ABSTRACT

INVESTIGATION OF AN INTEGRATED REGIONAL ENVIRONMENTAL WATERSHED METHODOLOGY

by
Marshall R. Boggio

Recent public awareness of the environment has placed increased emphasis on the health and current state of the regional watershed. The watershed has been defined as that area in which water flowing across and beneath a given land surface drains into a specific stream or river, ultimately flowing through a single point or outlet on that stream or river. Since the processes involved are many and are analyzed in the literature on an individual basis, the current investigation attempts a more holistic approach by suggesting a methodology that integrates all elements of the hydrologic cycle. The investigation utilizes the area topography in the form of a digital elevation model (DEM) as the base for analysis.

Basic to any watershed model is a characterization of the water flow in streams by a mathematical function expressed through the hydrograph. The investigation explores the hydrograph and proposes that it can be constructed from hydrological components in a feedback concept with precipitation as input and the volume of flow as output. Feedback, for example, is represented as ground water and infiltration. An approach is presented to develop the watershed hydrograph from a Taylor series expansion using the derivatives of measured flow as parameters. The expansion result is transformed through LaPlace techniques into a representation of the hydrograph. Once done, the resulting time function can be transformed by the Fourier operator and a unique spectral signature

of the stream obtained. It is further asserted that the national network of stream gages can be a useful source of data for this construct.

Included in the research is an investigation of the framework needed to package the information describing the watershed model. The Geographic Information System (GIS) is suggested as the ideal method to organize and provide clarity to the watershed model. Particularly important is the structured relational database required in this approach. Added to this are spatial geographic capabilities, which did not exist in the past.

Lastly, an investigation into the project management tasks necessary for the successful pursuit of a watershed-monitoring program is outlined. Emphasis here is placed on the inclusion of all the interested parties in the care taking of the watershed.

The analysis and modeling of watersheds are gaining increasing attention as managers and custodians become more acutely aware of the interactions of human activity and the environmental health of the watershed. Government investment in the streamgaging networks will contribute to this process by providing improved physical data to be used as input into the modeling efforts. The future holds greater promise to manage our natural resources through more comprehensive models of the environment.

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by
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APPROVAL PAGE

INVESTIGATION OF AN INTEGRATED REGIONAL ENVIRONMENTAL WATERSHED METHODOLOGY

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ACKNOWLEGEMENT

When this research began -- has it been several years? -- it seems that the mention of the watershed in textbooks was minimized. Over the years environmentalists and those of concern have come to recognize the important role that the watershed has in the scheme of things. In fact, it is only recently that several books have been published specifically devoted to watersheds. This investigation took longer than I expected and the literature seems to have caught up.

But for the support and encouragement of several individuals, this report may not have progressed. It is to these individuals that I express my thanks.

First, I commend my advisor, Dr. Yuan Ding, for her patience and critique of the drafts as they were submitted. This provided direction to the effort. To Drs. John Schuring, Robert Dresnack, and Fadi Deek, I am especially thankful for their taking the time to review and provide helpful critique of the effort. To Dr. Paul Chan, I appreciate his continued support and encouragement over the years. And, of course, I needed the "prodding" of my wife Shirley to finish the effort. I would be remiss if I did not acknowledge the help of my daughter, Dawn, for her computer skills in the preparation of the report. Thank you, all.

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CHAPTER 1

INTRODUCTION

1.1 Research Investigation

This research will focus on some aspects of the watershed. It will explore the fundamental mathematical concepts defining a watershed and current software available to model a watershed. Data sources required to satisfy the model are suggested and examples developed. It is asserted that the watershed concept is perhaps the result of very important analyses of our global community to ultimately determine human survival. The health of a watershed both protects and jeopardizes life sustaining of human existence.

One source[1] defines the watershed as shown in Figure 1.1 which provides an overall view of the concept. Points worth noting and which form a basis of this study:

- The fundamental concept of hydrology is the hydrological cycle: its global-scale of an endless recirculatory process linking water in the atmosphere, on the continents, and in the oceans. This cyclical process is usually thought of in terms of reservoirs (i.e., oceans, atmosphere, etc.) and the volumetric flows of water between them.
- Within the hydrological cycle, the dynamic processes of water vapor formation and transport of vapor and liquid in the atmosphere are driven by solar energy, while precipitation and many of the various flows of water at or beneath the Earth's surface are driven primarily by gravitational and capillary forces.
- For given control volume, a water budget may be constructed based on the principle of conservation of mass: the time rate of change of mass stored within

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[1] Ref. 16, Page 11.

the control volume is equal to the difference between the mass inflow rate and the mass outflow rate.

- A catchment is defined as an area of land in which water flowing across the land surface drains into a particular stream or river and ultimately flows through a single point or outlet on that stream or river.
- Catchments are delineated on the basis of land-surface topography. The boundary of a catchment is called a divide.
- On an average annual basis, the water budget for a catchment indicates that precipitation is balanced by surface water runoff and evapotranspiration..

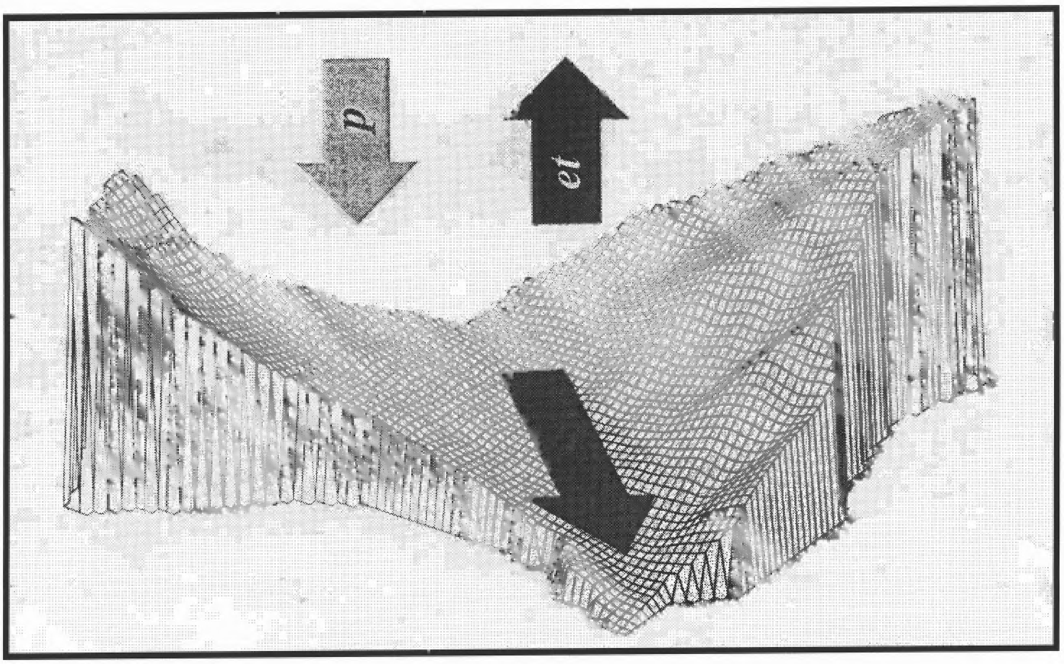

Figure 1.1 The Watershed. The boundary of the watershed is referred to as a divide. If the catchment area has been properly delineated, there should be no surface-water inflows or outflows across the divide, except at the outlet. In this case, the major inflow is precipitation *(p)*, and the major outflows are evapotranspiration *(et)* and surface-water outflow through the catchment outlet *(r)*. The topography of the land surface controls where divides are drawn, in the figure, two mountain peaks, and their adjacent ridges, constitute the divide.

1.2 Scope and Objectives

The current status of watershed management is disjointed because the responsibility for policy implementation is at the local level. This situation results in conflicting decisions by adjacent communities. Currently, there is recognition that a regional approach is more sensible when the watershed as a whole is considered. Both the Federal and State Governments are placing increased emphasis on this approach. This evolution is placing a greater impact on the development of improved models and database structures. Because the watershed forms a natural boundary separating water resources, this investigation explores the issues involved. These are listed as follows:

- The Digital Elevation Model (DEM) as the base to build a watershed model.
- Mathematical expressions for watershed phenomena.
- The role of the Geographical Information System in developing a database.
- The impact of the National streamgaging network.
- The “new” management team.

1.3 Contributions

This new emphasis on the watershed has resulted in an evolutionary process of refining and improving the physical and ecological description of the phenomena involved. This investigation contributes to the process in the following ways:

- The utilization of the DEM as a unifying source for model development.
- The feedback concept applied to water processes of integrating surface and groundwater flow.
- Producing a spectral unique signature identifier of the river and channel flow.
- Importance of including the stream gage network data into a dynamic database.

1.4 Overview

The state of the watershed is important in the determination of the region under stress. This not only relates to areas under intense precipitation but conversely under extreme periods of drought. Predicting the impact of these conditions is enhanced by the construction of a regional model of the watershed. This research will concern itself with the construction of watershed models utilizing current software for surface, groundwater, and watersheds. Details of the process - the study will focus on the Metedeconk River basin in Ocean County from which a model will be demonstrated.

