Figure 2.5: ArcInfo display of Southeast Asia

ArcInfo is a GIS program developed by the Environmental Systems Research Institute (ESRI). It is a polygon-based program used in the analysis of businesses, governments, utilities, and companies. Figure 2.5 shows an ArcInfo map of Southeast Asia. The purple points on the map are the endpoints of the *polygons*. With pre-written scripts, ArcInfo can perform quick data manipulation or preprogrammed operations. For example, pre-written scripts can easily organize and convert between the temperature readings of Celsius, Fahrenheit, and Kelvin, and can import and export data from various files. Geographic information entered by the user is incorporated into layers. The information can include data from an outside database such as Visual Access, or can be combined with programming languages such as Perl and Visual Basic. The more effective features of ArcInfo are:

- Topological map overlay
- Database support
- Proximity analysis
- Spatial and logical query
- Hydrologic modeling
- Surface analysis
- On screen editing
- GIS Drawing Engine
- Sophisticated tabular analysis

These features provide powerful applications to the user. Overlays, layers, on screen editing, surface analysis, and the GIS drawing engine makes it easier for the user to view and draw the maps. Database support, queries, and tabular analysis make it easier for the user to handle the data. Help for various codes and scripts is available online and shows how to make projections and topographical features with ArcInfo ["Introduction to ArcView 2," 1999].

2.6.3 ArcView

ArcView allows the user to create high detail maps and edit them. The program is based on the Raster method, and is unable to convert between both methods. Like ArcInfo, the user can import data from outside databases. ArcView also uses *Geocoding,* which aligns the layers in the proper proportions so they lay properly with the original layer.

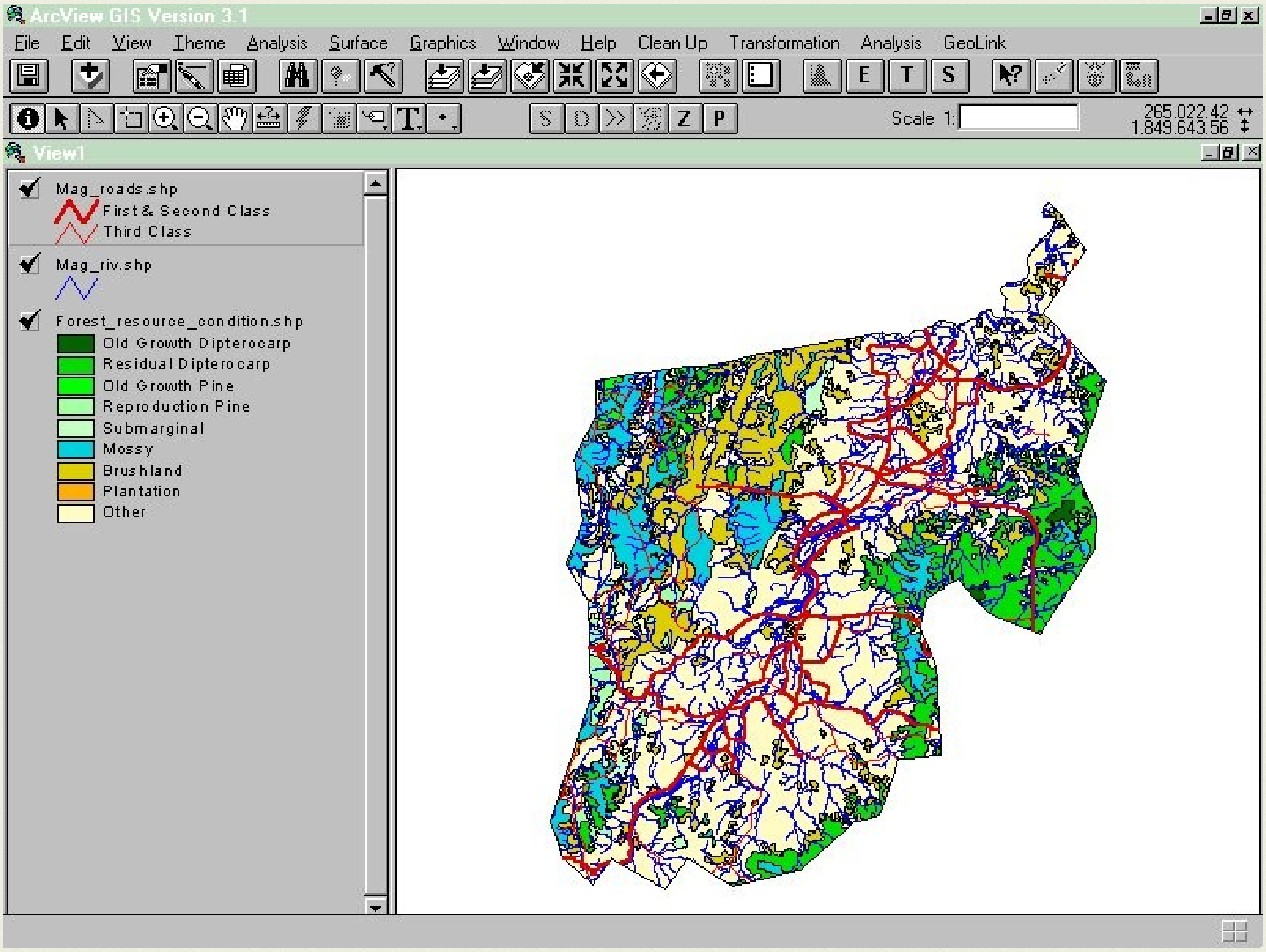


Figure 2.6: ArcView screen displaying the Magat Watershed in the Philippines

Figure 2.6 shows the program displaying the Magat Watershed in the Philippines using three compiled layers [Alba, 1998]. Important features in ArcView are its facilities for editing maps. These features include color ramps, importing images, cropping, and even a wizard that leads novices through the basic functions of the program ["ArcInfo," 1999]. Figure 2.3 depicts the variables as different colored sections for different types of vegetation. The constants are the blue lines on the map, which represent rivers and the red lines on the map, which represent roads.

2.6.4 Surfer

Surfer is a GIS Gridding program, which performs three-dimensional contour mapping and surface mapping. It uses a technique known as *gridding*. Gridding is the process of selecting a height (Z-axis) for a grid (X/Y axis)

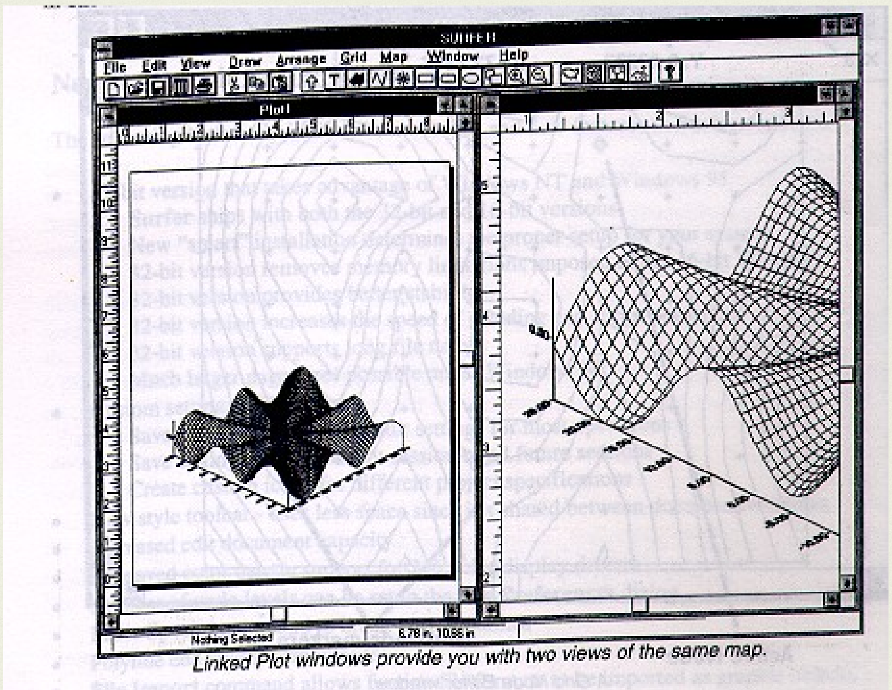
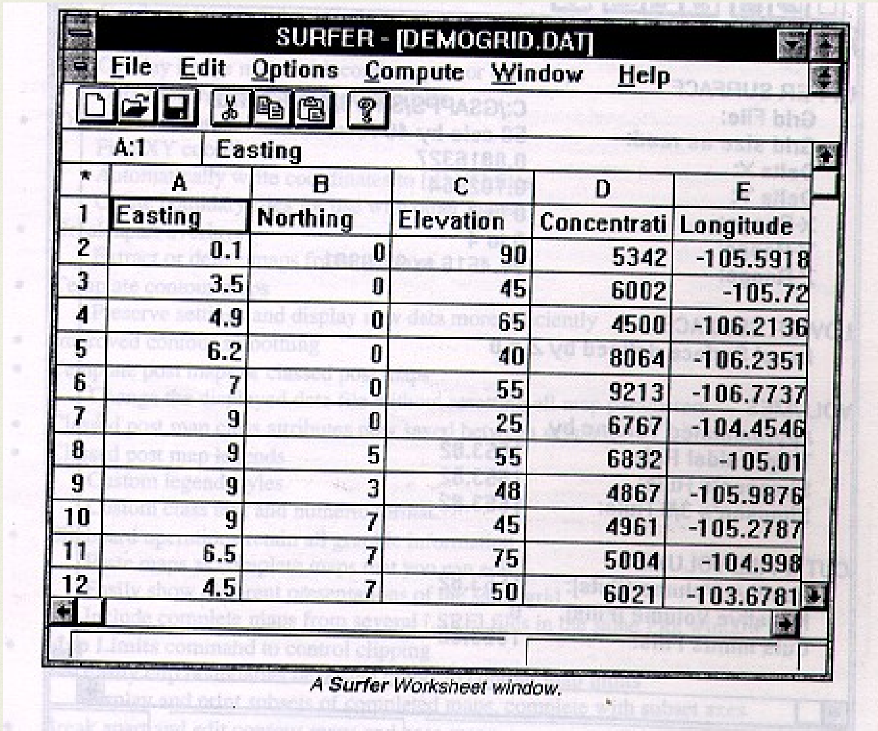


Figure 2.7: Screen of Surfer displaying gridding

An example of a grid is shown in Figure 2.7. The screen displays the bottom x, y coordinate grid and then unknown heights are approximated from know Z values. Scripts can automatically select these coordinates or they can be entered manually. The program allows the user to zoom in and out or change viewing angles. The user can also actually see the x, y coordinates that apply to the three-dimensional surface map.



SURFER - [DEMOGRID.DAT]

File Edit Options Compute Window Help

A:1 Easting

*	A	B	C	D	E
1	Easting	Northing	Elevation	Concentrati	Longitude
2	0.1	0	90	5342	-105.5918
3	3.5	0	45	6002	-105.72
4	4.9	0	65	4500	-106.2136
5	6.2	0	40	8064	-106.2351
6	7	0	55	9213	-106.7737
7	9	0	25	6767	-104.4546
8	9	5	55	6832	-105.01
9	9	3	48	4867	-105.9876
10	9	7	45	4961	-105.2787
11	6.5	7	75	5004	-104.998
12	4.5	7	50	6021	-103.6781

A Surfer Worksheet window.

Figure 2.8: Data Tables in Surfer

Data for the coordinates and heights for gridding are stored in tables as shown in Figure 2.8 either as variables or constants. Each data table affects the display of the surface. A variable such as elevation or temperature from the column can be selected for the height of the map. Once the height has been selected, then other *GIS attributes* such as color, size, angle, and slope can be applied to the map.

2.7 GIS Applications

GIS can be used to predict the effects of natural disasters; the results can be used to minimize damages. A GIS model of Taiwan may consist of data such as population growth rate, building size, population density, lakes, and rivers. Using this information, the user can analyze the potential damage of earthquakes, and take preventative measures such as introducing building codes to minimize destruction. This would help to save lives, building restorations, and property.

The increase in toxic waste being added to the environment has created a new field in the scientific community, Environmental Toxicology or *Ecotoxicology*. Ecotoxicology is the study of the adverse effect that plants and animals receive from pollutants entering their ecosystem. This new field uses GIS to monitor pollutants in the water system. Scientists are able to mathematically track chemicals without doing costly field studies. They can make predictions on where the chemicals will concentrate and what possible measures will avoid further pollution.

2.8 GIS Model of River Basins

A river basin is all of the land that surrounds a river and is determined by how far away rain can fall and still flow to the river. All the rain that falls into a river basin runs directly into only that specific river. All landmasses can be divided by river basins, and often each major river basin can be broken down into the smaller river basins of the tributaries. A significant area is classified as a river basin. There are many rivers that run throughout each landmass, and each river has only one river basin. Chemicals do not have to be directly dumped into the river for them to enter the river. Rainwater runoff can carry pollutants to the river if it is being dumped anywhere in the river basin area [Davis, 1998].

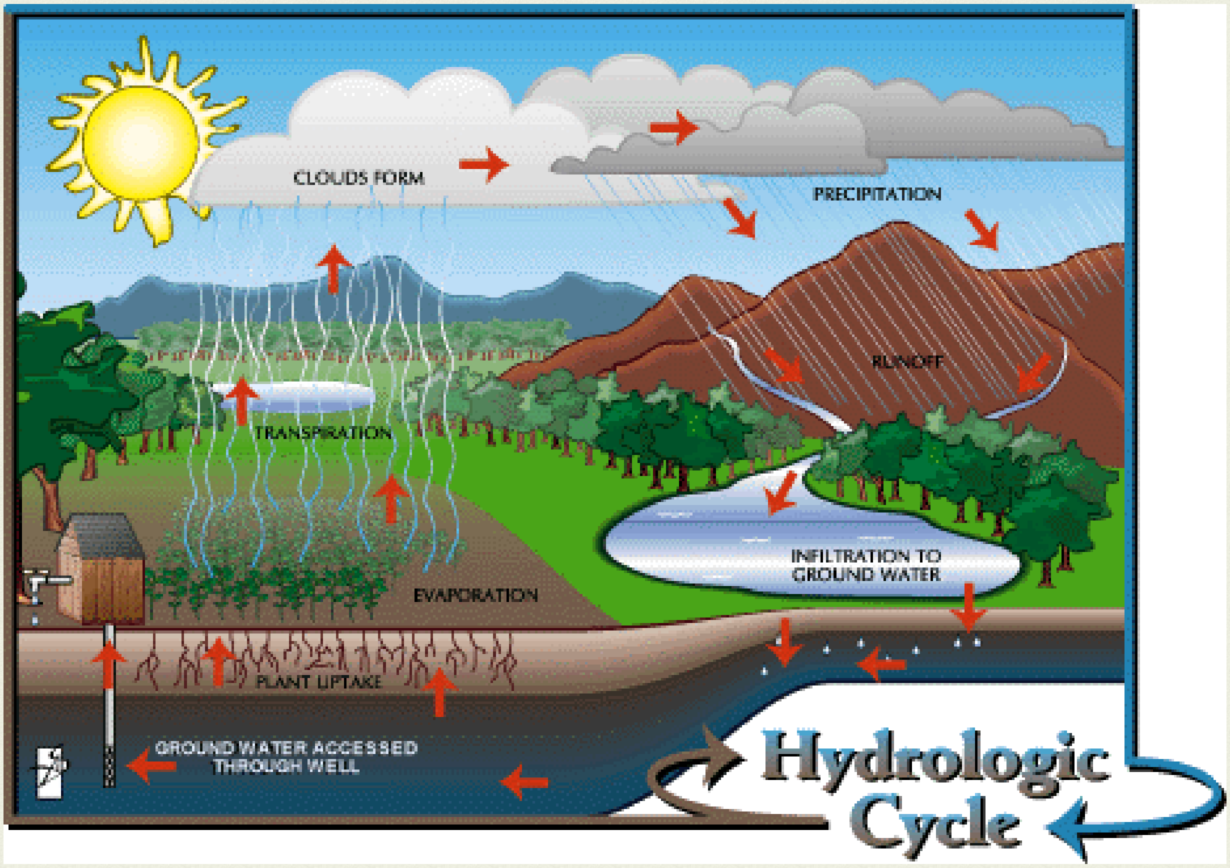


Figure 2.9: The Hydrologic Cycle

The Hydrologic cycle describes the paths water can take in the environment as shown in Figure 2.9. Precipitation that falls over a river basin ultimately runs into the largest river and then towards a last body of water, a major lake, or an ocean, and evaporates again to form precipitation. Some rainwater becomes trapped in the vegetation layer while the rest is soaked into the ground or carried away as runoff. The water absorbed into the soil can be used by trees or percolate into the ground water by infiltration. Evaporation removes water from the soil and returns it to the clouds. The most common path for a water molecule is to be evaporated from a body of water, move in the form of clouds over land, and fall as rain. Then it flows along the ground and collects with other drops forming a small trickle. This soon becomes a small tributary where it follows preset channels. These tributaries then empty into small streams and these streams then empty into rivers and back to a large body of water [Davis, 1998].

To model a pollutant in a river one must gather information on the river's speed, depth, width, length, and discharge. There are many factors involved in calculating *river discharge*. To completely understand a river, extensive research on how water travels through the river is necessary.

2.8.1 Precipitation

Precipitation is a classification of all types of metrological activity that releases water in any state, including sleet, hail, snow, and rain. Rain is the most common precipitation on the Chao Phraya River basin, especially during the monsoon season. Rain is quantified in three categories, frequency, duration, and intensity. Frequency is a measure of how often a rainstorm occurs. During the rainy season, the Chao Phraya River Basin receives extremely intense rain almost daily. Duration is a measure of how long it rains for and intensity is a measure of how much rain falls in a given time period. Short, high intensity storms are more likely to cause floods than storms that leave the same amount of rain over a longer duration.

Three parameters are important for determining net runoff, the area of the river basin, the intensity of the storm, and a constant for the given area called the coefficient of runoff. The value for the coefficient of runoff is determined by the slope, vegetation, soil makeup and porosity, and concentration of water already present in the soil. The coefficient of runoff is a number between zero and one and used in the equation:

$$\text{Runoff (cfs)} = C \times I \times A \quad \textbf{[Eq. 2.2]}$$

This equation above calculates the runoff in cubic feet per second (cfs) and uses the parameters C (coefficient of runoff), A (area) and I (intensity). Area is measured in acres and intensity is measured in inches per hour. The coefficient of runoff is a unitless number. A high coefficient value of runoff yields a larger volume of runoff. Once the coefficient of runoff reaches one, the equations says that all rain that falls over a given area becomes runoff. This is likely in industrial and paved areas where there is no opportunity for the water to enter the ground or be absorbed by vegetation. A coefficient of zero means that all the water that hits the ground will be absorbed into the ground at that very spot; there is no runoff ["American Water Works Association," 1971].

2.8.2 Throughfall

Throughfall is the volume of precipitation that passes through the vegetation canopy. The vegetation canopy includes trees, bushes, plants, or other forms of greenery. Throughfall also includes the amount of precipitation that drips off from the leaves or twigs [Maidment, 1993]. Factors that influence the amount of throughfall include total leaf coverage, wind velocity, rainfall intensity, and the number and type of layers in the vegetation canopy [Lewis, 1996]. In a detailed hydrologic system, the quantity of throughfall affects the amount of water that flows to the river. In the runoff, it also affects what chemicals are carried to the river. It is important to determine the amount of throughfall, to calculate the amount of water available to be absorbed by the soil in a process called infiltration or to be carried away as runoff [Maidment, 1992].

2.8.3 Infiltration

Infiltration is the volume of precipitation that is absorbed into the soil. Infiltration is the source of water for vegetation. Factors that influence infiltration include the condition of the surface crust, temperature, rainfall intensity, water quality, soil properties, and the type and extent of the vegetation coverage [Lewis, 1999]. If a field that has been sprayed with fertilizer has a low infiltration capacity, then when it rains the runoff will contain a high concentration of fertilizer. It is important to know what the infiltration rate is so one can determine the concentration of chemicals in the runoff. The lower the infiltration rate, the higher the runoff rate. A simple equation to measure infiltration is:

$$\text{Infiltration} = \text{Throughfall} - \text{Runoff} \quad \text{[Eq. 2.3]}$$

Looking at the Hydrologic Cycle on Fig. 3.1 identifies this relationship [Viessman, 1996].

2.8.4 Baseflow

Runoff is only one path in which water can enter the river. All water flowing into a stream or river can be divided into three subcategories of water; baseflow, interflow, and saturated overland flow. Baseflow is the quantity of water that is constantly returning from the ground water storage table to the river. All river water flowing during droughts is baseflow. Interflow is the water that falls as rain and enters a small gullet, natural piping system, or seepages zones, and then it is channeled to the stream. Saturated overland flow is the water that falls as rain and makes its way over land to the river or stream. Saturated overland flow and interflow are often categorized as one entity called surface runoff. This leaves any stream or river composed of two variables, surface runoff, and baseflow. Baseflow and surface runoff have different containments. Surface runoff may contain fertilizers, pesticides, and other compounds commonly spread over land. Baseflow can contain heavy metals, exotic manmade chemicals, or dangerous organic compounds that are saturated in ground water [Viessman, 1996].

2.8.5 Groundwater Flow

Porous soils and rocks below the surface of the earth can become saturated with water. These saturated regions can hold large quantities of water called groundwater. Groundwater can be stored in two different subsurface regions called aquifers and aquitards. If the water trapped in the soil is able to percolate through the soil, the region is called an aquifer. If the water is unable to flow, then the region is called an aquitard. Water that is able to flow is forced through the soil by gravity, which cleanses it of particulates, however saturated pollutants are able to stay in solution.

The uppermost point of soil or rock that is saturated with water is the beginning of the watertable. Water moves from watertables with high elevations to water tables of lower elevation. Many regions of land can be below the water table; these areas fill with water and form lakes and rivers. When groundwater flows into a lake or stream it is called base flow.

Groundwater is replenished when surface runoff and precipitations are able to percolate down through the upper layers of soil into an aquifer. Often pollutants are saturated in this water and are carried down into the groundwater. This manner of contamination is called non-point pollution sources. Non-point means that the contamination enters the water supply from many different places in small concentrations. In urban areas, groundwater is often contamination by point source pollution. These point source contaminators deposit concentrated quantities directly in to the groundwater. These types of contamination include storage tanks, industrial treatment facilities, and municipal waste plants [Maidment, 1992].

2.8.6 Soil

Soil properties affect how much and how quickly water can be absorbed into the soil. There are many different types of soils, all of which have different concentrations of three central components; clay, silts, and sand.

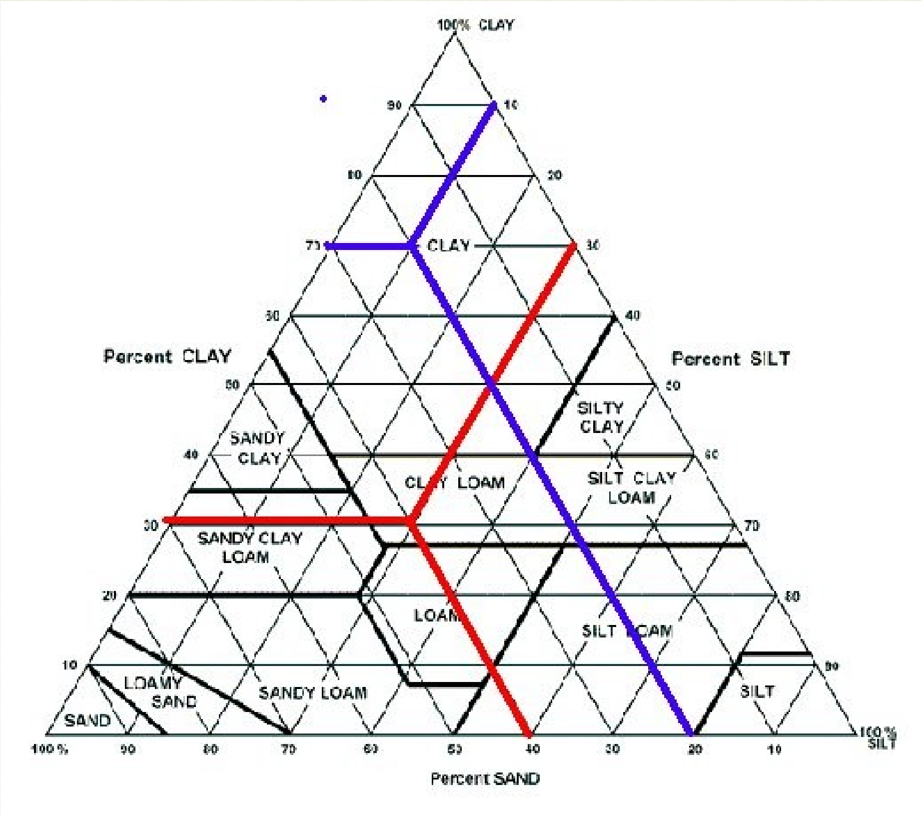


Figure 2.10: Soil Compositions

The many possible types of soil are shown in Figure 2.10. The red and blue lines show different soils at their intersection points. The blue soil is a type of clay soil and the red is clay loam. These lines can be followed to the edge of the triangle to understand their granular make. The blue soil is 10% silt, 20% sand, and 70% clay. The red soil is 30% silt, 40% sand, and 30% clay. Each type of soil has different properties. Some soils are rich in nutrients and support plant growth, while some soils have various industrial applications such as sand blasting and water filtering. Each different soil has a different water retention time and a different saturation time. Saturation time is a measure of how long it takes the soil to absorb the maximum amount of water it can hold. Water retention is a measure of the rate at which water leaves the soil after it is saturated. A soil rich in sand might easily become saturated but also would have a small retention time. A soil rich in clay would have a large saturation time and a large retention time.

This information is particularly relevant in calculating the coefficient of runoff for a certain area. Soils that have a high saturation time are more likely to have a high runoff coefficient in short intense storms, because the soil saturates too slowly to absorb any measurable amount of rainwater falling in the storm. The possibility of flash floods is greater in regions with this soil type because there is a high percentage of storm runoff ["Soil Oxygen Availability," 2000].

2.8.7 Wilting Point

Concentration of water in the soil greatly affects water runoff. The *wilting point* is a condition that occurs when the quantity of water in the soil is insufficient for osmosis in the plant's roots. *Osmosis* is the passive diffusion of water through a permeable membrane. This means the water enters the roots because there is a lower concentration of water inside the plant than in the surrounding soil. When not enough water is available for the roots, the water cannot use osmosis to enter the plant. In these conditions, the plant will wilt or die if no water is added to the soil. The other extreme, called *field capacity* is the maximum amount of water the soil can hold.

If the soil is at the wilting point then it is very dry and unable to sustain life. When the soil is dry it is susceptible to flash floods, which causes intense erosion. When plants wilt or die their cell walls become flaccid and weak from the lack of water pressure. This causes the plant stems to sag to the ground, and the roots to be unable to hold themselves into the ground. Often, the cell walls become weaker and the roots break. When roots break they are unable to hold the soil in place so it is more susceptible to erosion. In modeling projects the field capacity and wilting point are important to determine the extremes of the water concentration in the soil. There are two tests done to measure these parameters. The first test determines the amount of water the soil can hold at field capacity. The second test determines how much water the soil holds when the plant roots cannot extract any more water from the soil

Wilting point and field capacity affect runoff into the river. The amount of water in the soil is measured in millimeters. The water level of the soil will always be between the field capacity and wilting point. Once the amount of water in the soil is known, then calculations can be done on the amount of expected runoff [Kurtz-Fernhart, 2000].

2.8.8 Plant Respiration

The amount plants respire determines how much water is removed from the soil. Plant respiration occurs during photosynthesis. Plants photosynthesize to produce simple sugars, and use carbon dioxide, water, and sunlight. Plants photosynthesize at different rates depending on their cell area index (CAI.) CAI is the surface area of photosynthesizing cells per unit leaf surface area. The larger the plants, the more water they need for respiration. Plants use water from the soil for respiration. The more plants and the larger the leaves, means there is more respiration and therefore more water loss from the soil. This decrease in soil water decreases rainwater runoff, which affects the amount of water discharge in the river ["Water Resources Information," 2000].

2.8.9 Evapotranspiration

Evapotranspiration is the removal of water from a system into the air including evaporation from soil as well as transpiration from plants. Transpiration from plants occurs when water is evaporated through the *stomata*, which are open pores in the leaves used for gas exchange in respiration. This process is necessary in order for photosynthesis to take place. The hotter and dryer the environment, the more water is evapotranspired. The warmer and dryer regions need more water to prevent the soil from drying out and becoming unable to support life. The environmental conditions determine how much water is evapotranspired. When the soil is dryer, it is able to absorb more water when it rains. This affects rainwater runoff. One way to measure evapotranspiration is to use a closed chamber gauging system, which can measure the evaporation from the soil as well as the gas exchange from plants ["Effect of Leaf Anatomy," 2000].

2.8.10 Flow Quantity

All of these ecological and geographical features determine the rivers flow quantity. The quantity of water that flows through a river can easily be calculated with:

$$Q = V \times A \quad \textbf{[Eq. 2.4]}$$

Where Q is total quantity, V is the average velocity, and A is the average cross sectional area of the river.

The water's speed or velocity is more difficult to determine. It is dependent on specific characteristics of the river. The characteristics are roughness of the riverbed, the shape and size of the river, and the slope of the land. These variables can be used in Manning's Equation:

$$V = \left(\frac{1.49}{N}\right) \times \left(\frac{A}{P}\right)^{\frac{2}{3}} \times S^{\frac{1}{2}} \quad \textbf{[Eq. 2.5]}$$

This equation calculates the velocity of the river. N is Manning's Coefficient of Roughness, A is the cross sectional area, P is the perimeter of the river bottom at any given point, and S is the slope ["Manning's Equation Calculator/Software," 2000]. With the proper understanding of these variables, predictions of river discharge can be made.

In any river, the slope, shape, and roughness are constant. Therefore, when more water flows through the riverbed, the water level will rise. If enough water flows at one time it will overflow the riverbanks. This means that in times of heavy rains and droughts the height of the river will vary.

Measuring the quantity of water flowing through a river is calculated and recorded at gauging stations. Gauging stations are located at intervals along the river and perform measurements at each location to obtain a periodic record of water levels. Measurements at these stations are typically taken every fifteen minutes [Maidment, 1992].

2.9 Background Discussion

A background discussion is one means of obtaining information for research. These discussions allow interactive contact with people who are of interest to our research. We have conducted two such discussions: One was with Jeganathan Jeganaesan and the other was with Dr. Anond Snidvongs, both of whom work for SEA START. Jeganathan was our project leader and Dr. Anond served as our liaison in Bangkok, Thailand.

2.9.1 Discussion with Jeganathan Jeganaesan (1-7-2000)

The goals for this project are to modify the new model from Seattle Washington, USA to work for the Chao Phraya River. The old model was available to use if we were unable to modify the new model. The model from Seattle was recently completed, and might not perform accurately for the Chao Phraya River.

There have been many research projects completed at SEA START on the Chao Phraya River that have information valuable to our project. These resources provided valuable information for our project. To begin modeling in GIS requires data preparation. Jeganathan instructed us how to prepare the statistical data so we would be able to enter it into a GIS model. Cropping data was necessary so all the values correspond to our model. Every area has to have data for each feature in order to be accurate. Once this was completed we were able to insert it into our GIS model.

2.9.2 Discussion with Dr. Anond Snidvongs (1-24-2000)

Our project was one of a series of projects that studied the Chao Phraya River. These modeling projects were created because real field-testing for every point on the river was expensive and inaccurate. SEA START has gauging markers used to calculate total water flow in the river. This was a relatively good method for measuring river flow in the northern sections; however, this technique did not produce accurate results near the river. The sticks in this section were affected by high and low tide. This would offset the calculations for total river flow. To accurately measure the delta region a more expensive method would have been necessary. As an alternative, GIS was proposed to measure the river flow, using the flow values of the northern region. This provided accurate predictions of water flow in the southern region from the information from the north. Once the river discharge was calculated, and constants important to the river system were tabulated and inserted into GIS then the rivers' hydrology could be modeled. Once this was done, the many pollutants could be entered. Completing an entire model is a long process because it is hard to receive accurate chemical concentrations and some chemicals are very scarce. Because of this we measured the more concentrated chemicals for our project.

The script of the old model was written in ArcInfo. This is an easier program to use and a much less expensive one to purchase. ArcView will be used to more clearly display results. In the end, our model will be distributed on ArcInfo so more researchers will have access to the information, because ArcView is too expensive for most organizations. The ultimate goal is for the model to be available to anyone who may want or need it.

Chapter 3: Methodology

Methodology

The present conditions of the Chao Phraya River are poor, and rapidly deteriorating, and it is becoming more apparent each year that preventative measures need to be enacted. Accurate modeling is one of the most effective means of understanding both the problems and the possible solutions. An accurate model is multi-facetted and extremely intricate. It cannot be made by simply combining problematic factors and data associated together. Many factors determine the river's properties and chemical concentrations in the various sections of the Chao Phraya River. There are two major subsections of our model, natural properties of the surrounding landscape and unnaturally introduced pollutants. Pesticides from runoff, human wastes, chemicals from factories, and boat engines are among the largest negative influences that humans have on the river. All these factors affect the COD, BOD, dissolved oxygen, pH, and alkalinity of the river. SEA START RC has already collected these concentrations in previous years. Using GIS, we made models of these factors. Cropping data was necessary to organize it, and have it accurately represent the area. The layers were input into GIS and once the model seemed accurate enough, it was used. Finally, water samples were taken from different sections of the river to compare with our GIS model. We analyzed the samples and entered the readings into our model.

3.1 GIS Model

There are five steps that we followed to create a model in GIS.