An essential element in the development is the digital elevation model (DEM) from which a delineation of the stream networks and watershed boundaries is obtained. Topological data contained in the DEM is used to determine flow directions, flow paths and accumulations. These computations serve to establish e.g. HEC-l interface where parameters such as loss rates, base flow, unit hydrograph and routing data are identified. Time of concentration, lag times and travel time along a routing reach is presented as a critical analytical step. Flood plain delineation is achieved in those cases where the stages of the watershed are needed to predict the impact of extremes in precipitation. Watersheds are subject to the analysis techniques employed in flood plain analysis. These floods may vary in intensity and duration as a function of the storm pattern, and the drainage basin characteristics. For example, a thunderstorm on a small watershed area could develop into a flood of high peak, but short duration. A large basin, on the other hand, might attenuate the peak through storage and flow resistance before reaching the outlet point. The various forms of behavior of watershed response are the subjects of this research.

1.5 Stream-gaging

The health of a watershed can be assessed by data derived from a stream-gaging network[2]. A stream-gage is a structure located beside a river that contains a device to measure and record the water level and flow in the river. Generally, these measurements may occur automatically every 15 minutes. Currently, about 5,000 individual stream-gage data sites are sent via satellite back to a USGS office once every 4 hours, and more frequently in times of flooding. There, USGS computers use a site-specific "rating curve" to convert the water level (or "gage-height") data into information about the flow of the river (typically measured in cubic feet per second). To keep the rating curve accurate and up-to-date, USGS hydrologic technicians visit each stream-gage about once every 6 weeks to measure the flow directly. Although there have been great advances in methods for measuring water levels, computing streamflow, and storing and transmitting data, the methods for measuring flow at many stream-gages are almost identical to those of 100 years ago. At a growing number of stations, however, the use of acoustic Doppler technology is dramatically changing the way flow is measured. These acoustic methods enhance the range of conditions for which accurate flow measurements are possible, but they do not provide enhanced efficiency or accuracy at most locations. No new technology has yet been found to provide accurate data over a wide range of hydrologic conditions more cost-effectively than traditional current-meter methods. Prudent management, however, requires that the USGS continue efforts to explore and test new technologies for stream-gaging that have the potential to enhance operational safety, reduce cost, improve accuracy, and (or) increase reliability of flow data. In the past three

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[2] Ref. 43.

years, the USGS has collaborated with university and private-sector partners in a search for new approaches to stream-gaging. Early tests of various new radar systems show promise, but much more testing and development are needed before major improvements in technology can be realized.

1.6 Purpose of Stream-gage Network

The flow and gage-height data are easily made available to users over the Internet[3]. Users access data for immediate use and in data sets that describe the average conditions, long-term variations, and trends in flow.

Families, communities, and businesses can also utilize information about rivers in their areas to aid in decision-making. For example:

- County or city planners need to know what area should be zoned as flood plain so that families and businesses will not build in locations that are vulnerable to floods.
- Families and businesses need warnings of impending floods to help them decide about evacuating and to decide about moving valuables (heirlooms, furniture, cars, boats, and appliances) out of harm's way.
- Communities need information to plan for their future water supplies.
- Communities and farmers need information about river conditions to help them develop strategies to help them through a drought.
- State and county highway departments need information so they can design adequate bridges, culverts, and roadways that will function safely during floods.
- Watershed organizations and regulatory agencies need riverflow information (along with water-quality data) to develop cost-effective plans to improve and protect water quality.

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[3] Visit site http://waterusgs2fov/nwis/

- Families planning to canoe, kayak, or fishing need information to avoid unsafe river conditions and to preclude costly trips to remote river locations when conditions are not suitable for recreation.

1.7 Historical Background

Essential in the development of civilizations is the availability of fresh water. The United States has depended on lakes, streams, and rivers to supply water and serve as lifelines allowing for growth, development, and expansions of its country.

As a result of rapid growth in the 1880's, the U.S. population began to branch westward into the drier regions of the country, leaving the usually dependable waterways of the East far behind. Around the same time, John Wesley Powell, the second director of the USGS, requested that streamflow[4] be monitored in eight river basins in the West. His goal was to measure the flow of streams and determine the potential for the irrigation systems that would be so vital to the economic development of this parched region. In 1889, the first U.S. stream-gaging station was established on the Rio Grande near Embudo, New Mexico. At this station, standard streamflow measurement procedures were devised.

Upon establishment of streamflow measurement methods at Embudo, personnel were dispersed to collect streamflow data at other western locations. Within two years the first streamflow measurements in the East were made on the Potomac River at Chain Bridge, near Washington, D.C., and a gaging station was established there on May 1, 1891. By 1895, discharge measurements were being made by the USGS in at least 27 states throughout the country.

Today, the USGS operates and maintains more than 85% of the nation's stream-gaging stations. This includes over 7,000 continuous-record stream-gaging stations in the United States, Puerto Rico, and the Trust Territories of the Pacific Islands. These stream-gaging stations are operated by the USGS and are used by such agencies as the Army Corps of Engineers, to manage more than 2,000 flood control, navigation, and water-supply reservoirs.

In the United States, there is an important resource which aids in preventing the loss of lives, saves on billion dollars a year in property losses, and allows bridges to be properly designed and drinking water allocated. Yet, it is a resource that the general public knows very little about. This resource is the USGS stream-gaging network, as represented in Figure 1.2.

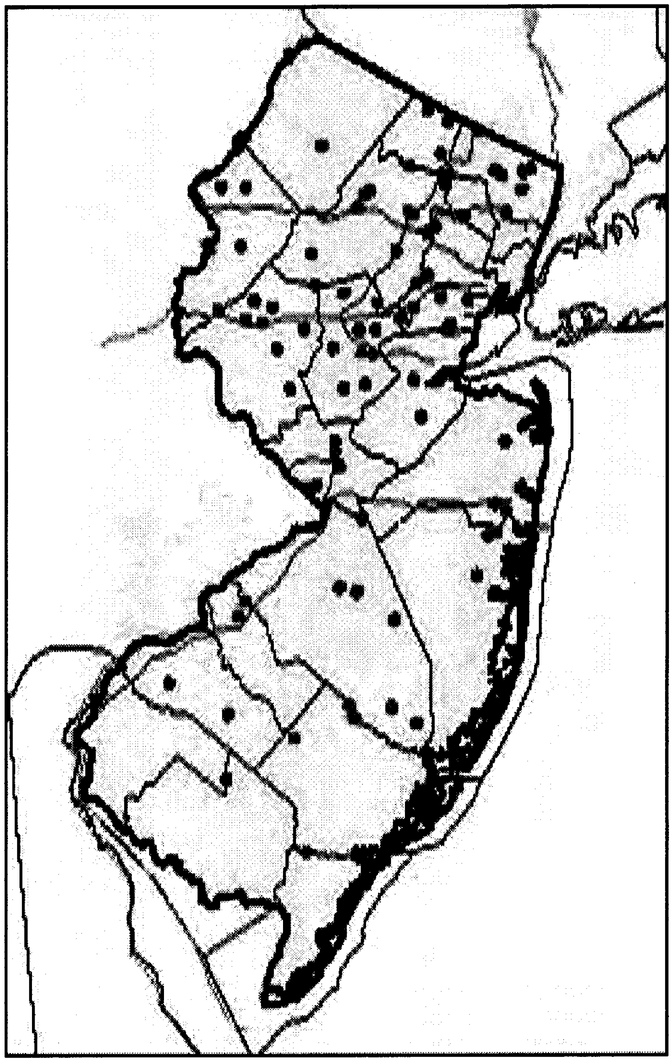

Figure 1.2 N.J. Active Stream-gages found at USGS Web Site ***water.usgs.gov.***

This network provides the hydrologic information needed to aid in defining, using,

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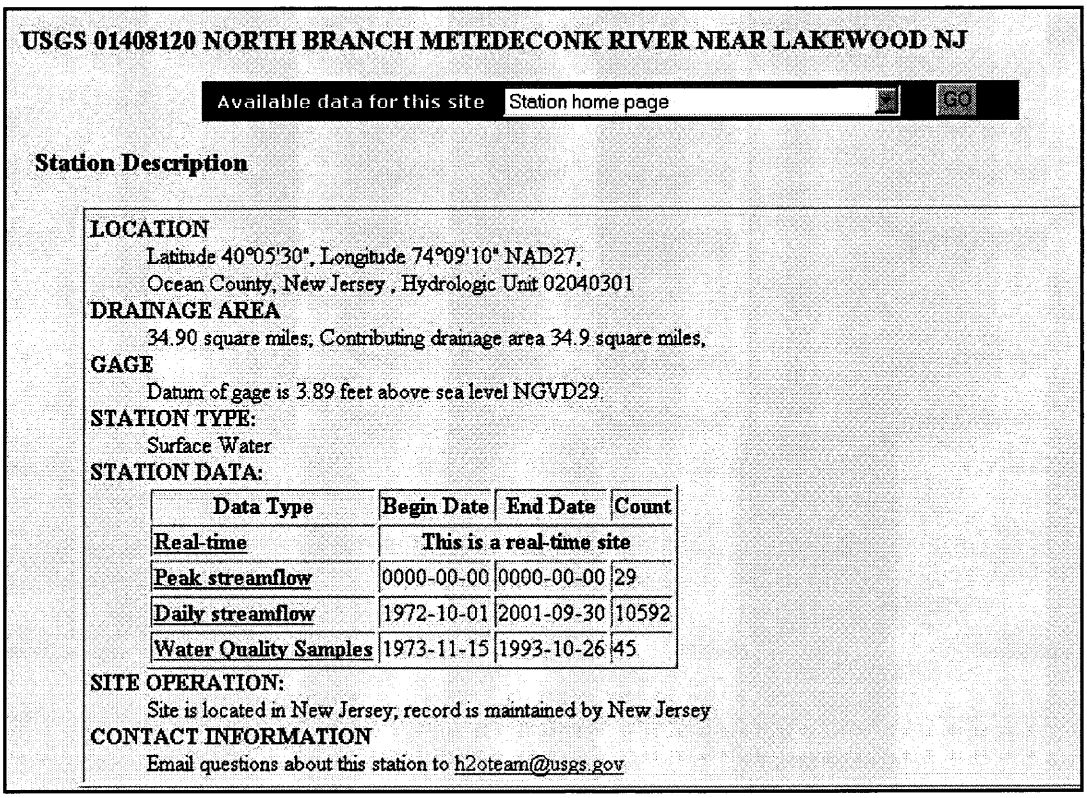
[4] Ref. 34.

and managing our country's invaluable surface water resources. A stream-gaging network provides a continuous source of well-archived, well-documented, and unbiased water data that are used in countless ways by governmental and private industries alike. See Figure 1.3 for an example of data provided by the USGS website. The water data are put to work for everyone, every single day.



USGS 01408120 NORTH BRANCH METEDECONK RIVER NEAR LAKEWOOD NJ

Available data for this site | Station home page | GO

Station Description

LOCATION
Latitude 40°05'30", Longitude 74°09'10" NAD27,
Ocean County, New Jersey , Hydrologic Unit 02040301
DRAINAGE AREA
34.90 square miles; Contributing drainage area 34.9 square miles,
GAGE
Datum of gage is 3.89 feet above sea level NGVD29.
STATION TYPE:
Surface Water
STATION DATA:

Data Type	Begin Date	End Date	Count
Real-time	This is a real-time site		
Peak streamflow	0000-00-00	0000-00-00	29
Daily streamflow	1972-10-01	2001-09-30	10592
Water Quality Samples	1973-11-15	1993-10-26	45

SITE OPERATION:
Site is located in New Jersey; record is maintained by New Jersey
CONTACT INFORMATION
Email questions about this station to h2oteam@usgs.gov

Figure 1.3 Example of stream-gage data provided at USGS website *water.usgs.gov.*

Thus, in general, streamflow information is needed to:

- Flood forecasting and flood-prone area mapping;
- Planning and managing water supplies and upholding interstate compacts;
- Developing water-quality standards and monitoring changes in flow;
- Designing structures such as dams, levees, bridges, and highways.

  Software development in recent years has produced comprehensive modeling capabilities for analysis of watershed responses to the varying precipitation patterns.

Thus, models are needed to analyze the watershed. These are listed as follows:

- Basin hydrology
- Flood frequency analysis
- Water surface profile computations
- Ground water flow

CHAPTER 2

MATHEMATICAL MODEL

2.1 Mathematical Basis of Model

The theoretical basis for watershed models has been developed from a variety of viewpoints. Statistical models based on data collected from precipitation and runoff have been published and described. Other models based upon the hydraulic laws of continuity have been described and one such example utilizes the Taylor series[5]. Some mathematical models employ the formulations suggested in the Green Ampt infiltration model. Several of the phenomena used in models will be discussed in the study. Most models that have been published appear to be deterministic with no provisions for immediate adjustments or modifications due to real time changing parameters. This aspect can be accommodated through stream-gauging data collection.

Thus, focus of this portion of the study is to investigate the mathematical formulation of the stream discharges over a river or channel reach, which would be determined from the data collected at stream-gauging stations. The discharge over the stream reach within a watershed is part of hydraulic/hydrologic systems analysis of the routing process. Flow routing has historically taken two approaches:

- Hydraulic routing where flow is described through set of hydrodynamic differential equations.
- Hydrologic routing that approximate the solutions of the hydrodynamic equations.

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[5] Appendix; Ref. 3, pp.791-804.

This investigation will concentrate on the second approach assuming the definition of a watershed to be the area of land draining into a stream or outlet at a given location. Factors involved in the draining process contribute to the storage and flow processes.

These phenomena manifest themselves in the following ways, as shown in Table 2.1:

Table 2.1 Impact

Phenomena	Inflow	Outflow	Storage
• Precipitation	√		
• Channel flow		√	
• Overland flow		√	
• Unsaturated flow		√	
• Ground water flow	√		√
• Soil moisture storage			√
• Surface storage			√
• Infiltration	√	√	
• Interception and evapotranspiration		√	

Taking a systems approach using precipitation as the primary input to the watershed and applying the relationships expressed in the basic hydrologic continuity equation is summarized.

$$\begin{bmatrix} \textit{inflow volume in} \\ \textit{time, } \Delta t \end{bmatrix} + \begin{bmatrix} \textit{change in volume of water} \\ \textit{stored by the hydraulic} \\ \textit{system during time, } \Delta t \end{bmatrix} = \begin{bmatrix} \textit{outflow volume} \\ \textit{in time } \Delta t \end{bmatrix} \quad (2.1)$$

2.2 A Flood Routing Model

The above represents the routing equation and it is the intent of this section to explore mathematically the impact of each of the flow and storage processes as they apply using the technique proposed by Chow and Kulandaiswamy [5].

This source has taken the continuity equation and defined a linear system in continuous time by linear nth order differential equations and expressing the storage function in terms of inflow and outflow. The resulting relationship is a polynomial.

$$Q(t) = \frac{M(D)}{N(D)} \; \mathrm{I}(t) \tag{2.2}$$

Where the D represents multiple differentiation.

The relationships are defined as a transfer function – similar in fact to concepts developed in electrical engineering systems. In one source[6], the concept is not developed further than a linear reservoir. Then one goal of the current investigation is to analyze this linear model beyond the simple case given.

Expressing a watershed mathematically as a linear model has been documented as long ago as 1966 by Eagleson, et al, where input-output of records are developed to create a unit hydrograph. Others[7] have used similar concepts to define a system model derived from the continuity equation:

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[6] Appendex; Ref. 3.
[7] Chow et al.

$$I - Q = \dot{S} \tag{2.3}$$

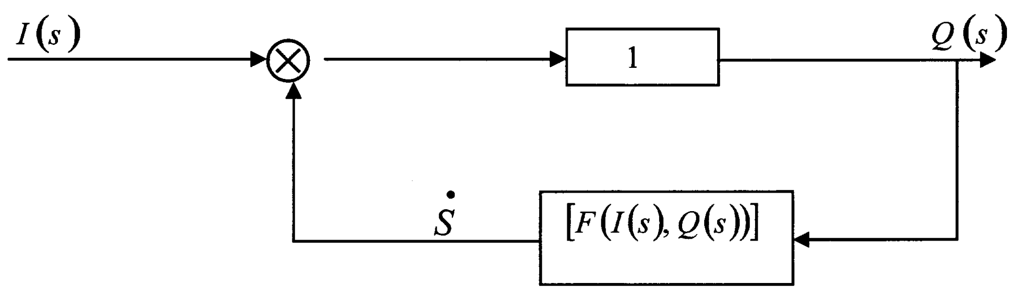
Where

I = input flow (2.4)

Q = output flow (2.5)

$\dot{S}$ = change in storage over time (2.6)

In this model the terms are expanded into the Taylor series about a steady state and expressed as polynomials containing higher order derivatives. The development proceeds to develop the concept by simplifying the expressions that result into the well-known linear reservoir Muskingum equation used to model flood routing. The purpose of the current investigation is to expand on the concepts developed[4] to higher order terms and to apply techniques more familiar to the Electrical Engineering Student – feedback and the transfer function. The guidelines[4] contained in the literature where assumed in that an acceptable model could be described mathematically by using derivatives of no higher order than two. Higher order terms than this were found to be insignificant. Then a feedback model could be represented by:



(2.7)

In this concept, the feedback function would include such phenomena as in infiltration.

One can rationalize this representation by reasoning that the input to the watershed in the form of precipitation manifests itself at the output by the influences of a dynamic hydrologic system. Parameters such as interception, evaporation, transpiration, infiltration, detention, retention, surface runoff, subsurface runoff, groundwater flow into or out of the watershed from an addition or subtraction to the input precipitation. Thus, the storage factor is considered a system feedback. Its behavior dictates the resulting routing flow – stable or unstable.

From Chow et al one obtains:

$$S = a_0 I + a_1 \dot{I} + b_0 Q + b_1 \dot{Q} + b_2 \ddot{Q}$$
$$Q = \left(\frac{1 - a_0 D - a_1 D}{1 + b_0 D + b_1 D^2 + b_2 D^3} \right) I \tag{2.8}$$

Using this feedback relationship the following equations apply.