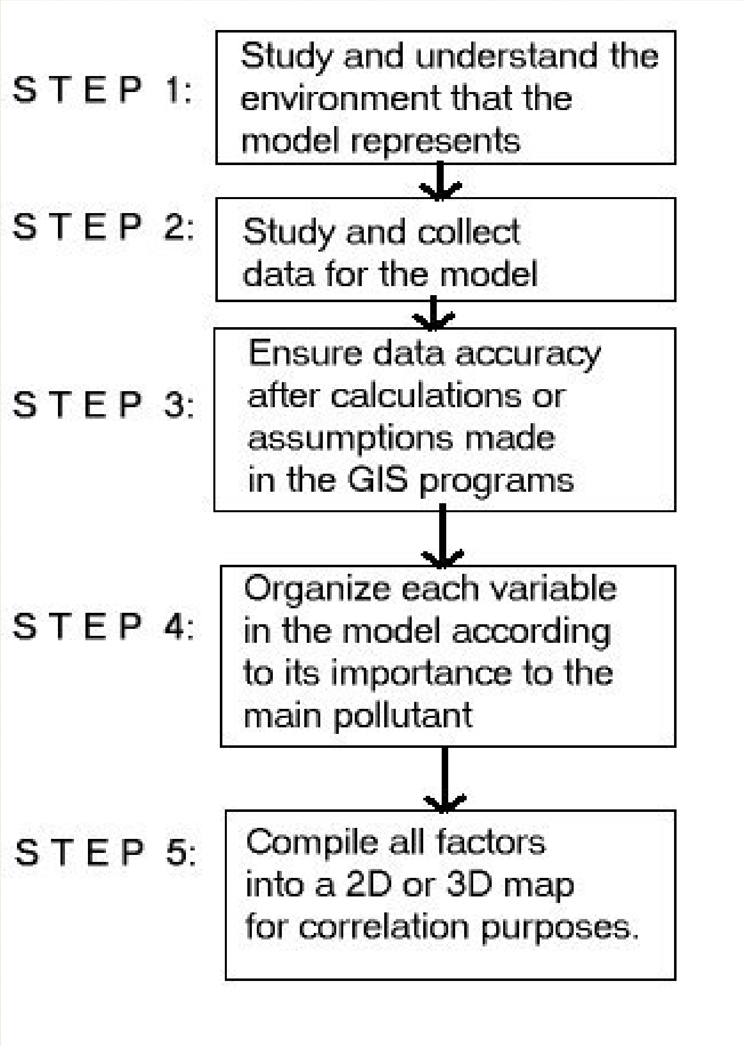


Figure 3.1: Steps used to creating a GIS model of the Chao Phraya River

The first step in the GIS Chao Phraya River model was to have a clear understanding of what the model would involve. The GIS model would correlate one pollutant and how humans contribute to that pollutant's concentration in the river. Understanding this human to pollutant correlation was the main goal of the model.

The reliability of the data source determined the accuracy of the model. The model's precision with calculations affected the stored values of the pollutants. Studying and collecting this data was the second step of the modeling process. The collected data was stored externally in an Excel spreadsheet. The major variables were COD, BOD, pH, and Alkalinity. All other data would be minor variables or constants. The main variable was affected by other minor data in the model. These data were easily imported into tables in ArcView.

The third step of the GIS model was to ensure the accuracy of the model's variables and constants. There were three main rules followed to ensure that the values received from the model were stored as accurately as possible. The first step was to make sure the units in the calculations were correct. The second step was to guarantee the appropriate significant digits in the calculations. The final step was to double-check the assumptions made for all unknown variables. The reason that calculations and assumptions were needed was because we did not have actual values for all data, some of this data was calculated or assumed from other data that was previously collected for the model.

We then imported the existing data from ArcView tables to ArcInfo, because ArcInfo manages and calculates information better. The calculations can be done manually or with the help of scripts. Once the calculations and assumptions were made to an acceptable accuracy, the data was transported back to ArcView for viewing purposes. The fourth step included an outline of the level of importance for each layer. In ArcView, these layers were called themes. Each theme consisted of one variable or constant. Each theme was ordered in terms of level of importance. One main variable was COD, which was the upper most layer, other minor variables were in layers below, and finally the digitized map was on the bottom most layer.

Once the data structures were organized appropriately, the fifth step was to compile these themes together. They could be compiled in a two-dimensional map in ArcView or imported to Surfer to get a three-dimensional contour map. Then, if necessary, the main theme was recalculated using different initial data and minor variables to form a new model.

3.2 Background Discussion Preparation

Background discussions allowed us to obtain information for research and to examine the direction and specifics of our project. These discussions gave us an interactive understanding from people who have specialized knowledge of our research.

This process was a casual interview. We did not completely follow our list of questions, and more questions were thought of during the discussion. These questions were just a guideline to ensure we received all the information we would need. Our preparation for these discussions included making a list of questions to ask.

1. What are SEA START's goals for this project?
2. What are your thoughts of our proposal? Is it focused enough?
3. What is the specific problem that SEA START needs to have addressed by this project?
4. Is there a specific pollutant that you would prefer us to use?
5. Which pollutants do you already have models for? Should we use these models, or create our own?
6. Do you have any information on the Chao Phraya River that we could use?
7. In our model what would be some layers that would be necessary for an accurate model?

3.3 Pollution Models

Understanding the waste problem in the river and its origins were important in developing our model in GIS. Pollutants introduced to the river affected COD, BOD, dissolved oxygen, pH, and alkalinity levels.

Once this model was created, it enabled us to observe the portions of the river with the highest pollution and we were able to determine the most probable location of pollutant introduction. It was also be possible to recommend measures to lessen the destructive effects that the heavily polluted areas had on the downstream portions of the river.

3.3.1 River Discharge Layer

The layers that incorporate the river's discharge were the corner stone of the model. All the pollution layers were dependent on how the water flowed. To accurately map the river's discharge, flow rates were taken at gauging stations along the river. This data was manipulated to form a layer in the GIS model. Landscape and precipitation statistics affected the flow at given points along the river. Statistical categories were:

- Precipitation
- Throughfall
- Infiltration
- Baseflow
- Groundwater Flow
- Type of Soil
- Salinity concentration of Soil
- Wilting point/ Field Capacity of soil
- Plant respiration
- Evapotranspiration
- Flow Quantity

Much of these statistics were available at SEA START. We inserted the data into an Excel spreadsheet and then imported it into the model.

3.4 Observations of the Chao Phraya River

We took a day riverboat trip of the Chao Phraya River and a daylong road trip to the middle section of the river. These trips allowed us to observe two different portions of the river, making observations of both the lower reach and the more central region of the river. This gave us the opportunity to make visual observations of the very industrialized region of the river and compare it to the central region. The trips also allowed us to better understand the pollution problem of the river.

3.5 Testing the Chao Phraya River

To take accurate water samples we had to select specific gauging stations that would be most beneficial to our model. We had to analyze a road map and pick the stations that were most easily accessible from the road. We selected four stations in the Bangkok area, three in the northern region around the entering tributaries, and the last was taken from a tributary, the Pa Sak River. We traveled along the Chao Phraya River and its tributaries collecting water samples for our model. In the laboratory, we analyzed alkalinity levels; however, we were forced to use last year's data for COD, BOD, and pH values to compare with our model.

The samples were taken from the river in a submergible container that trapped only water from a chosen depth. This was important because in many places there was a film of oil and concentrated pollutants on the surface of the water. Then the container was mechanically closed, sealing the water we chose to sample inside. We chose a depth of 0.5 meters to 1.0 meter to gather our samples. This depth was chosen because it was where the water was steadily moving and has the most homogenous mixture of all chemical concentrations. The sample was transferred to a clean container and was immediately filtered to remove the sediments that could interfere with our results. We took three 120 ml bottles of samples from each site.

3.5.1 Water Sample Laboratory Work

The alkalinity test was performed on our samples. The alkalinity test involved using a pipette to titrate a 0.5 molar concentration hydrochloric acid, and an electromagnetic millivolt reader.

Figure 3.2 Michael performing our alkalinity test

Figure 3.2 shows titration being performed. Twenty-five milliliters of river water were poured into a beaker. Hydrochloric acid was added until the solution reached 250 millivolts of conductivity. The quantity of acid added to reach this reading was recorded. Then acid was added so the millivolt values increased in increments of ten, up to 310 millivolts of conductivity. The additional acid added was recorded at each step of ten millivolts, and a curve was plotted. This was done twice with each sample. This data provided valuable information about the buffering ability of the Chao Phraya River at different points. The curves of these graphs were exponential. When the river water natural alkalinity could no longer neutralize acid, the solution jumped in millivolts because all of the natural buffering components were all bound to the acid. Using this data, a layer was constructed in GIS and curves were plotted in Microsoft's Excel.

3.6 Comparing the Accuracy of our Model

Actual water sample data were necessary to compare with our model's predictions to test its accuracy. We used the data of our water samples and compared them with the GIS printouts. If the values compared well with our model, then it can be assumed that the model works. Normally one would test the correlation between the sample data and actual data, however we did not have adequate time to complete them all. For our model to be used by researchers, one must test it with data to determine its accuracy.

Chapter 4:
Results

Results

For our project, we used GIS to make a visual representation of the pollution problem of the Chao Phraya River. After our model was completed, water samples were taken to compare it with actual data. We also created a data query program to make our information more available via the World Wide Web and Compact Disk.

4.1 GIS Model, NAGA 2.1

The GIS model that was used to predict changes in chemical concentrations of the Chao Phraya River Basin, NAGA 2.1, is a result of the development of previous NAGA models 1.0, 1.2, and 1.3. The NAGA 2.1 model incorporated runoff changes in the basin by using similar code from NAGA 1.0 and NAGA 1.2. It also applied ArcView techniques that were used in NAGA 1.3 to analyze the chemical results from the model. With ArcView, the user can view changes in chemical concentrations utilizing a visual theme.

We modeled alkalinity, COD, BOD and pH of the Chao Phraya River Basin, and had the computer predict the concentrations of these chemicals in one year. NAGA 2.1 produced data so that we could view river discharge, runoff, and precipitation on a map. Our GIS map spanned from just south of Nakhon Swan to north of Bangkok. This is a good combination of both the populated and industrialized region of Thailand, excluding Bangkok, at the bottom of the map, and a more rural region towards the top of the map. Our map was compared to another map that consisted of averaged chemical values that had been gathered over previous years. These computed concentrations from the NAGA 2.1 model are the most probable occurrences in the future, given our data and current trends.

Results

4.1.1 Alkalinity Correlation

The alkalinity layer displays a measure of the river's ability to neutralize acid. Alkalinity is necessary in the right concentrations to buffer the water system. Too much or too little inhibits aquatic life.

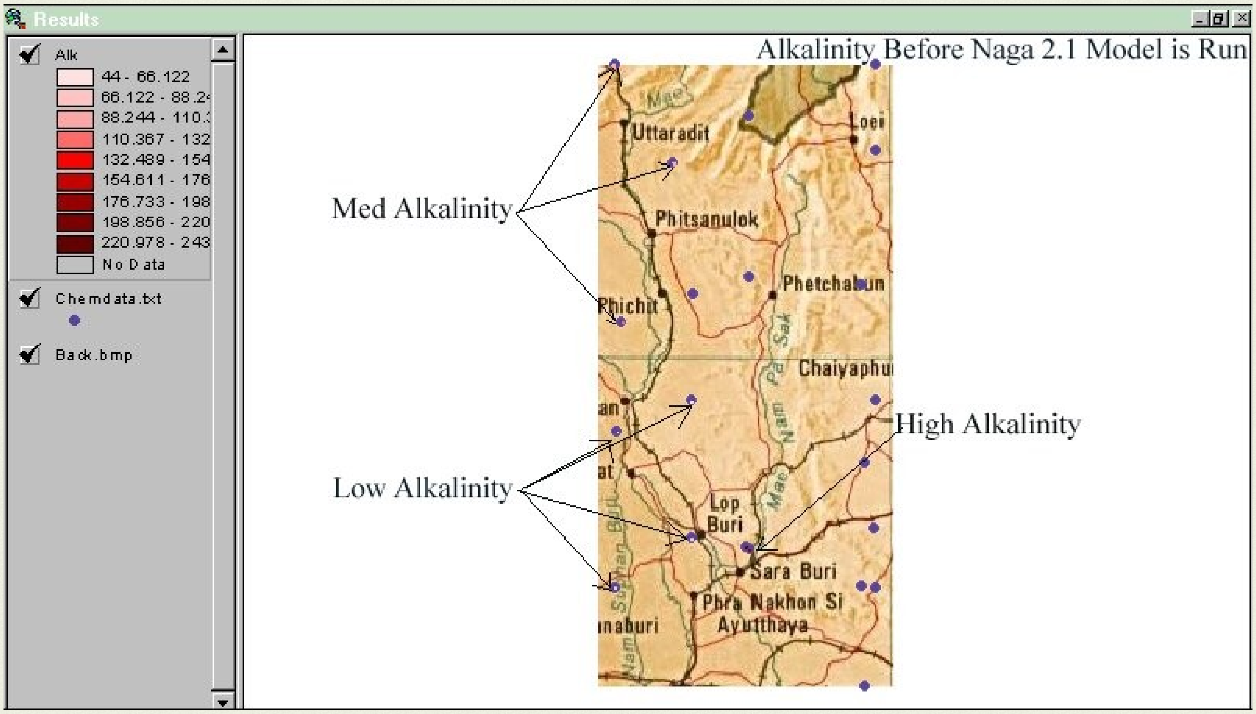


Figure 4.1. Average Alkalinity Data

The averaged alkalinity levels before the model was run are displayed in Figure 4.1. The northern section of the map displays more alkalinity than the middle section. Most values are as expected, except where the Pa Sak River enters the Chao Phraya River, where there is a high alkalinity value.

Results

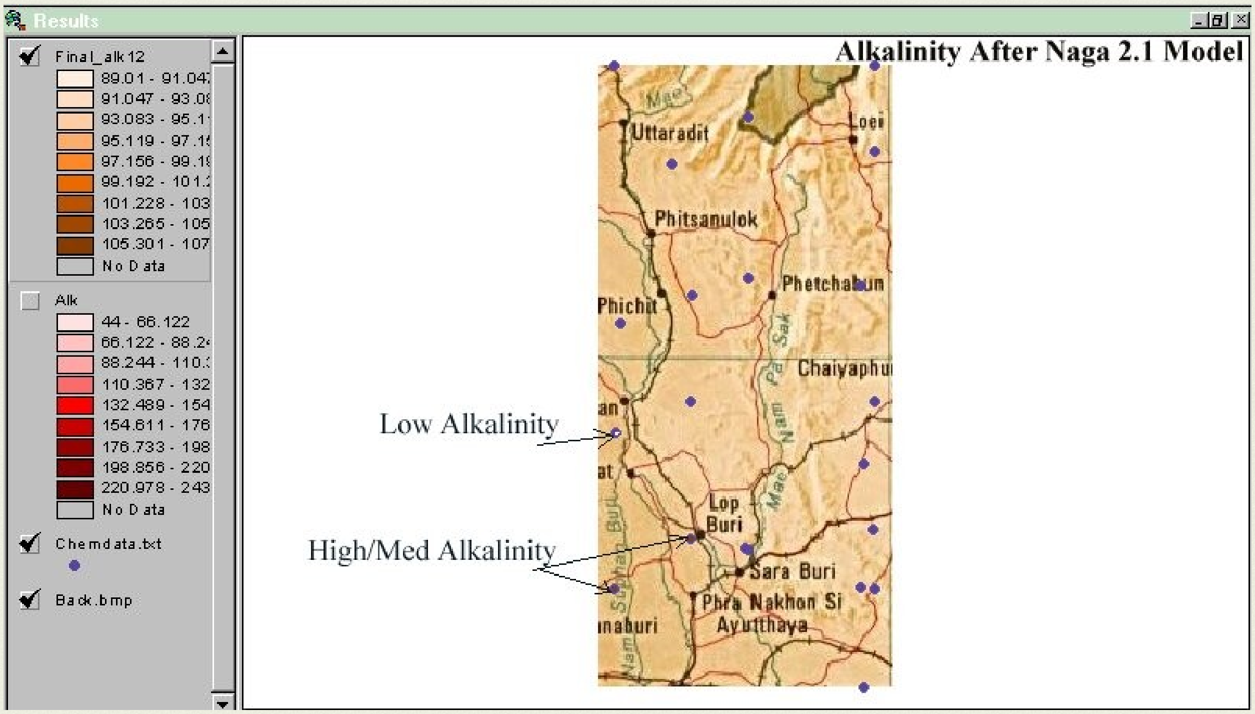


Figure 4.2. Alkalinity Data From NAGA 2.1 Prediction

The alkalinity model was run for twelve months, and the results are shown in Figure 4.2. GIS predicted an average alkalinity near the intersection of the Pa Sak River and the Chao Phraya, and predicted that further north there would be a lower alkalinity value. The middle and bottom sections of data did not noticeably change over the twelve-month period. Many of the northern sites experienced little or no difference; however, the southern regions did endure rising alkalinity levels. This means that twelve months from February 2000, the alkalinity concentrations should higher.

4.1.2. COD Correlation

The COD layer displays the amount of oxygen needed in the water to reduce the chemicals to their most stable states. The COD data before the model was run can be seen in Figure 4.3.