In the Laplace format, the continuity equation becomes:

$$I(s) - \dot{S}(s) = Q(s) \tag{2.9}$$

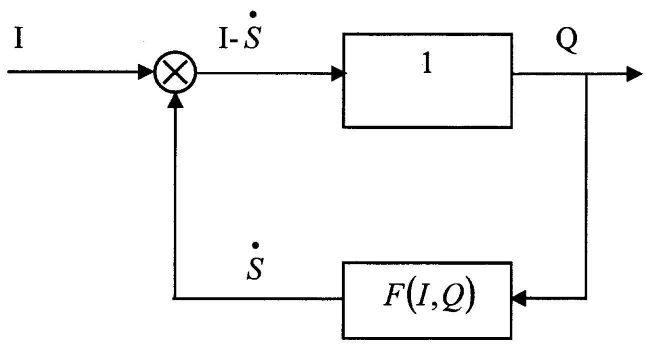
and

$$QF\left(I, Q\right) = \dot{S} \ or \ F\left(I, Q\right) = \frac{\dot{S}}{Q} \tag{2.10}$$

The equations reduce to:

$$F(I,Q) = \frac{\left(1 + b_0 s + b_1 s^2 + b_2 s^3\right)\left(a_0 s + a_1 s^2\right) + b_0 s + b_1 s^2 + b_2 s^3}{1 - \left(a_0 + a_1\right) s} \tag{2.11}$$

Then the feedback block diagram relationship becomes:



(2.12)

From the block diagram then:

$$Q = \frac{1-(a_0+a_1)s}{1+b_0 s+b_1 s^2+b_2 s^3} I \tag{2.13}$$

In this representation it is seen that the storage function F(I,Q) is composed of parameters "*a*" and "*b*" the constant coefficients of the derivatives of the Taylor series expansion.[8] These parameters will be dependent on the input and the discharge hydrographs[9]. If the input is represented by the unit impulse function which in Laplace format translates to a one, then the resulting polynomial for the basic outflow is dictated by the transfer function which can be represented by a differential equation. Its solution in Laplace terms and applying partial fraction expansion:

$$Q = \frac{1-(a_0+a_1)s}{1+b_0 s+b_1 s^2+b_2 s^3} = \frac{k_0}{s+r_0} + \frac{k_1}{s+r_1} + \frac{k_3}{s+r_2} \tag{2.14}$$

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[8] Ref. 3.

[9] It is the author's opinion that this is a serious limitation of the technique. Only negative real parts of roots are considered in a physically, realizable system.

The polynomial in the denominator has three roots. The relation of these parameters then determines the stability of the watershed, i.e. is the inflow-outflow uniform or an unstable flood condition. Remembering the "a" and "b" coefficients of the transfer function represent the partial derivatives of the Taylor series expansion. This series is in the form of the unit hydrograph of transfer function of the watershed system. The system model as based on the continuity equation:

$$I - Q = \dot{S} \tag{2.15}$$

Thus the Taylor series is the means by which the system model is developed. Noting that the coefficients are related to the input and output flow by:

$$a_0 = \frac{\partial f}{\partial I}, a_1 = \frac{\partial f}{\partial \dot{I}}, a_z = \frac{\partial f}{\partial \ddot{I}} \ldots \tag{2.16}$$

and

$$b_0 = \frac{\partial f}{\partial Q}, b_1 = \frac{\partial f}{\partial \dot{Q}}, b_2 = \frac{\partial f}{\partial \ddot{Q}} \ldots \tag{2.17}$$

Now each of these functions are related to the upper and lower hydrographs of a reach in the routing in a watershed. To establish values of the a and b coefficient data has been compiled on several watersheds.[10] From the data it is seen that the coefficients are relatively constant but the b coefficients vary relative to the peak out flow. It is emphasized that the coefficients are functions of time and are determined at discrete points in the input/output hydrograph curves. Graphs of Q_p versus $a_0, a, b_0, b_1 \, and \; b_2$ of

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[10] Ref. 3, pp. 798 and 799.

a watershed the Laplace form of representation was applied to the transfer function. It is noted that the referenced paper[11] suggests that derivatives beyond the second order contribute little to the analysis. Also the reader is reminded that the coefficients represent the state of the watershed at any given time during a storm event. The state of the soils, saturation, infiltrating river stage will all impact the values of the a and b coefficients. Points of the peak "Q_p" flow from the curves of the Chow et el have been chosen and solved, as shown in Table 2-2.

Table 2.2 Points of the Peak "*Q*" [12]

	Q_p	a_0	a_1	b_0	b_1	b_2
Case I	.04	1.5	-4	16	70	40
Case II	.12	1.5	-4	14	35	28
Case III	.20	1.5	-4	10	18	24

[11] Ref. 3.
[12] Ref. 3.

Case I – Transfer Polynomial, $Q_p = 0.04$ and data from Table 2.2.

$$\frac{Q(s)}{I(s)} = \frac{1-(a_0+a_1)s}{1+b_0 s+b_1 s^2+b_2 s^3} = \frac{1-(1.5-4)s}{1+bs+70s^2+40s^3} \qquad (2.18)$$

Reduction of polynomial results in:

$$\frac{Q(s)}{I(s)} = \frac{0.025+0.0625s}{(0.025+0.45+1.755^2+s^3)} \qquad (2.19)$$

Solving for the roots of the denominator results in:

$$s = -0.15, \ -0.107, \ -1.49 \qquad (2.20)$$

Thus:

$$\frac{Q(s)}{I(s)} = \frac{0.025+0.0625s}{(s+0.150)(s+0.107)(s+1.49)} \qquad (2.21)$$

or using partial fraction expansion to solve for constants k. This results in:

$$\frac{Q(s)}{I(s)} = \frac{-0.271}{s+0.15)} + \frac{0.308}{(s+0.107)} + \frac{0.037}{(s+1.49)} \qquad (2.22)$$

Then, a solution:

$$\frac{Q(t)}{I(t)} = -0.271e^{-0.15t} + 0.308e^{-0.107t} - 0.037e^{-1.49t} \qquad (2.23)$$

The graph and data for Case I are shown in Figure 2.1 and Table 2.3, respectively.

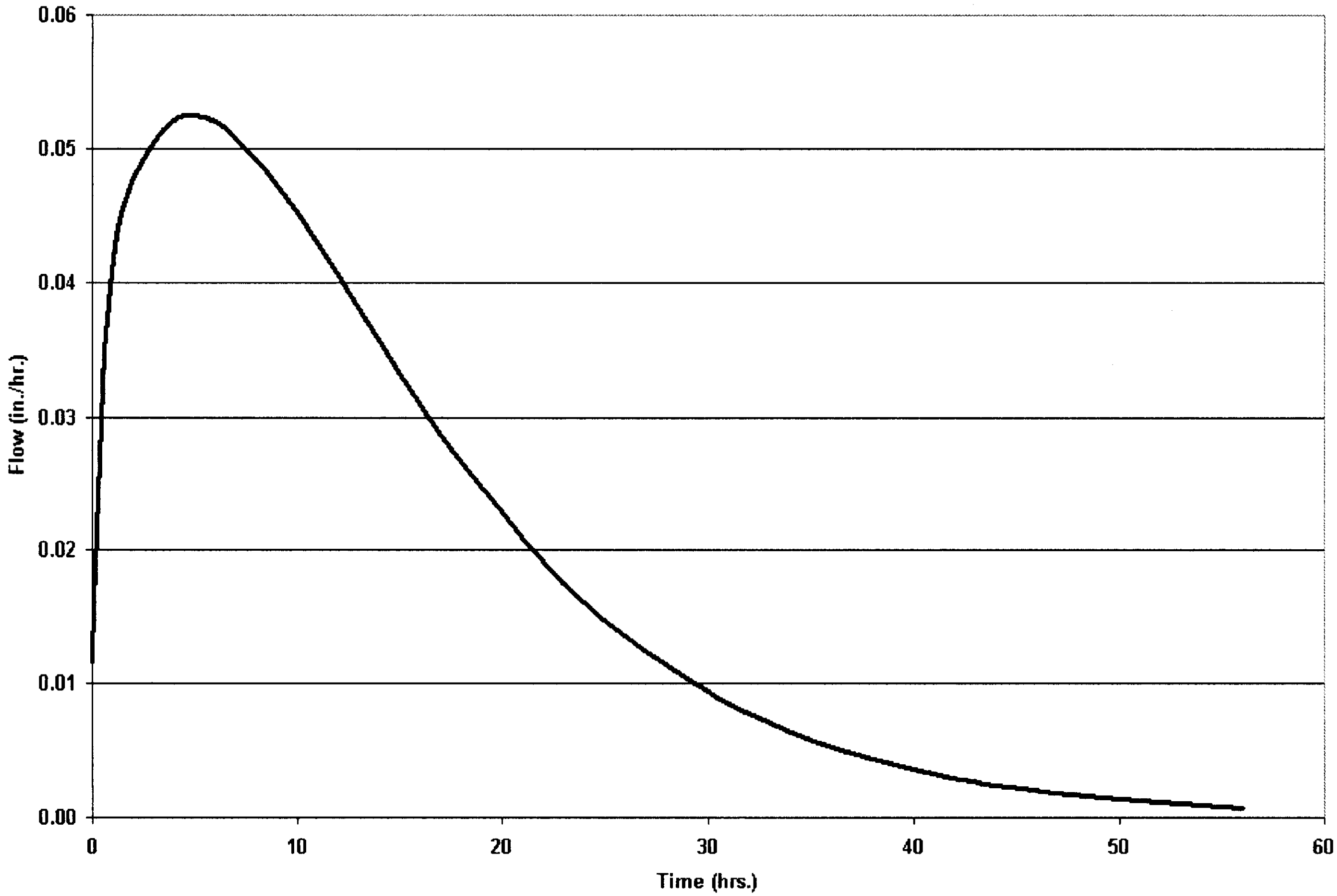

Figure 2.1 Hydrograph Case I, based on Equation 2.23.