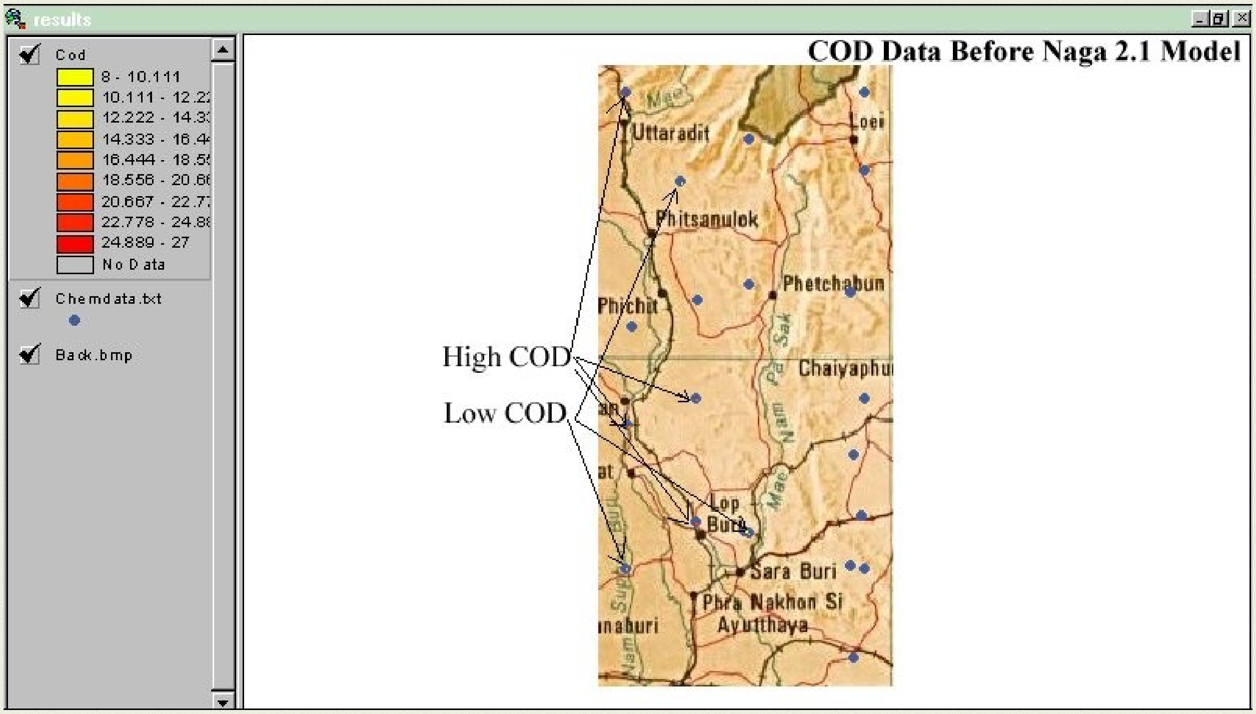


Figure 4.3. Average COD Data

Data of COD concentrations were randomly spread, so it is difficult to see any correlations between the concentrations. This shows that there is no pattern between average population density and COD. However, each point of high COD could be situated near or on a factory which deposits chemicals into the water.

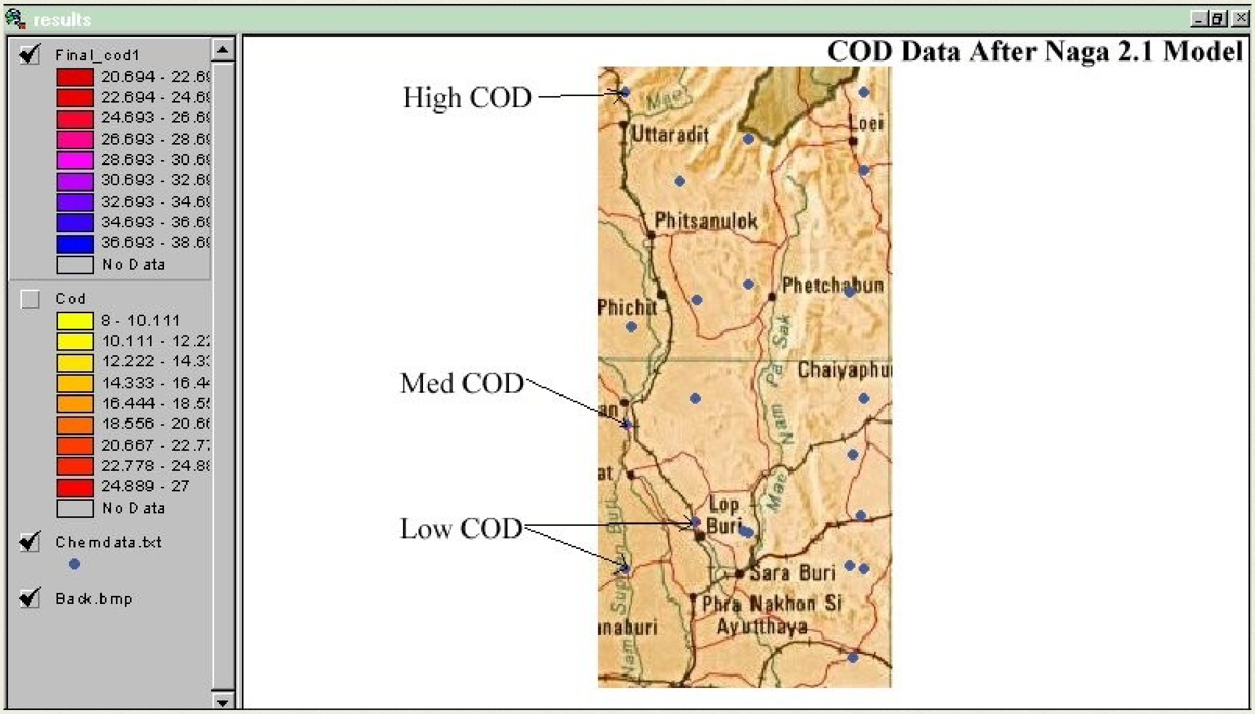


Figure 4.4: COD Data From NAGA 2.1 Prediction

The COD model was also run for twelve months and the results are displayed in Figure 4.4. This map shows high COD concentration at the upper most stations, a medium concentration at the middle stations, and a low COD concentration at the lower stations. We assumed these results are most likely due to pesticides and fertilizers on the farms in the upper regions, because there was a great deal of seasonal change among the values.

4.1.3. BOD Correlation

The BOD layer displays a measure of the amount of dissolved oxygen needed to completely break down organic matter. Most BOD in a river is a result of storm runoff or municipal waste.

Results

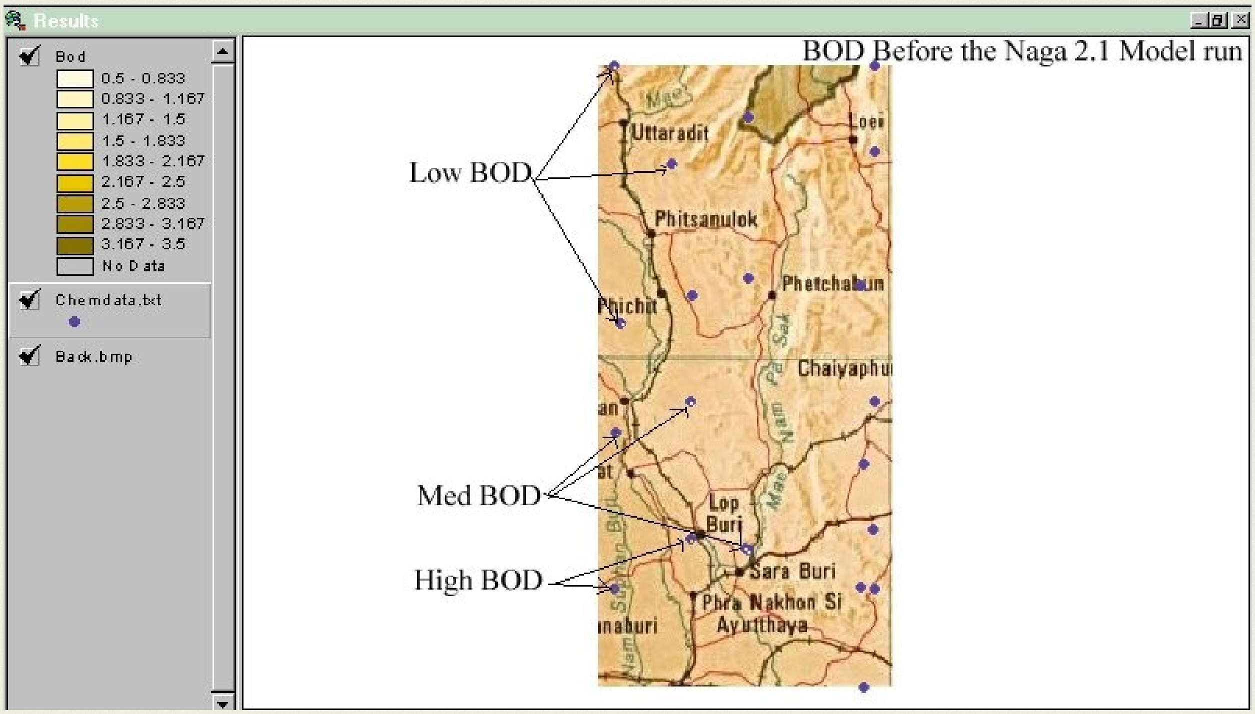


Figure 4.5: Average BOD Data

The BOD data before the model was run is shown in Figure 4.5. This map shows a clear division of BOD concentrations. The top of the map has low BOD concentrations, the middle section has medium concentrations, and the bottom has high concentrations. Further south, near Bangkok, there is higher BOD concentration most likely due to the population intensity and poor waste disposal.

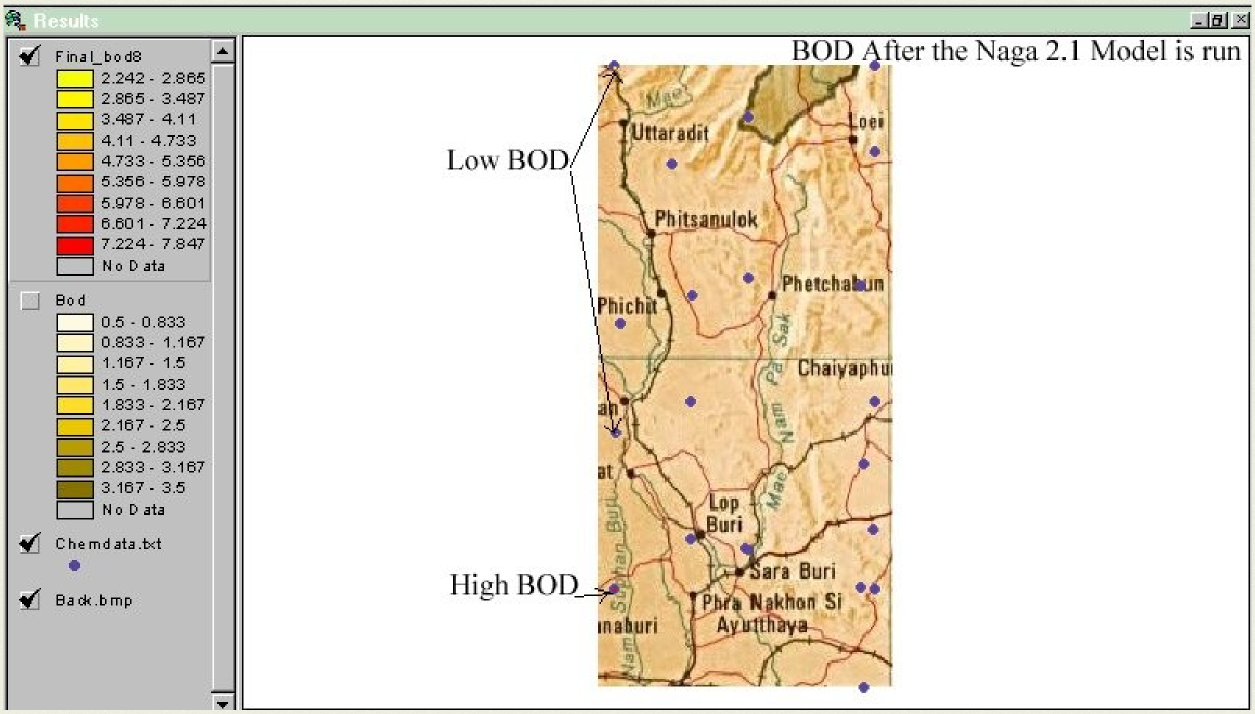


Figure 4.6: BOD Data from NAGA 2.1 Prediction

The predictions that the BOD model made after running for twelve months are displayed in Figure 4.6. These values are similar to the averages before the model was executed. The main difference is the lower BOD concentration sites in the upper reach. This could mean that the BOD concentrations will be getting better in these regions or that there is some error.

4.1.4. Correlations Regarding pH

The pH layer displays the acidity of the water at different locations. As there is only a narrow pH in which life can survive, the scale that we used was very rigid; high and low pH values in our map are at most plus or minus one unit from neutral, which is seven.

Results

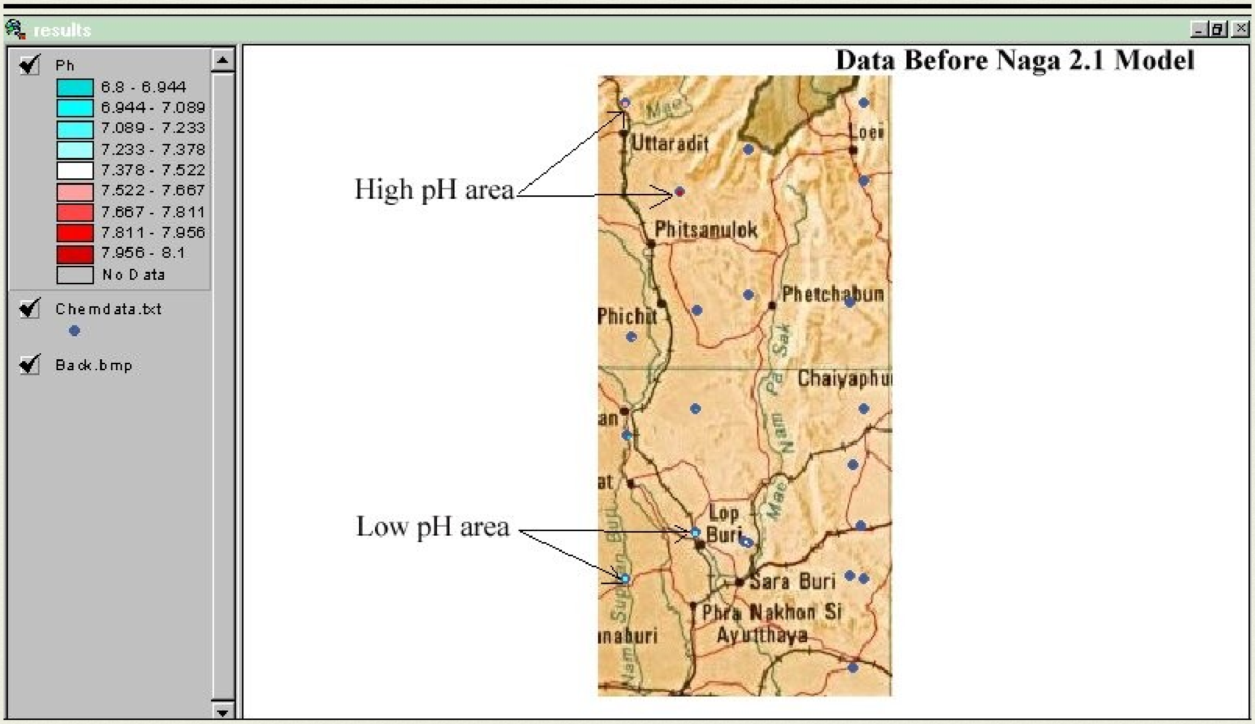


Figure 4.7: Average pH Data

The results of the pH test are displayed in Figure 4.7. Before the model is run, the average pH is high in the upper region and low in the lower region. This was unexplainable, but we feel that the data was accurate and plentiful enough so that there is little chance of error.

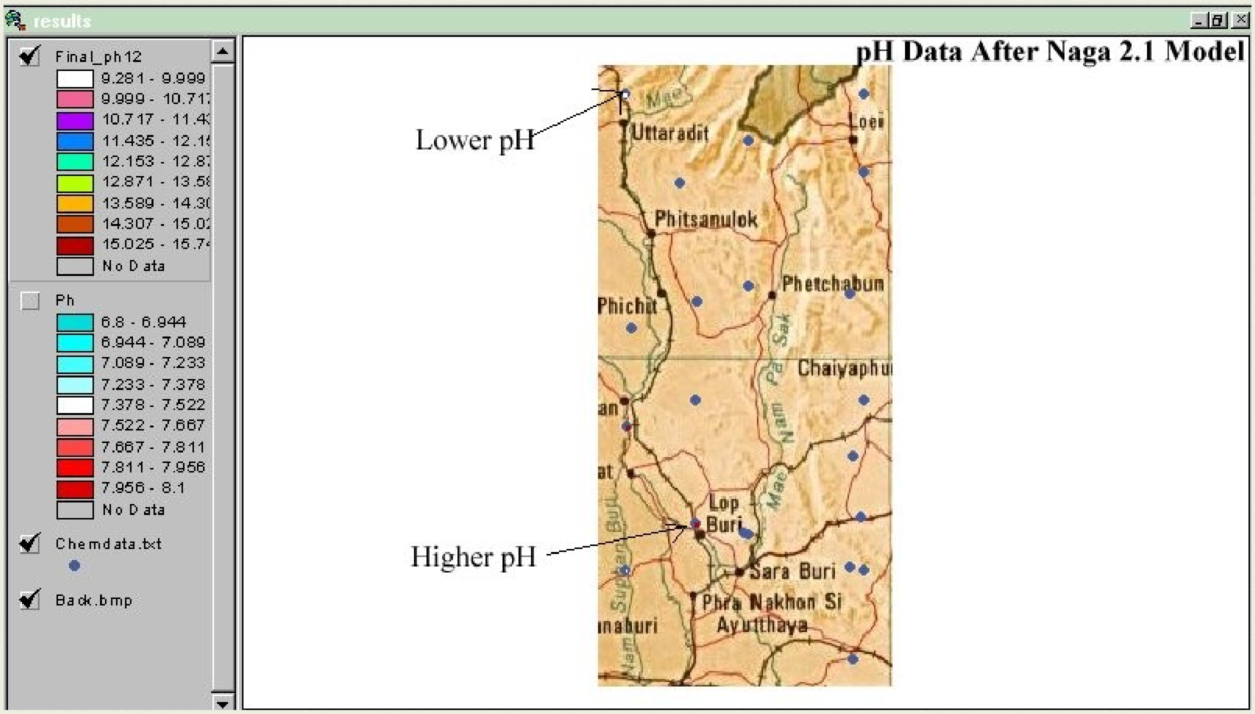


Figure 4.8: pH Data from NAGA 2.1 Prediction

The pH results predicted by the model are shown in Figure 4.8. The pH values seem to be reversed after the model is run for one year. However, now the readings seem more logical. There is more vegetation in the water of the upper region, which produces acid as a photosynthetic by-product. In addition, the lower region has a high pH which is indicative of little aquatic vegetation. This can easily explain why pH is lower in the upper region and higher in the lower region.