Table 2.3 Tabulated calculations for Hydrograph Case I, based on Equation 2.23.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	t (time)	Exponential	A x B	Expontential (C)	Constant	D x E	Exponential	A x G	Exponential (H)	Constant	I x J	Exponential	A x L	Exponential (M)	Constant	N x O	Sum (F + K + P)
2	0.00	-0.15	0	1	-0.271	-0.271	-0.107	0	1	0.308	0.308	-1.49	0	1	-0.037	-0.037	0.011507
3	0.25	-0.15	-0.0375	0.963194	-0.271	-0.26103	-0.107	-0.02675	0.973605	0.308	0.29987	-1.49	-0.3725	0.68901	-0.037	-0.02549	0.021279
4	0.50	-0.15	-0.075	0.927743	-0.271	-0.25142	-0.107	-0.0535	0.947906	0.308	0.291955	-1.49	-0.745	0.474734	-0.037	-0.01757	0.032198
5	1.00	-0.15	-0.15	0.860708	-0.271	-0.23325	-0.107	-0.107	0.898526	0.308	0.276746	-1.49	-1.49	0.225373	-0.037	-0.00834	0.041615
6	2.00	-0.15	-0.3	0.740818	-0.271	-0.20076	-0.107	-0.214	0.807348	0.308	0.248663	-1.49	-2.98	0.050793	-0.037	-0.00188	0.047806
7	4.00	-0.15	-0.6	0.548812	-0.271	-0.14873	-0.107	-0.428	0.651811	0.308	0.200758	-1.49	-5.96	0.00258	-0.037	-9.5E-05	0.052025
8	6.00	-0.15	-0.9	0.40657	-0.271	-0.11018	-0.107	-0.642	0.526239	0.308	0.162082	-1.49	-8.94	0.000131	-0.037	-4.8E-06	0.051901
9	8.00	-0.15	-1.2	0.301194	-0.271	-0.08162	-0.107	-0.856	0.424858	0.308	0.130856	-1.49	-11.92	6.66E-06	-0.037	-2.5E-07	0.049233
10	10.00	-0.15	-1.5	0.22313	-0.271	-0.06047	-0.107	-1.07	0.343009	0.308	0.105647	-1.49	-14.9	3.38E-07	-0.037	-1.3E-08	0.045178
11	12.00	-0.15	-1.8	0.165299	-0.271	-0.0448	-0.107	-1.284	0.276927	0.308	0.085294	-1.49	-17.88	1.72E-08	-0.037	-6.4E-10	0.040498
12	14.00	-0.15	-2.1	0.122456	-0.271	-0.03319	-0.107	-1.498	0.223577	0.308	0.068862	-1.49	-20.86	8.72E-10	-0.037	-3.2E-11	0.035676
13	16.00	-0.15	-2.4	0.090718	-0.271	-0.02458	-0.107	-1.712	0.180504	0.308	0.055595	-1.49	-23.84	4.43E-11	-0.037	-1.6E-12	0.031011
14	18.00	-0.15	-2.7	0.067206	-0.271	-0.01821	-0.107	-1.926	0.14573	0.308	0.044885	-1.49	-26.82	2.25E-12	-0.037	-8.3E-14	0.026672
15	20.00	-0.15	-3	0.049787	-0.271	-0.01349	-0.107	-2.14	0.117655	0.308	0.036238	-1.49	-29.8	1.14E-13	-0.037	-4.2E-15	0.022745
16	22.00	-0.15	-3.3	0.036883	-0.271	-0.01	-0.107	-2.354	0.094988	0.308	0.029256	-1.49	-32.78	5.81E-15	-0.037	-2.1E-16	0.019261
17	24.00	-0.15	-3.6	0.027324	-0.271	-0.0074	-0.107	-2.568	0.076689	0.308	0.02362	-1.49	-35.76	2.95E-16	-0.037	-1.1E-17	0.016215
18	26.00	-0.15	-3.9	0.020242	-0.271	-0.00549	-0.107	-2.782	0.061915	0.308	0.01907	-1.49	-38.74	1.5E-17	-0.037	-5.5E-19	0.013584
19	28.00	-0.15	-4.2	0.014996	-0.271	-0.00406	-0.107	-2.996	0.049987	0.308	0.015396	-1.49	-41.72	7.61E-19	-0.037	-2.8E-20	0.011332
20	30.00	-0.15	-4.5	0.011109	-0.271	-0.00301	-0.107	-3.21	0.040357	0.308	0.01243	-1.49	-44.7	3.86E-20	-0.037	-1.4E-21	0.009419
21	32.00	-0.15	-4.8	0.00823	-0.271	-0.00223	-0.107	-3.424	0.032582	0.308	0.010035	-1.49	-47.68	1.96E-21	-0.037	-7.3E-23	0.007805
22	36.00	-0.15	-5.4	0.004517	-0.271	-0.00122	-0.107	-3.852	0.021237	0.308	0.006541	-1.49	-53.64	5.06E-24	-0.037	-1.9E-25	0.005317
23	40.00	-0.15	-6	0.002479	-0.271	-0.00067	-0.107	-4.28	0.013843	0.308	0.004264	-1.49	-59.6	1.31E-26	-0.037	-4.8E-28	0.003592
24	44.00	-0.15	-6.6	0.00136	-0.271	-0.00037	-0.107	-4.708	0.009023	0.308	0.002779	-1.49	-65.56	3.37E-29	-0.037	-1.2E-30	0.002410
25	50.00	-0.15	-7.5	0.000553	-0.271	-0.00015	-0.107	-5.35	0.004748	0.308	0.001462	-1.49	-74.5	4.42E-33	-0.037	-1.6E-34	0.001313
26	56.00	-0.15	-8.4	0.000225	-0.271	-6.1E-05	-0.107	-5.992	0.002499	0.308	0.00077	-1.49	-83.44	5.79E-37	-0.037	-2.1E-38	0.000709

Case II – Transfer Polynomial, $Q_p = 0.12$ and data from Table 2.2.

$$\frac{Q(s)}{I(s)} = \frac{1-(a_0+a_1)s}{1+b_0 s+b_1 s^2+b_2 s^3} = \frac{1-(1.5-4)s}{1+11s+35s^2+28s^3} \tag{2.24}$$

A reduction of polynomial results in :

$$\frac{Q(s)}{I(s)} = \frac{0.35+0.089s}{0.035+0.393s+1.25s^2+s^3} \tag{2.25}$$

Solving for the roots of the denominator results in:

$$s = -0.8,\ -0.092,\ -0.358 \tag{2.26}$$

Thus:

$$\frac{Q(s)}{I(s)} = \frac{0.035+0.893s}{(s+0.800)(s+0.092)(s+0.358)} \tag{2.27}$$

or, using partial fraction expansion to solve for constants K

$$\frac{Q(s)}{I(s)} = \frac{K_1}{(s+0.8)} + \frac{K_2}{(s+0.092)} + \frac{K_3}{(s+0.358)} \tag{2.28}$$

This results in:

$$\frac{Q(s)}{I(s)} = \frac{-0.114}{(s+0.8)} + \frac{0.146}{(s+0.092)} - \frac{0.032}{(s+0.358)} \tag{2.29}$$

Then

$$\frac{Q(s)}{I(s)} = -0.114e^{-0.8t} + 0.146e^{-0.092t} - 0.032e^{-0.358t} \tag{2.30}$$

The graph and data for Case II are shown in Figure 2.2 and Table 2.4, respectively.