4.2 Results of Water Testing of the Chao Phraya River

We gathered water samples for testing from the Chao Phraya River to gather water samples for testing. We were looking for varying intensities of pollution indicators, such as COD, BOD, pH, and alkalinity at the eight gauging stations along the river.

Results

Station #	Location	Province
Station 1	Prasamut Jaedee	Samut Prakan
Station 2	Prapadang	Samut Prakan
Station 3	Sathorn Bridge	Bangkok
Station 4	Rama VI Bridge	Bangkok
Station 5	Bang Pa-In	Ayutthaya
Station 6	Bridge at Nakhon Luang	Ayutthaya
Station 7	Bang Pa Han	Ayutthaya
Station 8	Muang District	Ang Thong

Figure 4.9: Eight sites for water testing

We had only one day for water testing, so we carefully chose the sites shown in Figure 4.9. After our samples were taken we performed lab tests.

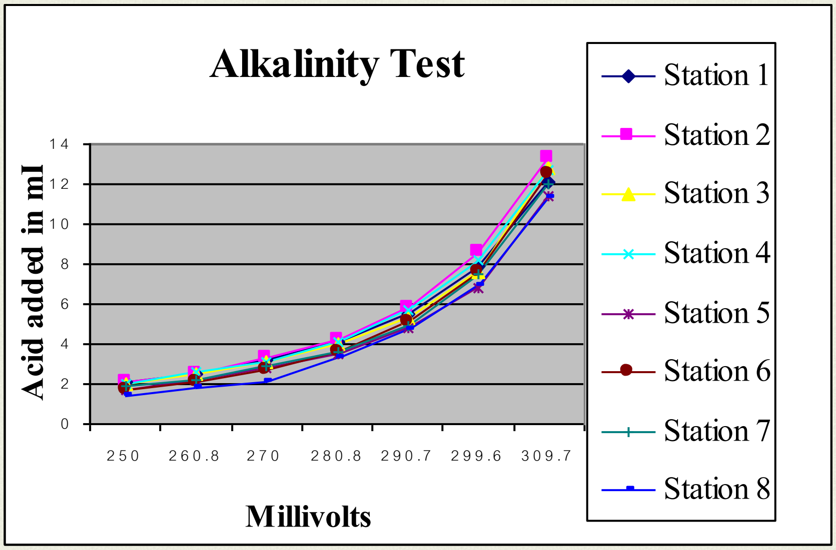


Figure 4.10: Results of alkalinity test

The results of our alkalinity test are shown in Figure 4.10. This chart shows the amount of acid added to our water samples versus millivolt conductivity in increments of ten. This test measures the water's ability to neutralize acid. All the samples taken from their respective locations exhibit similar curves. This similarity most likely means that there is little or no correlation between population densities, the use of the river, and the alkalinity in the river.

Due to time constraints, we used last year's COD, BOD, and pH test data to compare with our model's predictions. We selected the data from February of last year so that the river system would be under the most similar conditions. Data correlation was only possible using the old data.

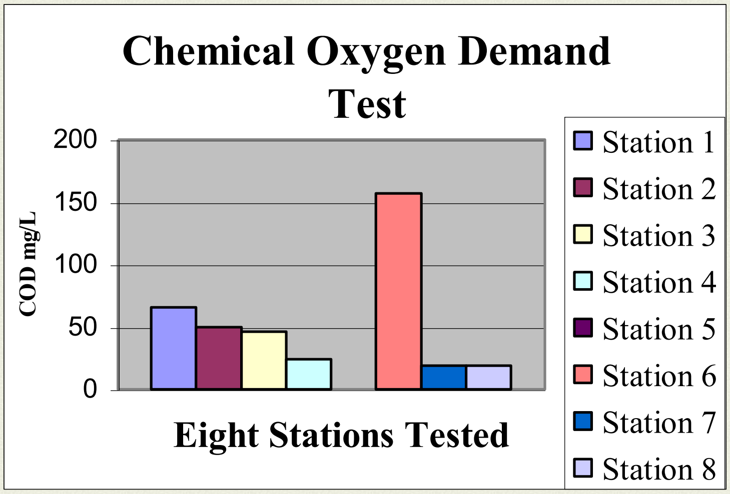


Figure 4.11: Results of COD test

Last year the COD test was accurately performed on all sites except for station six, as shown in Figure 4.11. Our data shows a higher concentration of COD around the industrialized part of the river, and a decreasing value further north. Station six's high reading can most likely to attributed to either poor testing procedures or to an extreme amount of pollution entering the river close to the gauging station. It would have been very beneficial to have the station five data because this is the site where the Pa Sak River enters the Chao Phraya. As shown in this figure, the Pa Sak River has a very high COD. Using this data we will compare with our GIS model to see if it confirms the COD values increasing around Bangkok.

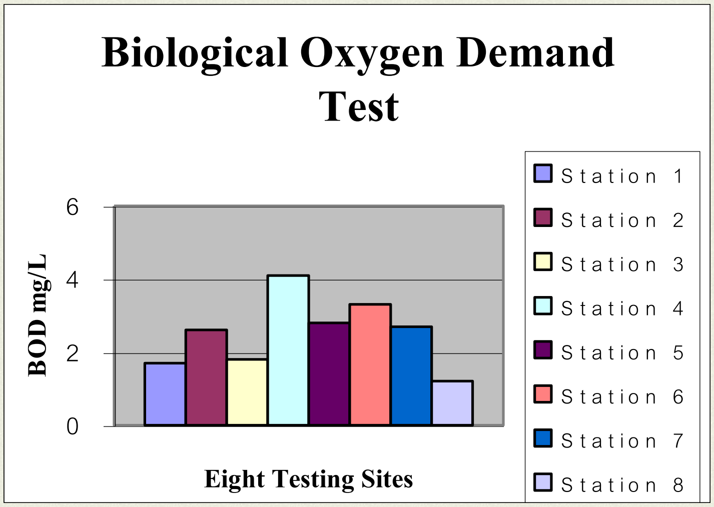


Figure 4.12: Results of BOD Test

The result of our BOD test is shown in Figure 4.12. There could be no definite correlations between the BOD values and location along the river. There is a definite increase in BOD north of Bangkok, but it seems erratic and starts to decrease again at station seven and eight.

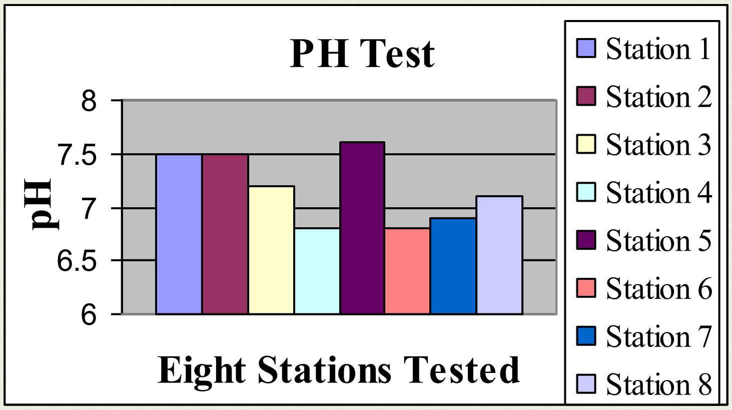


Figure 4.13: Results of the pH test

The pH test shows the existence of a more basic aquatic environment in the Bangkok area, and a more acidic aquatic environment in the northern regions, as shown in Figure 4.13. This result could be explained because the weak acid normally produced by photosynthesis is non-existent because there is little or no plant life in the river around Bangkok.

4.3 Testing the Model with River Data

The data from our day trip to the Chao Phraya River was compared with our GIS predictions. Most of our data correlated very well. Time constraints prevented us from testing the model for precision, or calibrating it using actual data.

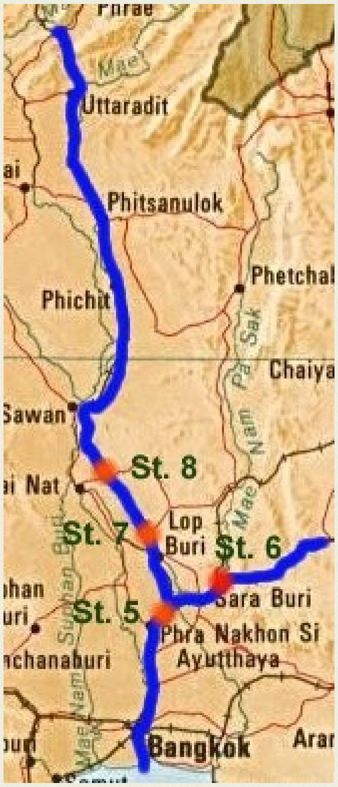


Figure 4.14: GIS output and gauging stations included in map

Three gauging stations overlapped with our GIS maps so that we could compare the data from both as a preliminary test of our model, as shown in Figure 4.14.

The alkalinity tests produced similar results. The GIS model predicted that there would be low alkalinity levels in the mid to northern region, and high alkalinity in the southern region. The data used was from last year, when the conditions may have been different.

The COD data we put together from last year had no value for station five, while station seven and station eight had relatively similar low values. This data was very similar with the COD prediction in the middle region of our GIS model.

The model's predictions of the BOD data we collected correlated very well. In our prepared model, data station five and station seven had high values when compared with station eight, which was unexplainably low. The data was similar throughout the sites. The GIS model predicted a high BOD concentration in the south that decreased in the mid to upper regions much like our data.

The pH data test also correlated to the model's predictions. The pH was lower in the mid region, and higher in the southern regions, which was the same for the sample data and the models predictions.

4.4 Model's Human Correlation

Outside factors introduced large amounts of chemicals in certain areas of the river basin, which we had predicted. We assumed that this was related to human use of the river, but this could not be corroborated since we did not have enough human data. Other factors that might introduce chemical increases include natural disturbances such as storms, strong winds, or erosion. Although the correlation could not be confirmed, we were pleased to discover that there was an outside factor changing concentrations in the model. Understanding what caused this concentration increase would be very valuable for creating a sustainable river. However, we did not have the time or facilities to accomplish this task.

4.5 Model's Availability

Large quantities of data are necessary to build accurate models. The data from our model is valuable not only to the user of the model, but also to researchers, environmental agencies, and environmental engineers. The availability of our model gives researchers and engineers the ability to use SEA START's data. We created a Data Query program to interface the data in our model. SEA START is in the process of making a Southeast Asia River Basins Compact Disk and a similar web utility to make the data from our model more available.

4.5.1 Data Query Compact Disk Program

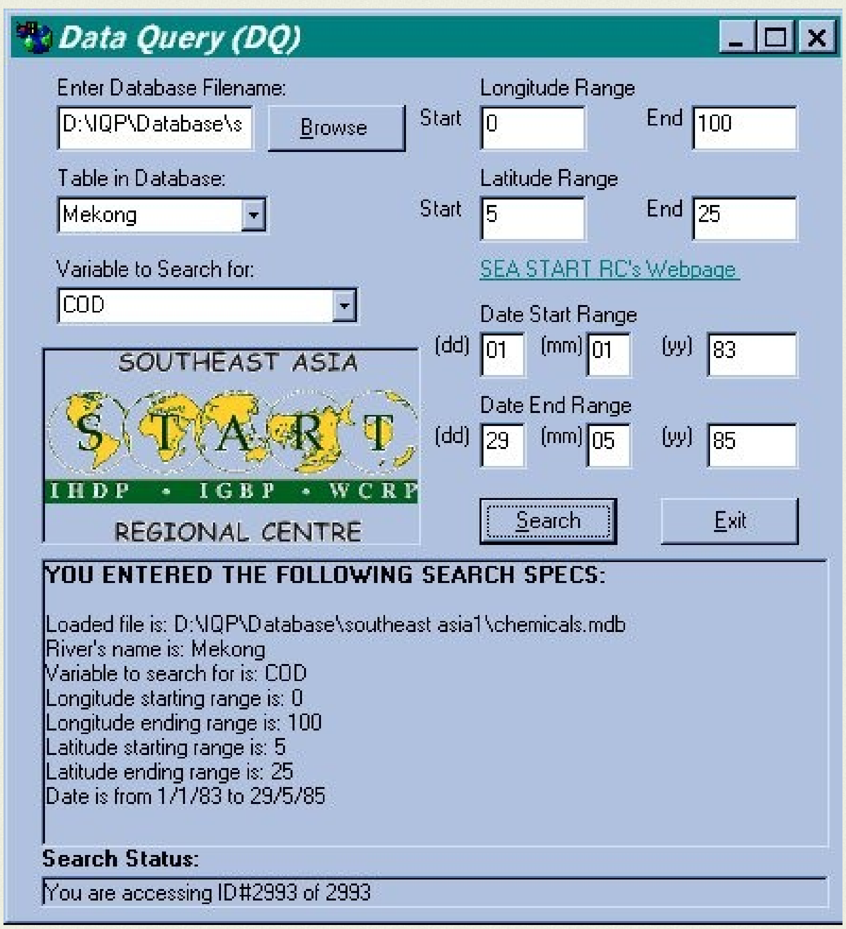


Fig. 4.15: Data Query Program

Results

The Data Query (DQ) program shown in Figure 4.15 is one of many programs that SEA START RC now has available on Compact Disk (CD). The CD includes our program and the data we compiled of the Chao Phraya River. Ranges can be entered for regional specific searches. DQ is a program developed to query for data in our GIS model. The capabilities of this program include querying various statistics such as chemicals, location, and water properties of the Chao Phraya River. Data from selected regions of the basin such as longitude, latitude, date, and temperature can be entered to search from the compiled databases in Microsoft Access format. The range search will truncate the data and display the results in a logical order.

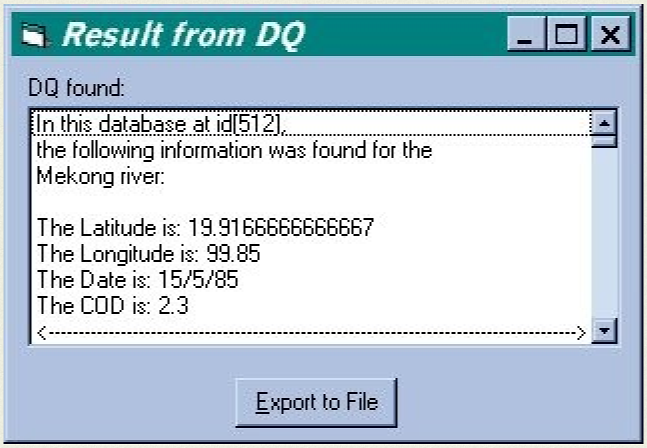


Fig. 4.16: Sample Result from DQ

Sample results from a DQ search are displayed in Figure 4.16. Also included in the program is the ability to export the information found to a text file. This tool allows the scientific community to use and understand information that would otherwise be inaccessible.

4.5.3 Chao Phraya Chemical Runoff Model Website

Figure 4.17: Website for this project: http://www.start.or.th/cpriver

To make information about our project and related studies immediately available, we created a website, as displayed in Figure 4.17. This website provides background information and project data along with downloadable objects. Documents and related model files, as well as this report, are available to download. Questions, related concerns, or feedback can be posted on the website.

Chapter 5: Conclusions

Conclusions

Our project provided us with an understanding of both the aquatic system of the Chao Phraya River, and the possibility for GIS models to be made of other rivers. Our model has the potential to be a valuable building block for future GIS models, just as the "Integrated Regional Model of River Basins in Southeast Asia" (IRMRBSA) provided our foundation [Kowalik, et al., 1999]. Our model forms a more complete simulation of the Chao Phraya River and all of its human and biological interactions.

5.1 Summary

We concluded that our GIS model was able to predict values for pH, BOD, COD, and alkalinity for the Chao Phraya River. With our GIS model, researchers will be able to evaluate these four concentrations, and using past data, monitor pollution levels of the present and future. As our model will be downloadable from the World Wide Web and accessible from Compact Disk, scientists will be able to manipulate the GIS code, and utilize the model on rivers other than the Chao Phraya. With the pollution analysis of these rivers, environmentalists and researchers alike will be able to determine where the largest contamination problems arise. These models can also be used to persuade companies and politicians to advocate changes in the production and disposal methods of the wastes that are detrimental to the environment.