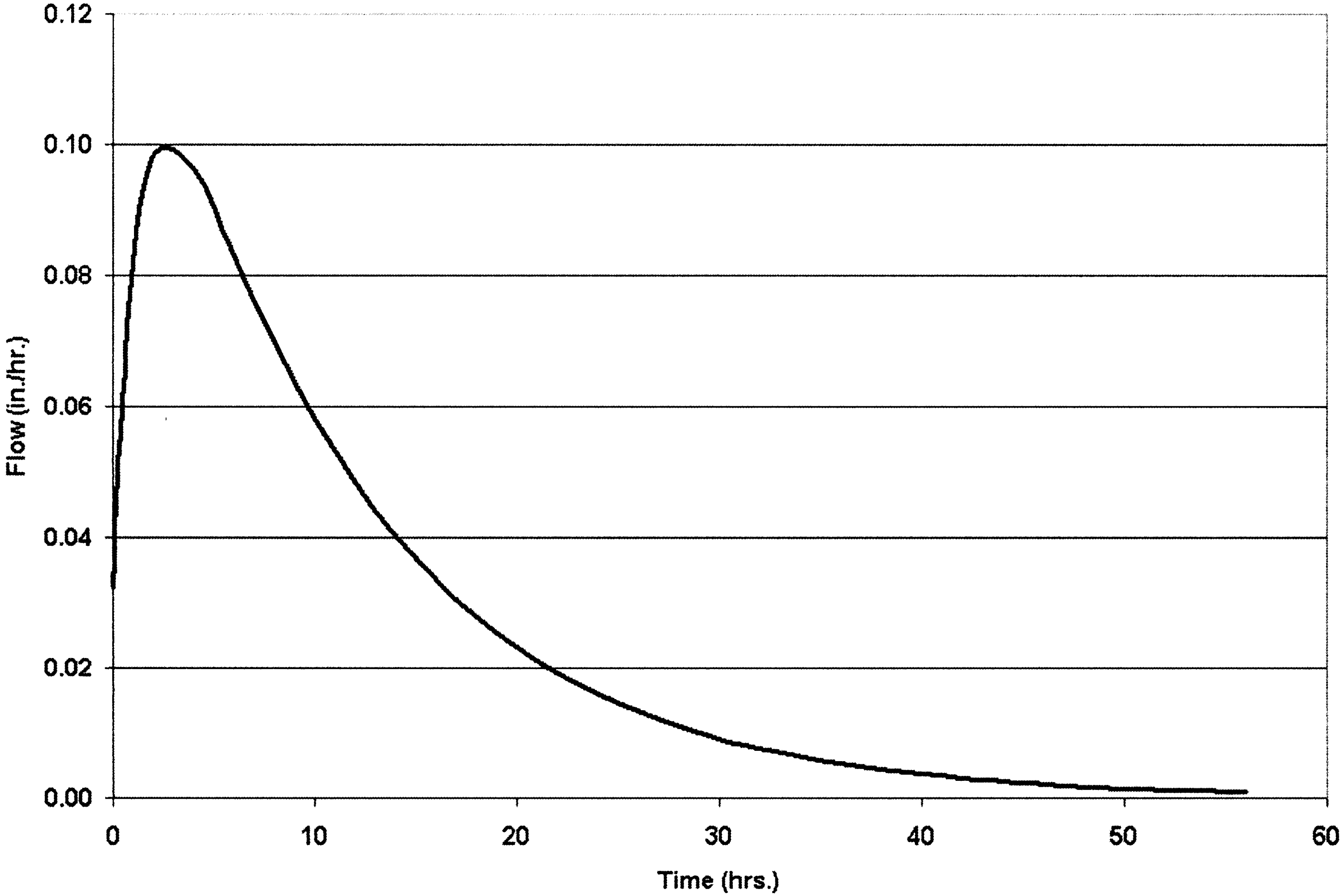

Figure 2.2 Hydrograph Case II based on Equation 2.30.

Table 2.4 Tabulated Calculations for Hydrograph Case II, based on Equation 2.30.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	t (time)	Exponential	A x B	Expontential (C)	Constant	D x E	Exponential	A x G	Exponential (H)	Constant	I x J	Exponential	A x L	Exponential (M)	Constant	N x O	Sum (F + K + P)
2	0.00	-0.8	0	1	-0.114	-0.114	-0.092	0	1	0.146	0.146	-0.358	0	1	-0.032	-0.032	0.032000
3	0.25	-0.8	-0.2	0.818730753	-0.114	-0.093335306	-0.092	-0.023	0.977262	0.146	0.14268	-0.358	-0.0895	0.914388265	-0.032	-0.029260424	0.049245
4	0.50	-0.8	-0.4	0.670320046	-0.114	-0.076416485	-0.092	-0.046	0.955042	0.146	0.139436	-0.358	-0.179	0.836105899	-0.032	-0.026755389	0.063020
5	1.00	-0.8	-0.8	0.449328964	-0.114	-0.051223502	-0.092	-0.092	0.912105	0.146	0.133167	-0.358	-0.358	0.699073075	-0.032	-0.022370338	0.081944
6	2.00	-0.8	-1.6	0.201896518	-0.114	-0.023016203	-0.092	-0.184	0.831936	0.146	0.121463	-0.358	-0.716	0.488703194	-0.032	-0.015638501	0.098446
7	4.00	-0.8	-3.2	0.040762204	-0.114	-0.004646891	-0.092	-0.368	0.692117	0.146	0.101049	-0.358	-1.432	0.238830783	-0.032	-0.007642585	0.096402
8	6.00	-0.8	-4.8	0.008229747	-0.114	-0.000938191	-0.092	-0.552	0.575797	0.146	0.084066	-0.358	-2.148	0.116717359	-0.032	-0.003734955	0.083128
9	8.00	-0.8	-6.4	0.001661557	-0.114	-0.000189418	-0.092	-0.736	0.479026	0.146	0.069938	-0.358	-2.864	0.057040143	-0.032	-0.001825285	0.069746
10	10.00	-0.8	-8	0.000335463	-0.114	-3.82427E-05	-0.092	-0.92	0.398519	0.146	0.058184	-0.358	-3.58	0.027875698	-0.032	-0.000892022	0.058146
11	12.00	-0.8	-9.6	6.77287E-05	-0.114	-7.72108E-06	-0.092	-1.104	0.331542	0.146	0.048405	-0.358	-4.296	0.013622942	-0.032	-0.000435934	0.048397
12	14.00	-0.8	-11.2	1.36742E-05	-0.114	-1.55886E-06	-0.092	-1.288	0.275822	0.146	0.04027	-0.358	-5.012	0.006657575	-0.032	-0.000213042	0.040268
13	16.00	-0.8	-12.8	2.76077E-06	-0.114	-3.14728E-07	-0.092	-1.472	0.229466	0.146	0.033502	-0.358	-5.728	0.003253578	-0.032	-0.000104114	0.032502
14	18.00	-0.8	-14.4	5.5739E-07	-0.114	-6.35425E-08	-0.092	-1.656	0.190901	0.146	0.027872	-0.358	-6.444	0.001590034	-0.032	-5.08811E-05	0.027871
15	20.00	-0.8	-16	1.12535E-07	-0.114	-1.2829E-08	-0.092	-1.84	0.158817	0.146	0.023187	-0.358	-7.16	0.000777055	-0.032	-2.48657E-05	0.023187
16	22.00	-0.8	-17.6	2.27205E-08	-0.114	-2.59013E-09	-0.092	-2.024	0.132126	0.146	0.01929	-0.358	-7.876	0.000379749	-0.032	-1.2152E-05	0.019290
17	24.00	-0.8	-19.2	4.58718E-09	-0.114	-5.22939E-10	-0.092	-2.208	0.10992	0.146	0.016048	-0.358	-8.592	0.000185585	-0.032	-5.93871E-06	0.016048
18	26.00	-0.8	-20.8	9.26136E-10	-0.114	-1.0558E-10	-0.092	-2.392	0.091447	0.146	0.013351	-0.358	-9.308	9.06958E-05	-0.032	-2.90226E-06	0.013351
19	28.00	-0.8	-22.4	1.86984E-10	-0.114	-2.13161E-11	-0.092	-2.576	0.076078	0.146	0.011107	-0.358	-10.024	4.43233E-05	-0.032	-1.41835E-06	0.011107
20	30.00	-0.8	-24	3.77513E-11	-0.114	-4.30365E-12	-0.092	-2.76	0.063292	0.146	0.009241	-0.358	-10.74	2.16609E-05	-0.032	-6.9315E-07	0.009241
21	32.00	-0.8	-25.6	7.62187E-12	-0.114	-8.68893E-13	-0.092	-2.944	0.052655	0.146	0.007688	-0.358	-11.456	1.05858E-05	-0.032	-3.38745E-07	0.007688
22	36.00	-0.8	-28.8	3.10684E-13	-0.114	-3.5418E-14	-0.092	-3.312	0.036443	0.146	0.005321	-0.358	-12.888	2.52821E-06	-0.032	-8.09026E-08	0.005321
23	40.00	-0.8	-32	1.26642E-14	-0.114	-1.44371E-15	-0.092	-3.68	0.025223	0.146	0.003683	-0.358	-14.32	6.03814E-07	-0.032	-1.9322E-08	0.003683
24	44.00	-0.8	-35.2	5.16219E-16	-0.114	-5.8849E-17	-0.092	-4.048	0.017457	0.146	0.002549	-0.358	-15.752	1.44209E-07	-0.032	-4.6147E-09	0.002549
25	50.00	-0.8	-40	4.24835E-18	-0.114	-4.84312E-19	-0.092	-4.6	0.010052	0.146	0.001468	-0.358	-17.9	1.68317E-08	-0.032	-5.38615E-10	0.001468
26	56.00	-0.8	-44.8	3.49629E-20	-0.114	-3.98577E-21	-0.092	-5.152	0.005788	0.146	0.000845	-0.358	-20.048	1.96456E-09	-0.032	-6.28658E-11	0.000845

Case III: Transfer Polynomial $Q_p = 0.2$ and data from Table 2.2.

$$\frac{Q(s)}{I(s)} = \frac{1-(a_0+a_1)s}{1+b_0 s+b_1 s^2+b_2 s^3} = \frac{1-(1.5-4)s}{1+10s+18s^2+24s^3} \tag{2.31}$$

A reduction of polynomial results in:

$$\frac{Q(s)}{I(s)} = \frac{0.042+0.0104s}{0.042+0.417s+0.75s^2+s^3} \tag{2.32}$$

Solving for the roots of the denominator:

$$s = -0.13, -0.315 - j0.492, -0.315 + j0.492 \tag{2.33}$$

Thus

$$\frac{Q(s)}{I(s)} = \frac{0.036+0.893s}{(s+0.13)(s+0.315+j0.492)(s+0.315-j0.492)} \tag{2.34}$$

Using partial fraction expansion to solve for constants K:

$$\frac{Q(s)}{I(s)} = \frac{K_1}{(s+0.130)} + \frac{K_2}{(s+0.315+j0.492)} + \frac{K_2^*}{(s+0.315-j0.492)} \tag{2.35}$$

This results in:

$$\frac{Q(s)}{I(s)} = \frac{0.103}{(s+0.13)} + \frac{(-0.0515+j0.099)}{(s+0.315+j0.492)} + \frac{(-0.0515-j0.099)}{(s+0.315-j0.492)} \tag{2.36}$$

Then

$$\frac{Q(t)}{I(t)} = 0.103e^{-0.13t} + \left((0.223)(\cos(0.315t + \tan^{-1}1.922)\right) \tag{2.37}$$

The graph and data for Case III are shown in Figure 2.3 and Table 2.5, respectively.