5.2 Recommendations

Even the most accurate GIS models can have supplementary layers added, or have its original layers rearranged, in order to create a more exact and informative model. Such is the case of our model; improvements can be made by restrucuring or altering the code, collecting more data, or adding or rearranging its layers. Another enhancement could be made by using more specific and defined coding, and/or writing better Arc Macro Language (AML) scripts.

In the future, COD and alkalinity can be used to calibrate our model for more accurate predictions. At this time, we are unable to determine what the margin of error currently is for the COD and alkalinity levels, because we do not feel that our data is substantial enough to provide precise concentration values.

The number of loops and code checks in the GIS scripting, known as its algorithm, dictates how quickly the model runs. Improving this code would increase the efficiency of the model.

More tests and analysis of the model are recommended. These tests can be accomplished by running the model several times and ensuring that the same results are obtained.

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Appendix A:
GIS Technical Background

GIS is a computer-based tool for mapping and analyzing events on the earth. This computer system uses layers compiled together to make a final map. Grids are vertical and horizontal lines evenly spaced to align the data in each layer into X/Y coordinates. AML and Avenue scripts are small-scale codes involved in the GIS programs.

A.1. GIS Layers

GIS Layers are a simple way of organizing variables and constants in a GIS model. In ArcView, the layers compile to make a two-dimensional layer map, where one layer is transparently on top of the other. Other GIS programs such as Surfer can display precompiled layers.

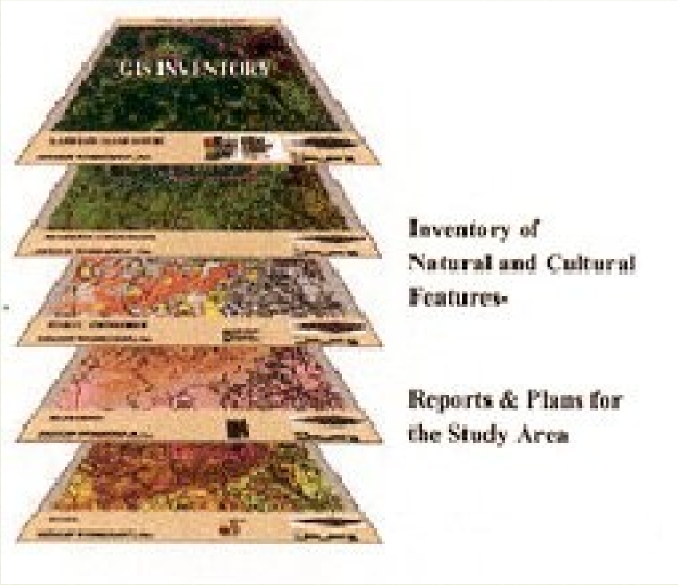

Figure A.1: Sample of precompiled GIS layers

Precompiled GIS layers can be seen in Figure A.1. The figure represents the forest and soil percentage near a watershed. The layers are organized by importance. The closer the layer is to the top, the more significance it has in the model. The topmost layer is the main object modeled.

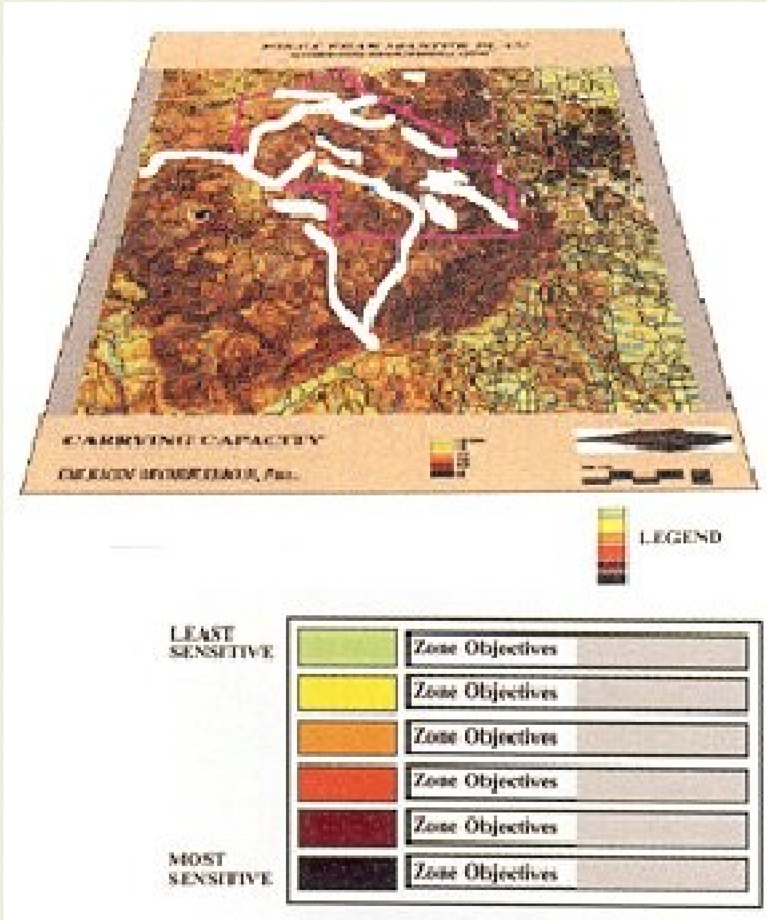

Figure: A.2 Compilation of GIS layers onto a map with a legend

A three-dimensional layer map is displayed in Figure A.2. In this figure, the zones are actually GIS layers. The sensitivity of the layers is automatically color-coded to visually show which layers are more important. The GIS model can also be automatically color-coded to show the values in each layer. In addition to the layers, a legend can be added. The legend can display the sensitivity of each layer or what each layer represents.

A.2. Grids

Grids are evenly spaced vertical and horizontal lines that can be placed on the layers. The purpose of using grids is to align the data each in layers onto X/Y coordinates. All data used in the GIS layers can be converted into grids. The advantage of having X/Y coordinates is to easily find the value at any X/Y coordinate on the map. All the data on the grids can be easily stored in Grid tables, which is in a special format. The format is called ArcInfo Grid. Using special features in ArcView known as extensions, ArcView can read and convert the data into an ArcInfo Grid.

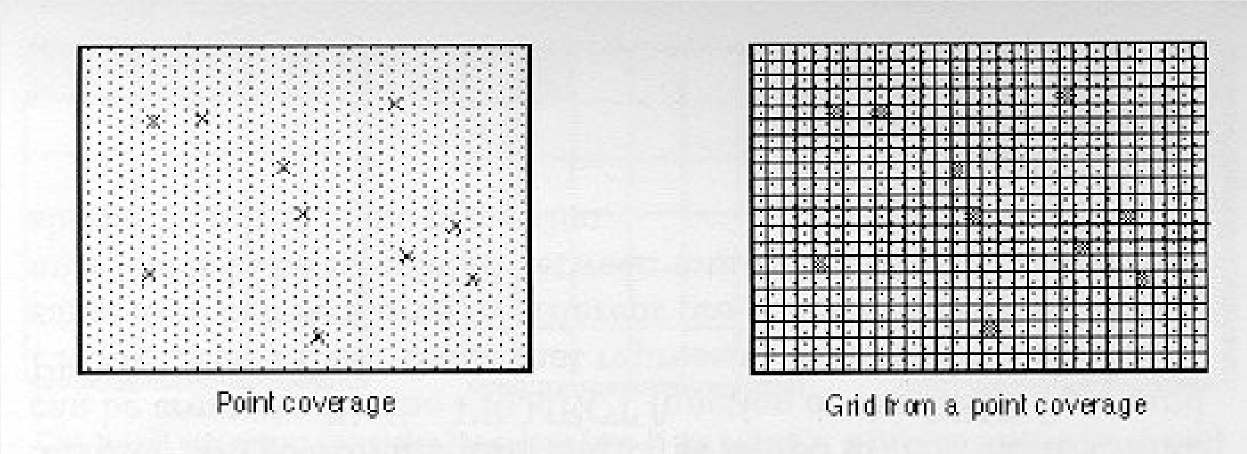

Figure A.3: Grid conversion of a point system

An example can be seen in Figure A.3 of a grid conversion from a point system. This system pixelizes the point system to a grid setup. The smaller the grid sizes, the higher the quality of the conversion. Besides pixels, grid conversion can also be applied to lines and polygons.

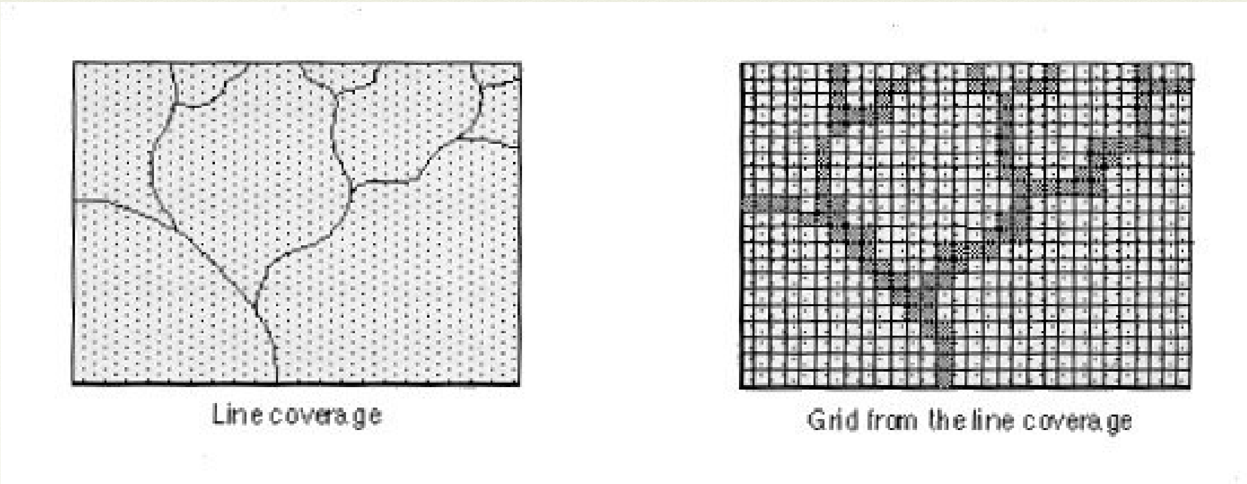

Figure A.4: Grid Conversion of a line system.

An example of grid conversion from a line system can be seen from Figure A.4. Notice the large pixel sizes in the grid causing the lines to be distorted. Again, a smaller pixel size use in the grid conversion will improve the quality in the conversion. Normally in many GIS Grid programs, this grid pixel size can be set by the user.

A.3. Extensions

Extensions are added features to a program that extends the program's capabilities. The extensions in ArcView are in (.avx) format. Spatial Analyst is a useful but expensive extension in ArcView that can be use to handle ArcInfo Grids. Other extensions can do model cropping or model conversions such as warping, hydrology modeling, or jpeg image conversion. These features prove very useful in specific situations. More complicated and useful extensions can be purchased from ESRI. If a simple extension is only needed to do a small calculation, then it can be downloaded from their website. The website is at http://gis.esri.com/arcscripts/scripts.cfm.

Some extensions come with scripts to show how to use the extension and to make the extension more productive.

A.4. AML and Avenue Scripts

AML and Avenue scripts are small scale coding available for two GIS programs, ArcInfo and ArcView respectively. Since ArcInfo handles data better than ArcView, the AML handles and manages data better than Avenue. Some of AML's capabilities include multiplying grids together on a cell by cell basis, comparing different grid values at each X/Y coordinate, connecting through a network known as NetStorm, or formatting the data to another format. Some of Avenue's capabilities include manipulating themes or views, making charts, or making visual buttons to run scripts in ArcView.

There are also readily–made available courses online related to the use of GIS. They extend over the theory and tools, along with the use of them in the real world [ESRI – Virtual Campus: 1999].

Appendix B:

NAGA 1.2 ArcInfo AML Code

Appendix B NAGA 1.2 ArcInfo AML code

```
/* ---------------------------------------------------------
/* NAGA 1.2 Easier to understand Runoff model
/* SEA START
/* Files are located on SEAGIS Solaris Machine
/* Filename is NAGAnew.aml
/* Require the grids in the masterc/new_model folder
/* Modified by Channarith Vanthin
/*
/* Model Description:  This is a modified version of
/* last year's Integrated Regional Model.  Runoff
/* is the grid layer being modeled here.  This version
/* includes easier to understand comments and better
/* codes.  Plus, this works.
/* Feb. 9, 2000
/* ---------------------------------------------------------

/* This sets the working directory
/* What this means is that the path where the grid folders are
/* stored is in this path "work2".
&sv path = work2

/* This sets the output path.
/* This means that the result of the model will be stored in this
/* folder.  So when you want to see the results, you can open this
/* folder as a theme in ArcView.
&sv outpath = run21

/* CONSTANT COEFFICIENTS
/* These are variables that are used throughout the calculations.
/* These don't change.  How well the model runs depends on these
/* constant coefficient assumptions
&sv fsmax = 0.02                /* This is the maximum field storage constant
&sv fsmin = 0.01                /* This is the minimum field storage constant
&sv fsexp = 1                          /* This is the exponential value of the field storage
                                       /*        This value affects the exponential correlation of the
                                       /*        field storage in the model.  (Very Important Correllation)
&sv kbas =  0.015 * 30.4375     /* This is a coefficient used in for the soil conductivity
&sv ekbas = exp(- %kbas%)       /* This is simply the exponential of the negative coefficient for kbas
                                       /*        after calculation, ekbas = .6334574171

/* CANOPY INTERCEPTION
/* Basically, these procedures map all the monthly
/* Canopy inputs of the model to the variables:
/* rint1a - rint12a, dfrac1a - dfrac12a,
/* rint1b - rint12b, dfrac1b - dfrac12b,
```

```
/* and thrufall1 - thrufall12
&do mth &list 1 2 3 4 5 6 7 8 9 10 11 12                    /* Loop to do this 12 times
rint%mth%a = %path%/frint * %path%/precip%mth%
/* rint#a (# = mth number) = intermediate rain intercept for that month
/* precip# = precipitation
/* EQUATION: rint#a = frint x precip#

dfrac%mth%a = 1 - (rint%mth%a / %path%/pet%mth%)
/* dfrac#a = intermediate fraction of the remainder of the rain intercept
/* pet# = potential evapotranspiration
/* EQUATION: dfrac#a = 1 - (rint#a / pet#)
rint%mth%b = con(dfrac%mth%a < 0, %path%/pet%mth%, rint%mth%a)
/* rint#b = final rain intercept for that month
/* CONDITION: if dfrac#a is less than 0,
/*            then rint#b is equal to the pet#
/*            else rint#b is equal to rint#a
dfrac%mth%b = con(dfrac%mth%a < 0, 0, dfrac%mth%a)
/* dfrac#b is the final fraction of the remainder
/* of the rain intercept
/* CONDITION: if dfrac#a is less than 0,
/*            then dfrac#b is 0
/*            else dfrac#b = dfrac#a

thrufall%mth% = %path%/precip%mth% - rint%mth%b
/* thrufall# = throughfall
/* EQUATION: thrufall# = precip# - rint#b

&end
&type Canopy done                                           /* finishes the mapping of the Canopy Inputs

/* START SIMULATION
/* Beginning of the model



/* STEP ONE: setup loop for 12 months and 4 years
/* Year counter
/* This model runs for 4 years
&do count = 1 &to 4 &by 1
/* Month counter
/* It calculates on a monthly basis for 4 years
&do mth &list 1 2 3 4 5 6 7 8 9 10 11 12
```

```
/* STEP TWO: setup and calculate the surface flow and infiltration
/* SOIL SURFACE THROUGHFALL INFILTRATION
/* This section handles and calculates the throughfall and infiltration on the soil's surface
/* awcmm = available water content in mm
/* $ = yearly count number
/* soilup$_(#-1) forces the soil to have a (#-1) value
/* (#-1) refers to the previous month's data
/* for example: soilup1_0 forces all zero
/* aqs$_# = intermediate amount of surface flow
/*                                                                     fsexp
/* EQUATION: aqs$_# = fsmin + (fsmax-fsmin) x (soilup$_(#-1)/awcmm)
aqs%count%_%mth% = %fsmin% + (%fsmax% - %fsmin%) * pow((soilup%count%_[calc %mth% - 1] / %path%/awcmm), %fsexp%)

/* qs$_# is the completed surface flow amount
/* EQUATION: qs$_# = aqs$_# x thrufall#
qs%count%_%mth% = aqs%count%_%mth% * thrufall%mth%

/* infiltrn$_# is the infiltration amount for the specific month and year
/* EQUATION: infiltrn$_# = thrufall# - qs$_#
infiltrn%count%_%mth% = thrufall%mth% - qs%count%_%mth%
&type Soil surface done                                  /* finishes up the soil surface calculation



/* STEP THREE: setup PET from the upper soil surface data
/* POTENTIAL TRANSPIRATION FROM UPPER SOIL SURFACE
/* theta$_# is change in the soil from the previous month with the wilting point
/* wpmm = wilting point in mm
/* EQUATION: theta$_# = soilup$_(#-1) + wpmm
theta%count%_%mth% = soilup%count%_[calc %mth% - 1] + %path%/wpmm

/* fss$_# is the fraction of soil storage amount for the specified month and year
/* sscmm is the soil storage capacity in mm
/*                                 4              4      4      4
/*                         [(sscmm ) - (theta$_# )] x [(sscmm ) - (wpmm )]
/* EQUATION: fss$_# = 1 -  ------------------------------------------------------------
/*                                                 4            4
/*                                     [(theta$_# )]  x [(wpmm )]
/*
fss%count%_%mth% = 1.0 - ((pow(%path%/sscmm, 4) - pow(theta%count%_%mth%, 4)) / pow(theta%count%_%mth%, 4)) / ((pow(%path%/sscmm, 4) -
pow(%path%/wpmm, 4)) / pow(%path%/wpmm, 4))

/* at_unsat$_# is the amount of atmospheric unsaturation for the specified month and year
/* EQUATION: at_unsat$_# = fss$_# x pet#
at_unsat%count%_%mth% = fss%count%_%mth% * %path%/pet%mth%
```

```
/* at_net$_# is the net amount of atmospheric flux
/*
/* EQUATION: at_net$_# = [((1 - aqs$_#) x (at_unsat$_#)) + (aqs$_# x pet#)] x dfrac#b
/*
at_net%count%_%mth% = (((1.0 - aqs%count%_%mth%) * at_unsat%count%_%mth%) + (aqs%count%_%mth% * %path%/pet%mth%)) * dfrac%mth%b
&type Potential Evapotranspiration done                    /* finishes up the PET calculations


/* STEP FOUR: setup Soil Moisture and Transpiration
/* UPPER LAYER SOIL MOISTURE AND ACTUAL SOIL TRANSPIRATION
/* su$_#a is the initial upper soil parameter
/* EQUATION: su$_#a = soilup$_(#-1) + infiltrn$_# - at_net$_#
su%count%_%mth%a = soilup%count%_[calc %mth% - 1] + infiltrn%count%_%mth% - at_net%count%_%mth%

/* Assign drainage depending on su and awcmm
/* drainage$_# is the water drainage amt based on the upper soil and the available water content
/* CONDITION: If su$_#a is less than or equal to the awcmm then
/*      drainage$_# = 0
/*      else drainage$_# = su$_#a - awcmm
drainage%count%_%mth% = con(su%count%_%mth%a <= %path%/awcmm, 0.0, su%count%_%mth%a - %path%/awcmm)

/* Adjust Upper soil in case undershot and to account for drainage
/* CONDITION: If su$_#a is less than 0 then
/*          su$_#b  = 0
/*          else su$_#b = su$_#a
su%count%_%mth%b = con(su%count%_%mth%a < 0.0, 0.0, su%count%_%mth%a)
/* CONDITION: If su$_#b is greater than awcmm then
/*          soilup$_# = awcmm
/*          else soilup$_# = su$_#b
soilup%count%_%mth% = con(su%count%_%mth%b > %path%/awcmm, %path%/awcmm, su%count%_%mth%b)
&type Upper Soil done                                      /* finishes the upper soil


/* STEP FIVE: setup Groundwater and Baseflow in the runoff model
/* GROUNDWATER AND BASEFLOW
/* qg$_# is the groundwater quantity
/* HERE is when the constants kbas and ekbas come into perspective
/*
/*                         drainage$_#
/* EQUATION: soillow$_# = [----------------  x (1 - ekbas)] + [soillow$_(#-1) x ekbas]
/*                            kbas
```

```
/*
soillow%count%_%mth% = ((drainage%count%_%mth% / %kbas%) * (1.0 - %ekbas%)) + (soillow%count%_[calc %mth% - 1] * %ekbas%)

/* EQUATION: qg$_# = drainage$_# - (soillow$_# - soillow$_(#-1))
qg%count%_%mth% = drainage%count%_%mth% - (soillow%count%_%mth% - soillow%count%_[calc %mth% - 1])
&type Lower soil done                                      /* finishes the lower soil



/* STEP SIX: Outputting the runoff result
/* OUTPUTS RUNOFF
/* runoffup$_# is the upper runoff amount for the specified year and month
/* runofflow$_# is the lower runoff amount
/* EQUATION: runoffup$_# = qs$_#
runoffup%count%_%mth% = qs%count%_%mth%
/* EQUATION: runoff$_# = qg$_#
runofflow%count%_%mth% = qg%count%_%mth%
/* total runoff is the sum of the upper and lower runoffs
/* EQUATION: runoff$_# = runoffup$_# + runofflow$_#
runoff%count%_%mth% = runoffup%count%_%mth% + runofflow%count%_%mth%
&type month [value mth] year [value count]

/* DELETE UNUSED LAYERS
/* Delete the temporary grids (layers) used in the calculations
kill aqs%count%_%mth%
kill qs%count%_%mth%
kill infiltrn%count%_%mth%
kill theta%count%_%mth%
kill fss%count%_%mth%
kill at_unsat%count%_%mth%
kill at_net%count%_%mth%
kill su%count%_%mth%a
kill su%count%_%mth%b
kill qg%count%_%mth%
kill drainage%count%_%mth%
kill runoffup%count%_%mth%
kill runofflow%count%_%mth%
&end

/* calculate the upper and lower soil amounts for the end of the year
soilup[calc %count% + 1]_0 = soilup%count%_12
soillow[calc %count% + 1]_0 = soillow%count%_12

&type End year [value count]

/* DELETE OLD SOILUP AND SOILLOW
```

```
&do mth &list 1 2 3 4 5 6 7 8 9 10 11 12
kill soilup%count%_%mth%
kill soillow%count%_%mth%
&end

&end

/* DELETE OTHER LAYERS

&do mth &list 1 2 3 4 5 6 7 8 9 10 11 12
copy runoff4_%mth% %outpath%/runoff4_%mth%

kill dfrac%mth%a
kill dfrac%mth%b
kill rint%mth%a
kill rint%mth%b
kill thrufall%mth%

&do count &list 1 2 3 4
kill runoff%count%_%mth%
&end
&end

&do count &list 2 3 4 5
kill soillow%count%_0
kill soilup%count%_0
&end

&return
```