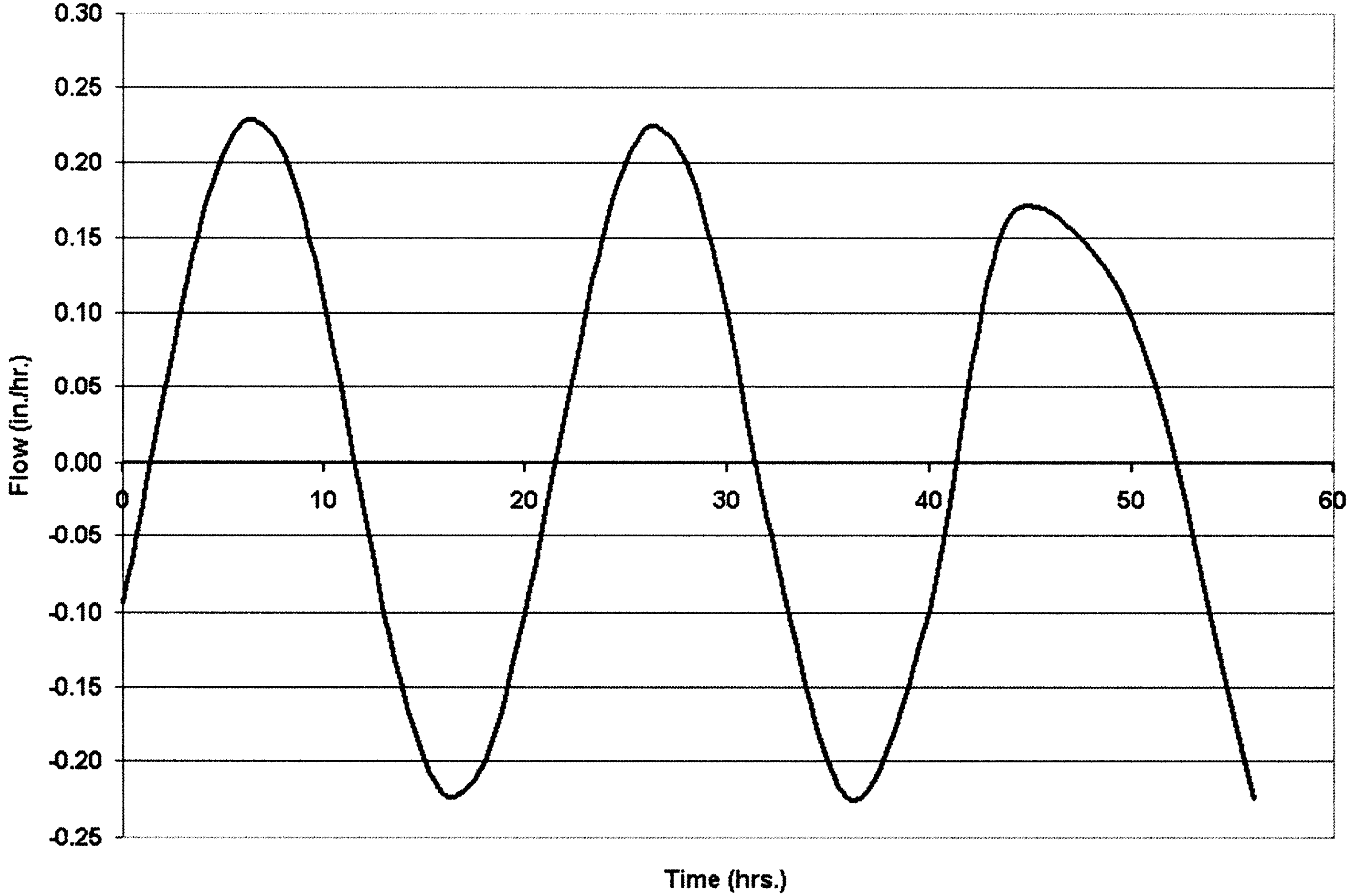

Figure 2.3 Hydrograph Case III, based on Equation 2.37.

Table 2.5 Tabluated Calculations Case III, based on Equation 2.37.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	t (time)	Exponential	A x B	Expontential (C)	Constant	D x E	Constant	A x G	Arctan(1.922) in Radians	H + I	Cos(J)	Constant	K x L	E x F	N + M
2	0	-0.13	0	1	0.103	0.103	0.315	0	4.232423	4.232423	-0.46175	0.226	-0.10436	0.010609	-0.09375
3	0.25	-0.13	-0.0325	0.968022	0.103	0.099706	0.315	0.07875	4.232423	4.311173	-0.39054	0.226	-0.08826	0.01027	-0.07799
4	0.5	-0.13	-0.065	0.937067	0.103	0.096518	0.315	0.1575	4.232423	4.389923	-0.31691	0.226	-0.07162	0.009941	-0.06168
5	1	-0.13	-0.13	0.878095	0.103	0.090444	0.315	0.315	4.232423	4.547423	-0.16422	0.226	-0.03711	0.009316	-0.0278
6	2	-0.13	-0.26	0.771052	0.103	0.079418	0.315	0.63	4.232423	4.862423	0.149472	0.226	0.033781	0.00818	0.041961
7	4	-0.13	-0.52	0.594521	0.103	0.061236	0.315	1.26	4.232423	5.492423	0.703304	0.226	0.158947	0.006307	0.165254
8	6	-0.13	-0.78	0.458406	0.103	0.047216	0.315	1.89	4.232423	6.122423	0.987106	0.226	0.223086	0.004863	0.227949
9	8	-0.13	-1.04	0.353455	0.103	0.036406	0.315	2.52	4.232423	6.752423	0.891913	0.226	0.201572	0.00375	0.205322
10	10	-0.13	-1.3	0.272532	0.103	0.028071	0.315	3.15	4.232423	7.382423	0.454275	0.226	0.102666	0.002891	0.105557
11	12	-0.13	-1.56	0.210136	0.103	0.021644	0.315	3.78	4.232423	8.012423	-0.15778	0.226	-0.03566	0.002229	-0.03343
12	14	-0.13	-1.82	0.162026	0.103	0.016689	0.315	4.41	4.232423	8.642423	-0.70926	0.226	-0.16029	0.001719	-0.15857
13	16	-0.13	-2.08	0.12493	0.103	0.012868	0.315	5.04	4.232423	9.272423	-0.98842	0.226	-0.22338	0.001325	-0.22206
14	18	-0.13	-2.34	0.096328	0.103	0.009922	0.315	5.67	4.232423	9.902423	-0.88808	0.226	-0.20071	0.001022	-0.19968
15	20	-0.13	-2.6	0.074274	0.103	0.00765	0.315	6.3	4.232423	10.53242	-0.44677	0.226	-0.10097	0.000788	-0.10018
16	22	-0.13	-2.86	0.057269	0.103	0.005899	0.315	6.93	4.232423	11.16242	0.166076	0.226	0.037533	0.000608	0.038141
17	24	-0.13	-3.12	0.044157	0.103	0.004548	0.315	7.56	4.232423	11.79242	0.715157	0.226	0.161626	0.000468	0.162094
18	26	-0.13	-3.38	0.034047	0.103	0.003507	0.315	8.19	4.232423	12.42242	0.989657	0.226	0.223663	0.000361	0.224024
19	28	-0.13	-3.64	0.026252	0.103	0.002704	0.315	8.82	4.232423	13.05242	0.884184	0.226	0.199825	0.000279	0.200104
20	30	-0.13	-3.9	0.020242	0.103	0.002085	0.315	9.45	4.232423	13.68242	0.439232	0.226	0.099266	0.000215	0.099481
21	32	-0.13	-4.16	0.015608	0.103	0.001608	0.315	10.08	4.232423	14.31242	-0.17436	0.226	-0.03941	0.000166	-0.03924
22	36	-0.13	-4.68	0.009279	0.103	0.000956	0.315	11.34	4.232423	15.57242	-0.99083	0.226	-0.22393	9.84E-05	-0.22383
23	40	-0.13	-5.2	0.005517	0.103	0.000568	0.315	12.6	4.232423	16.83242	-0.43166	0.226	-0.09756	5.85E-05	-0.0975
24	44	-0.13	-5.72	0.00328	0.103	0.000338	0.315	13.86	4.232423	18.09242	0.726809	0.226	0.164259	3.48E-05	0.164294
25	50	-0.13	-6.5	0.001503	0.103	0.000155	0.315	15.75	4.232423	19.98242	0.424065	0.226	0.095839	1.59E-05	0.095855
26	56	-0.13	-7.28	0.000689	0.103	7.1E-05	0.315	17.64	4.232423	21.87242	-0.99296	0.226	-0.22441	7.31E-06	-0.2244