APPENDIX C:

NAGA 1.3 ArcView Description

Reader's Note: The script in Avenue for NAGA 1.3 is too lengthy to print in this IQP. If desired, it is accessible from the CD in the script folder as text files. Other needed files are located on the CD in specific.

Most GIS models lack user accessibility. Ideally, users from around the world should be able to access and use the model. Unfortunately, cost is also a major obstacle for a model's availability. ArcInfo is an expensive program and as a result, the NAGA 1.2 model cannot be accessed by many companies and research groups. NAGA 1.3 partially solves this problem by converting the code to ArcView's Avenue script. However, this script only runs the model for a period of one year. There are two main scripts in NAGA 1.3. One script handles input into the model, and the other handles output from the model.

C.1 NAGA 1.3 Input Script

The implementation and algorithm behind the Input Script is very simple and understandable. The purpose of the input script is to read in all the input data that the model will use and display it. It will be displayed as Views.

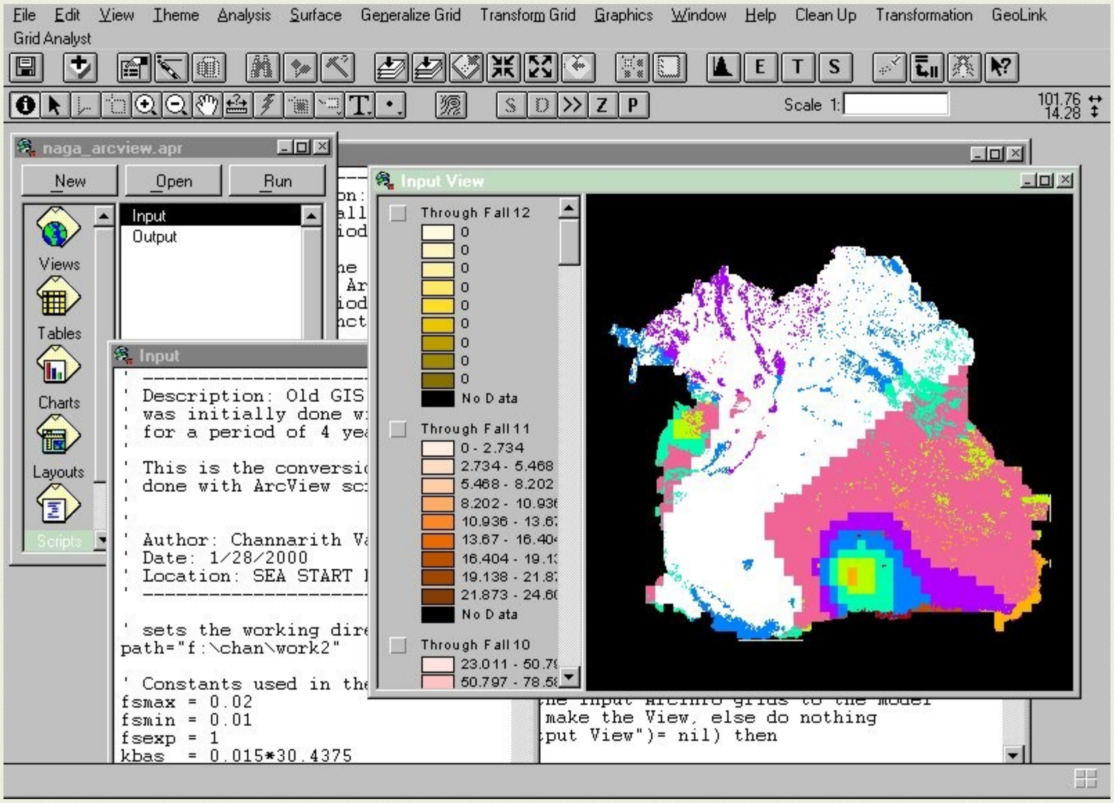

Figure C.1: Input Layer View of Through Fall DATA to NAGA 1.3

The layers, views, and script involved in the input script for NAGA 1.3 can be seen in Figure C.1. The Figure clearly shows the correlation of throughfall data that will be used in the model. An initial working directory will be required to store the input for the model. Whatever the working directory's name, one has to change the "path" variable set in the code. Other layers in ArcView can be displayed by checking the square boxes next to the layer's name. Once the grid layers are viewed as themes, one can analyze them with the charts on the left window as shown in Figure C.1 or with the "Surface" and "Analysis" feature at the top of the ArcView screen. If specific data is needed from the model, the user can click a spot on the map and an information dialog will appear giving one the numerical value at that location on the map.

C.2 NAGA 1.3 Output Script

The NAGA 1.3 output script is a direct conversion from NAGA 1.2. It incorporates all calculations done in the equations with all the conditions that the model compares. Once it completely calculates all the results, it displays them in an Output View.

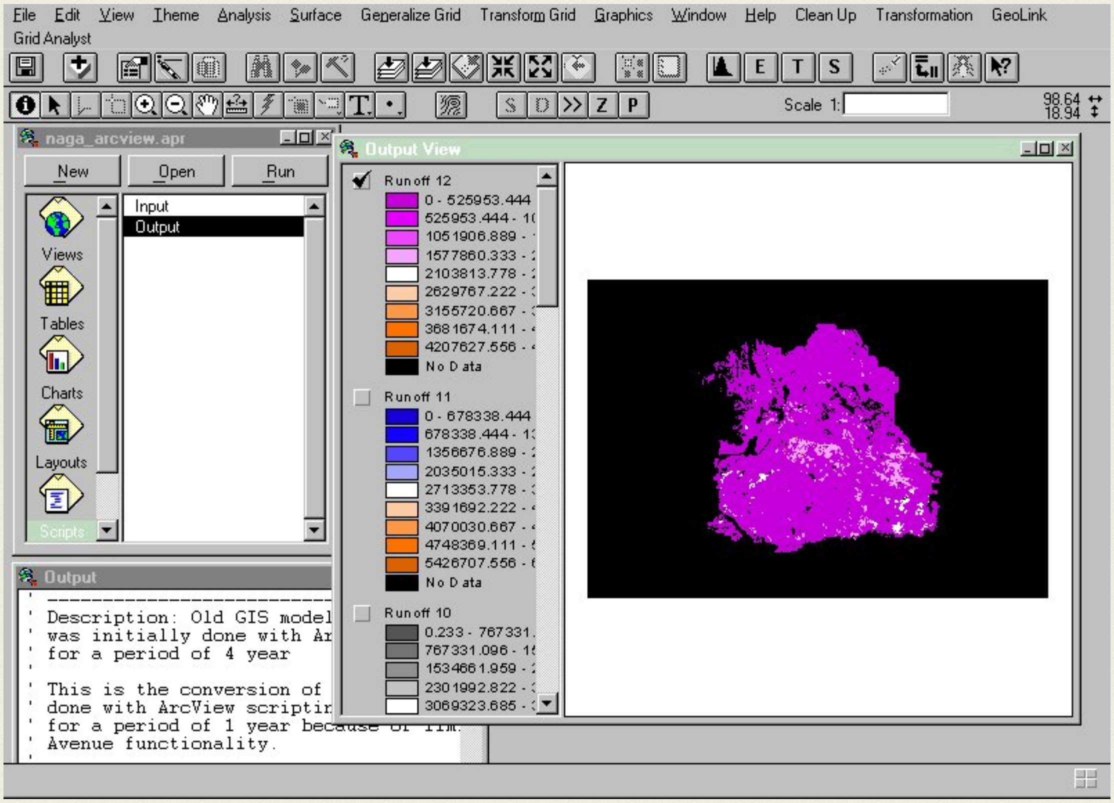

Figure C.2: Runoff from Output script in NAGA 1.3 model

The runoff prediction from the NAGA 1.3 can be seen in Figure C.2. ArcView automatically selects color gradients for the user to show distinction in different Runoff values. It can be seen that certain regions experience more runoff than others, these regions are represented by the lighter colors. Similar to the input grid, all runoff results can be analyzed and charted. The functionality and analytic capabilities of ArcView are helpful in analyzing the model's runoff prediction.

APPENDIX D:
NAGA 2.1 ArcInfo AML Code

Appendix D NAGA 2.1 ArcInfo AML Code

```
/* -----------------------------------------------------------------------------------------------
/* NAGA 2.1
/* SEA START RC
/*
/* Author: Channarith Vanthin
/* Date: Feb. 19, 2000
/*
/* File: NAGAchem.aml located in 'NAGA3_chem' folder in
/*       'masterc' account on the Seagis Solaris machine
/*
/* Description: This program will predict the movement or dispersion
/*                          of chemicals in the Chao Phraya River Basin
/*                          due to natural process such as runoffs, precipitation,
/*                          and location (lat & long).  The prediction is a yearly
/*                          prediction.  These predictions can be compared to
/*                          collected data to see any correspondence.
/* -----------------------------------------------------------------------------------------------

/* This sets the working directory
/* What this means is that the path where the grid folders are
/* stored is in this path "input".
&sv path = input

/* This sets the output path.
/* This means that the result of the model will be stored in this
/* folder.  So when you want to see the results, you can open this
/* folder as a theme in ArcView.
&sv outpath = output

/* CONSTANT COEFFICIENTS
/* These are variables that are used throughout the calculations.
/* These don't change.  How well the model runs depends on these
/* constant coefficient assumptions
&sv fsmax = 0.02                    /* This is the maximum field storage constant
&sv fsmin = 0.01                    /* This is the minimum field storage constant
&sv fsexp = 1                       /* This is the exponential value of the field storage
                                           /* This value affects the exponential correlation of the
                                           /* field storage in the model.  (Very Important Correllation)
&sv kbas =  0.015 * 30.4375    /* This is a coefficient used in for the soil conductivity
&sv ekbas = exp(- %kbas%)    /* This is simply the exponential of the negative coefficient for kbas
                                           /* after calculation, ekbas = .6334574171

/* SETUP Chemical Coefficients for movement using the
/* Ten-Fold Half process.
&sv c1 = 0.5
&sv c2 = 0.25
&sv c3 = 0.125
&sv c4 = 0.0625
&sv c5 = 0.03125
&sv c6 = 0.015625
&sv c7 = 0.0078125
&sv c8 = 0.00390625
&sv c9 = 0.001953125
&sv c10 = 0.0009765625

/* CANOPY INTERCEPTION
/* Basically, these procedures map all the monthly
```

```
/* Canopy inputs of the model to the variables:
/* rint1a - rint12a, dfrac1a - dfrac12a,
/* rint1b - rint12b, dfrac1b - dfrac12b,
/* and thrufall1 - thrufall12
&do mth &list 1 2 3 4 5 6 7 8 9 10 11 12                    /* Loop to do this 12 times
rint%mth%a = %path%/frint * %path%/precip%mth%              /* rint#a (# = mth number) = intermediate rain intercept for that month
/* precip# = precipitation
/* EQUATION: rint#a = frint x precip#
dfrac%mth%a = 1 - (rint%mth%a / %path%/pet%mth%)            /* dfrac#a = intermediate fraction of the remainder of the rain intercept
                                                            /* pet# = potential evapotranspiration
/* EQUATION: dfrac#a = 1 - (rint#a / pet#)
rint%mth%b = con(dfrac%mth%a < 0, %path%/pet%mth%, rint%mth%a)      /* rint#b = final rain intercept for that month
/* CONDITION: if dfrac#a is less than 0,
/*            then rint#b is equal to the pet#
/*            else rint#b is equal to rint#a
dfrac%mth%b = con(dfrac%mth%a < 0, 0, dfrac%mth%a)          /* dfrac#b is the final fraction of the remainder
                                                            /* of the rain intercept
/* CONDITION: if dfrac#a is less than 0,
/*            then dfrac#b is 0
/*            else dfrac#b = dfrac#a
thrufall%mth% = %path%/precip%mth% - rint%mth%b             /* thrufall# = throughfall
/* EQUATION: thrufall# = precip# - rint#b

&end
&type Canopy done                                           /* finishes the mapping of the Canopy Inputs

/* START SIMULATION
/* Beginning of the model

/* STEP ONE: setup loop for 12 months and 1 years
/* Month counter
/* It calculates on a monthly basis for 1 year
&do mth &list 1 2 3 4 5 6 7 8 9 10 11 12



/* STEP TWO: setup and calculate the surface flow and infiltration
/* SOIL SURFACE THROUGHFALL INFILTRATION
/* This section handles and calculates the throughfall and infiltration on the soil's surface
/* awcmm = available water content in mm
/* (#-1) refers to the previous month's data
/* aqs_# = intermediate amount of surface flow
/*                                                                          fsexp
/* EQUATION: aqs_# = fsmin + (fsmax-fsmin) x (soilup_(#-1)/awcmm)
aqs_%mth% = con(%mth% <= 1, %fsmin%, %fsmin% + ((%fsmax% - %fsmin%) * pow((soilup_[calc %mth% - 1] / %path%/awcmm), %fsexp%)))

/* qs_# is the completed surface flow amount
/* EQUATION: qs_# = aqs_# x thrufall#
qs_%mth% = aqs_%mth% * thrufall%mth%

/* infiltrn_# is the infiltration amount for the specific month and year
/* EQUATION: infiltrn_# = thrufall# - qs_#
infiltrn_%mth% = thrufall%mth% - qs_%mth%
&type Soil surface done
```

```
/* STEP THREE: setup PET from the upper soil surface data
/* POTENTIAL TRANSPIRATION FROM UPPER SOIL SURFACE
/* theta_# is a variable used to describe soil change
/* wpmm = wilting point in mm
/* EQUATION: theta_# = soilup$_(#-1) + wpmm
theta_%mth% = soilup_[calc %mth% - 1] + %path%/wpmm

/* fss$_# is the fraction of soil storage amount for the
/* specified month and year
/* sscmm is the soil storage capacity in mm




/*                                          4       4              4        4
/*                                   [(sscmm ) - (theta_# )] x [(sscmm ) - (wpmm )
/* EQUATION: fss_# =     1 -  -------------------------------------------------------------
/*                                                    4                  4
/*                                          [(theta_# )]  x [(wpmm )]
/*
fss_%mth% = (1 - (((pow(%path%/sscmm, 4) - pow(theta_%mth%, 4)) * (pow(%path%/sscmm, 4) - pow(%path%/wpmm, 4))) / (pow(theta_%mth%, 4) * pow(%path%/wpmm, 4))))

/* at_unsat_# is the amount of atmospheric unsaturation for the specified month and year
/* EQUATION: at_unsat_# = fss_# x pet#
at_unsat_%mth% = fss_%mth% * %path%/pet%mth%

/* at_net_# is the net amount of atmospheric flux
/*
/* EQUATION: at_net_# = [((1 - aqs_#) x (at_unsat_#)) + (aqs_# x pet#)] x dfrac#b
/*
at_net_%mth% = (((1.0 - aqs_%mth%) * at_unsat_%mth%) + (aqs_%mth% * %path%/pet%mth%)) * dfrac%mth%b
&type Potential Evapotranspiration done                                  /* finishes up the PET calculations



/* STEP FOUR: setup Soil Moisture and Transpiration
/* UPPER LAYER SOIL MOISTURE AND ACTUAL SOIL TRANSPIRATION
/* su$_#a is the initial upper soil parameter
/* EQUATION: su_#a = soilup_(#-1) + infiltrn_# - at_net_#
su_%mth%a = soilup_[calc %mth% - 1] + infiltrn_%mth% - at_net_%mth%

/* Assign drainage depending on su and awcmm
/* drainage_# is the water drainage amt based on the upper soil and the available water content
/* CONDITION: If su_#a is less than or equal to the awcmm then
/*        drainage_# = 0
/*        else drainage_# = su_#a - awcmm
drainage_%mth% = con(su_%mth%a <= %path%/awcmm, 0.0, su_%mth%a - %path%/awcmm)

/* Adjust Upper soil in case undershot and to account for drainage
/* CONDITION: If su_#a is less than 0 then
/*              su_#b  = 0
/*              else su_#b = su_#a
su_%mth%b = con(su_%mth%a < 0.0, 0.0, su_%mth%a)
/* CONDITION: If su_#b is greater than awcmm then
/*              soilup_# = awcmm
/*              else soilup_# = su_#b
soilup_%mth% = con(su_%mth%b > %path%/awcmm, %path%/awcmm, su_%mth%b)
&type Upper Soil done                                                    /* finishes the upper soil
```

```
/* STEP FIVE: setup Groundwater and Baseflow in the runoff model
/* GROUNDWATER AND BASEFLOW
/* qg$_# is the groundwater quantity
/* HERE is when the constants kbas and ekbas come into perspective
/*
/*                              drainage_#
/* EQUATION: soillow_# = [-----------  x (1 - ekbas)] + [soillow_(#-1)ekbas]
/*                                kbas
/*
soillow_%mth% = ((drainage_%mth% / %kbas%) * (1.0 - %ekbas%)) + (soillow_[calc %mth% - 1] * %ekbas%)

/* EQUATION: qg_# = drainage_# - (soillow_# - soillow_(#-1))
qg_%mth% = drainage_%mth% - (soillow_%mth% - soillow_[calc %mth% - 1])
&type Lower soil done                                          /* finishes the lower soil



/* STEP SIX: Outputting the runoff result
/* OUTPUTS RUNOFF
/* runoffup_# is the upper runoff amount for the specified year and month
/* runofflow_# is the lower runoff amount
/* EQUATION: runoffup_# = qs_#
runoffup_%mth% = qs_%mth%
/* EQUATION: runoff_# = qg_#
runofflow_%mth% = qg_%mth%
/* total runoff is the sum of the upper and lower runoffs
/* EQUATION: runoff_# = runoffup_# + runofflow_#
runoff_%mth% = runoffup_%mth% + runofflow_%mth%
&type month [value mth]



/* STEP SEVEN
/* START CHEMICAL SIMULATION
/* chemical changes depend on the coefficient variables
/* (check the values to see if there is little or alot of change)
/* Calculate pH changes according to the location in latitude
pH_%mth%a = con(lat < 10100, %path%/ph + (%path%/ph * %c2%), %path%/ph * (%c1% + %c2% + %c3%))
/* Calculate pH changes according to the precipitation
/* If there is alot of rain, it should dissolve the water
/* and decrease pH more than with little rain.  Either way pH still is
/* decreased.
pH_%mth%b = con(%path%/precip%mth% <= 2, ph_%mth%a * (%c1% + %c2% + %c3% + %c4% + %c5% + %c6% + %c7% + %c8%), ph_%mth%a * (%c1% + %c3% + %c4%))
/* Calculate pH changes according to the runoff, it should increase
ph_%mth%c = con(runoff_%mth% <= 3000000, ph_%mth%b + (ph_%mth%b * (%c5% + %c6% + %c9% + %c10%)), ph_%mth%b + (ph_%mth%b * (%c1% + %c2% + %c4% + %c5% + %c6%)))
&type pH chemical[value mth] done



/* STEP EIGHT
/* Calculate Salinity changes
/* with latitude
Sal_%mth%a = con(lat < 10100, %path%/sal + (%path%/sal * ((2 * %c1%) + %c1% + %c2% + %c4%)), %path%/sal)
/* with precipitation
```

```
Sal_%mth%b = con(%path%/precip%mth% <= 2, Sal_%mth%a * (%c1% + %c2% + %c4% + %c6% + %c7% + %c8% + %c9%), Sal_%mth%a * (%c1% + %c2% + %c4% + %c5% + %c6%))
/* with runoff
Sal_%mth%c = con(runoff_%mth% <= 3000000, Sal_%mth%b + (Sal_%mth%b * (%c5% + %c6% + %c8% + %c10%)), Sal_%mth%b + (Sal_%mth%b * (%c2% + %c3% + %c7%)))
&type Salinity[value mth] done


/* STEP NINE
/* Calculate Dissolved Oxygen Changes
/* with latitude
DO_%mth%a = con(lat < 10100, %path%/do + (%path%/do * (%c1% + %c2% + %c5% + %c8%)), %path%/do)
/* with precipitation
DO_%mth%b = con(%path%/precip%mth% <= 2, DO_%mth%a * (%c1% + %c2% + %c3% + %c4% + %c5% + %c6% + %c7% + %c8% + %c9%), DO_%mth%a * (%c1% + %c2% + %c4% + %c6%
+ %c9% + %c10%))
/* with runoff
DO_%mth%c = con(runoff_%mth% <= 3000000, DO_%mth%b + (DO_%mth%b * (%c1% + %c3% + %c8% + %c10%)), DO_%mth%b + (DO_%mth%b * (%c1% + %c3% + %c7%)))
&type Dissolved Oxygen[value mth] done


/* STEP TEN
/* Calculate Biochemical Oxygen Demand (BOD) changes
/* with latitude
BOD_%mth%a = con(lat < 10100, %path%/bod + (%path%/bod * (%c1% + %c2% + %c5% + %c8%)), %path%/bod + (%path%/bod * (%c1% + %c2%)))
/* with precipitation
BOD_%mth%b = con(%path%/precip%mth% <= 2, BOD_%mth%a * (%c2% + %c3% + %c4% + %c5% + %c6% + %c7% + %c9%), BOD_%mth%a * (%c1% + %c2% + %c6% + %c8% + %c10%))
/* with runoff
BOD_%mth%c = con(runoff_%mth% <= 3000000, BOD_%mth%b + (BOD_%mth%b * (%c1% + %c3% + %c8% + %c10%)), BOD_%mth%b + (BOD_%mth%b * (%c1% + %c3% + %c7%)))
&type Biochemical Oxygen Demand[value mth] done


/* STEP ELEVEN
/* Calculate TP
/* with latitude
TP_%mth%a = con(lat < 10100, %path%/tp + (%path%/tp * (%c2% + %c4% + %c6%)), %path%/tp + (%path%/tp * %c6%))
/* with precipitation
TP_%mth%b = con(%path%/precip%mth% <= 2, TP_%mth%a * (%c1% + %c4% + %c7% + %c10%), TP_%mth%a * (%c3% + %c6%))
/* with runoff
TP_%mth%c = con(runoff_%mth% <= 3000000, TP_%mth%b + (TP_%mth%b * (%c1% + %c3% + %c8% + %c10%)), TP_%mth%b + (TP_%mth%b * (%c1% + %c3% + %c7%)))
&type TP[value mth] done

/* STEP TWELVE
/* Calculate Alkalinity Changes
/* with latitude
ALK_%mth%a = con(lat < 10100, %path%/alk + (%path%/alk * (%c1% + %c5% + %c7%)), %path%/alk + (%path%/alk * (%c3% + %c8%)))
/* with precipitation
ALK_%mth%b = con(%path%/precip%mth% <= 2, ALK_%mth%a * (%c1% + %c4% + %c7% + %c10%), ALK_%mth%a * (%c8% + %c9%))
/* with runoff
ALK_%mth%c = con(runoff_%mth% <= 3000000, ALK_%mth%b + (ALK_%mth%b * (%c1% + %c3% + %c8% + %c10%)), ALK_%mth%b + (ALK_%mth%b * (%c1% + %c3% + %c7%)))
&type Alkalinity[value mth] done


/* STEP THIRTEEN
/* Calculate Chemical Oxygen Demand changes
/* with latitude
COD_%mth%a = con(lat < 10100, %path%/cod + (%path%/cod * (%c1% + %c5% + %c7%)), %path%/cod + (%path%/cod * (%c3% + %c8%)))
/* with precipitation
COD_%mth%b = con(%path%/precip%mth% <= 2, COD_%mth%a * (%c1% + %c4% + %c7% + %c10%), COD_%mth%a * (%c8% + %c9%))
/* with runoff
```

```
COD_%mth%c = con(runoff_%mth% <= 3000000, COD_%mth%b + (COD_%mth%b * (%c1% + %c3% + %c8% + %c10%)), COD_%mth%b + (COD_%mth%b * (%c1% + %c3% + %c7%)))
&type Chemical Oxygen Demand[value mth] done


/* STEP FOURTEEN
/* Finalize Chemicals for indescrepencies
pH_%mth%final = con(ph_%mth%c <= 0, 0, ph_%mth%c)
Sal_%mth%final = con(Sal_%mth%c <= 0, 0, Sal_%mth%c)
DO_%mth%final = con(DO_%mth%c <= 0, 0, DO_%mth%c)
BOD_%mth%final = con(BOD_%mth%c <= 0, 0, BOD_%mth%c)
TP_%mth%final = con(TP_%mth%c <= 0, 0, TP_%mth%c)
Alk_%mth%final = con(Alk_%mth%c <= 0, 0, ALK_%mth%c)
COD_%mth%final = con(COD_%mth%c <= 0, 0, COD_%mth%c)



/* STEP FIFTEEN
/* DELETE UNUSED LAYERS
/* Delete the temporary grids (layers) used in the calculations
kill aqs_%mth%
kill qs_%mth%
kill infiltrn_%mth%
kill theta_%mth%
kill fss_%mth%
kill at_unsat_%mth%
kill at_net_%mth%
kill su_%mth%a
kill su_%mth%b
kill qg_%mth%
kill drainage_%mth%
kill runoffup_%mth%
kill runofflow_%mth%
/* delete temporary grid layers used in the calculation
kill pH_%mth%a
kill pH_%mth%b
kill pH_%mth%c
kill Sal_%mth%a
kill Sal_%mth%b
kill Sal_%mth%c
kill DO_%mth%a
kill DO_%mth%b
kill DO_%mth%c
kill BOD_%mth%a
kill BOD_%mth%b
kill BOD_%mth%c
kill TP_%mth%a
kill TP_%mth%b
kill TP_%mth%c
kill ALK_%mth%a
kill ALK_%mth%b
kill ALK_%mth%c
kill COD_%mth%a
kill COD_%mth%b
kill COD_%mth%c

&end
```

```
/* DELETE OLD SOILUP AND SOILLOW

&do mth &list 1 2 3 4 5 6 7 8 9 10 11 12
kill soilup_%mth%
kill soillow_%mth%
&end

/* DELETE OTHER LAYERS

/* BackUP final ones to output directory
&do mth &list 1 2 3 4 5 6 7 8 9 10 11 12
copy runoff_%mth% %outpath%/runoff4_%mth%
copy pH_%mth%final %outpath%/final_pH%mth%
copy Sal_%mth%final %outpath%/final_Sal%mth%
copy DO_%mth%final %outpath%/final_DO%mth%
copy BOD_%mth%final %outpath%/final_BOD%mth%
copy TP_%mth%final %outpath%/final_TP%mth%
copy Alk_%mth%final %outpath%/final_Alk%mth%
copy COD_%mth%final %outpath%/final_COD%mth%

/* DELETE FINAL Layers and Input Layers
kill dfrac%mth%a
kill dfrac%mth%b
kill rint%mth%a
kill rint%mth%b
kill thrufall%mth%
kill runoff_%mth%
kill pH_%mth%final
kill Sal_%mth%final
kill DO_%mth%final
kill BOD_%mth%final
kill TP_%mth%final
kill Alk_%mth%final
kill COD_%mth%final
&end
&type AML PROGRAM NAGA 2.1 COMPLETED
&type written by Channarith Vanthin
&type HAVE A NICE DAY!

&return
```

APPENDIX E:
Glossary

Appendix E Glossary

Alkalinity- A measure of the ability of a solution to neutralize acid; a measure of all possible bases in a solution.

Biochemical Oxygen Demand- A measure of the amount of dissolved oxygen needed to completely break down organic compounds.

Bioamplification- The term used to describe that more genetically intricate organisms are more likely to experience chromosomal deformation.

Biogeneration- The term used to describe that mammals pass pollutants to their offspring.

Biopersistence- The term used to describe that pollutants can last several lifetimes affecting many generations of organisms.

Chemical Oxygen Demand- A measure of the amount of dissolved oxygen needed to reduce chemicals to their most stable states.

Coliform- Bacteria that thrive in wastewater; their concentrations are an indicator of a lack of water quality in many water quality tests.

Exotoxicology- The study of the adverse effect that plants and animals experience from pollutants entering their ecosystem.

Eutriphication- A condition that occurs when alterations in aquatic systems promote substantial algae growth.

Evapotranspiration- A term describing the water lost through transpiration of plants and evaporation.

Field Capacity- A term used when soil is completely saturated with water.

Floodplain- A depressed belt of land that runs adjacent to a river that is underwater during times of flooding.

Geocoding- The proper proportions and alignment of GIS Maps and images in to a GIS model so that they over lay properly with the original layer.

GIS Attributes- Tabular data associated with geographic features.

GIS Geographic Features- The points, lines, and polygons that make up the GIS map.

GIS Item- Information pieces stored on layers in GIS.

Gridding- The process of using elevation readings at various points and creating smooth contour lines by approximating unknown values.

Layers- A two-dimensional theme in GIS used to organize information.

Osmosis- Diffusion of water through a semi-permeable membrane.

PH- The negative log of the concentration of H^+ ions in a solution.

Polygon- Area enclosed by a string of x, y coordinate vectors.

River Discharge- The amount of water flowing through a river.

Scripts- Low level code.

Stomata- A pore in a leaf where gas exchange occurs during respiration.

Wilting Point- A point when the quantity of water in the soil is insufficient for osmosis in the plant's roots.