2.3 Relations to Other Routing Functions

Using the proceeding as a basis of determining a hydrograph solution of the river routing based upon the Taylor Series and the Muskingum-Cunge Method[13], the data obtained from the stream-gage of the north branch of the Metedeconk River near Lakewood will be the basis for some of the constants. First some constraints placed upon the parameters to show the hydrograph can be derived from the relationship developed by Chow et el. Using the first terms of the polynomial obtained in Equation 2.38. The transfer function of inflow vs outflow becomes:

$$\frac{Q(s)}{I(s)} = \frac{1 - a_0 s}{1 + b_0 s} = \frac{1}{1 + b_0 s} - \frac{a_0 s}{1 + b_0 s} \qquad (2.38)$$

One of the most recognizable routing functions is the Muskingum equation and it is based on the continuity equation. If the first terms of the techniques described in the previous section are used to define the watershed routing, one can relate these to the Muskingum equation:

$$\begin{aligned} \dot{S} &= a_0 I \\ \dot{S} &= sS \end{aligned} \qquad (2.39)$$

and

$$\frac{Q}{I} = \frac{1 - a_0 s}{1 + b_0 s} \quad or \; I(1 - a_0 s) = Q(1 + b_0 s) \qquad (2.40)$$

and

$$I - Q = Ia_0 s + Qb_0 s \qquad (2.41)$$

Applying the continuity equation and substituting yields:

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[13] Ref. 35, Page 356.

$$I - Q = \dot{S} \tag{2.42}$$

and

$$Ia_0 + Qb = S \tag{2.43}$$

Then, a form for the well known Muskingum equation:

$$S = Ia_0 + Qb_0 \tag{2.44}$$

One reference[14] cites the Muskingum equation to be:

$$S = K[xI + (1-x)O] \tag{2.45}$$

Where x = Weighting factor
K = Storage time constant
O = Volumetric flow output
I = Volumetric flow input

This further reduces to the following equation through a partial fraction expansion:

$$\frac{Q(s)}{I(s)} = \frac{1}{\left(b_0(s + \frac{1}{b_0})\right)} - \frac{a_0}{\left(b_0{}^2(s + \frac{1}{b_0})\right)} + \frac{a_0}{b_0} \tag{2.46}$$

Taking the inverse Laplace results in:

$$\frac{Q(t)}{I(t)} = \frac{1}{b_0}e^{-\frac{t}{b_0}} - \frac{a_0}{b_0^2}e^{-\frac{t}{b_0}} + \frac{a_0}{b_0}\delta(t) \tag{2.47}$$

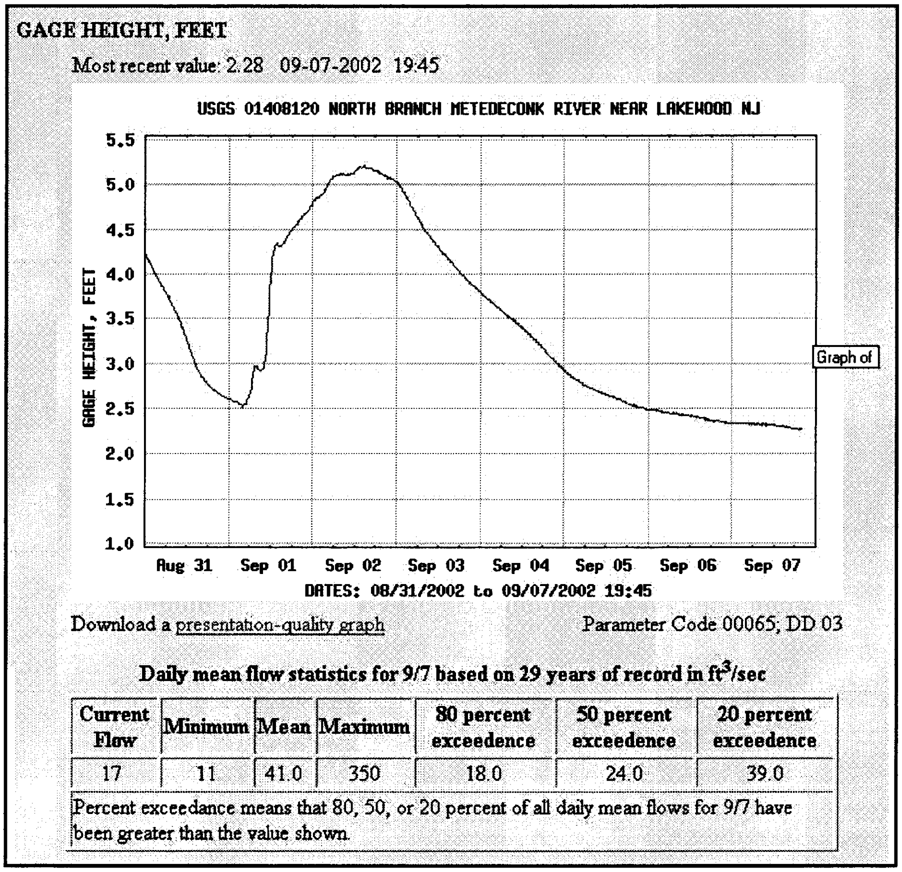
Further reduction yields:

$$\frac{Q(t)}{I(t)} = \left(\frac{b_0 - a_0}{b_0{}^2}\right)\frac{e^{-t}}{b_0} + \frac{a_0}{b_0}\delta(t) \tag{2.48}$$

---

[14] Ref. 35, Page 600.

Several authors[15] have analyzed solutions to the River Routing Muskingum-Cunge approach and related the physiography of the river to the parameters of the equation. These relations are expressed as follows, using the following physical data obtained from the stream gage[16] Figures 2.4 and 2.5.



Current Flow	Minimum	Mean	Maximum	80 percent exceedence	50 percent exceedence	20 percent exceedence
17	11	41.0	350	18.0	24.0	39.0

Percent exceedance means that 80, 50, or 20 percent of all daily mean flows for 9/7 have been greater than the value shown.

Figure 2.4 Real-time data for USGS 0111408120 North Branch of the Metedeconk River near Lakewood, New Jersey showing discharge in cfs.

[15] Ref. 19, pp. 345-361.
[16] Ref. 25, North Branch of the Metedeconk River.

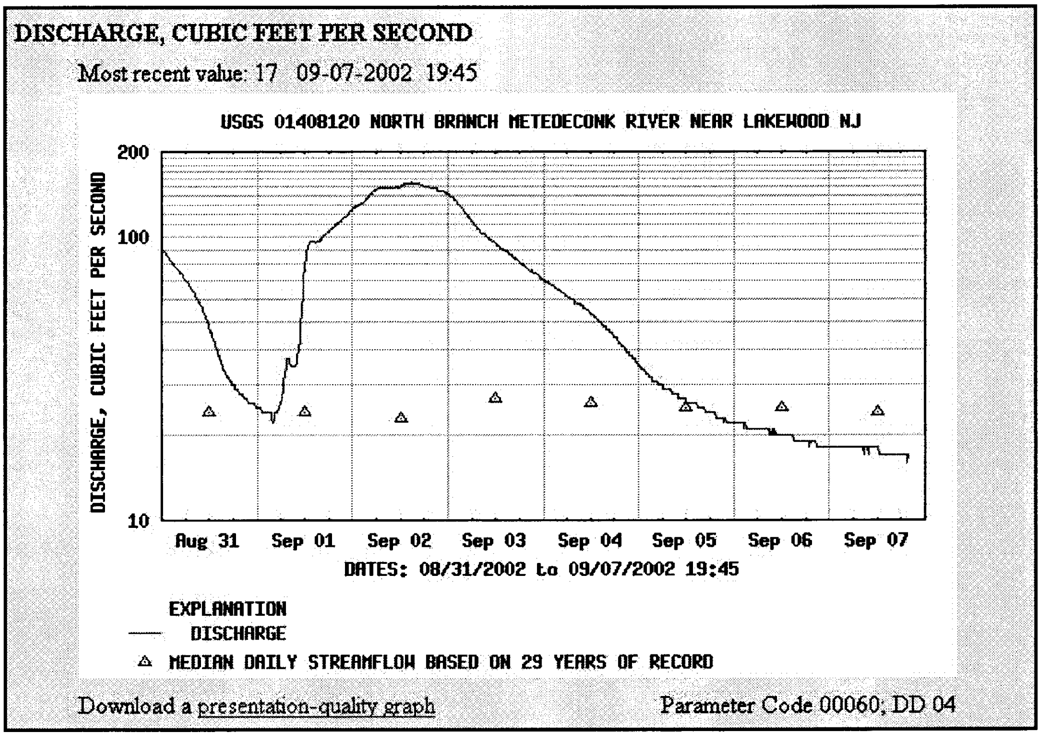


Figure 2.5 Real-time data for USGS 0111408120 North Branch of the Metedeconk River near Lakewood, New Jersey showing gage height in feet.

The following parameters were derived from the data to be used in the physical model

dQ = 70-20+50 ft 3/s (2.49)

dy = 3.75-2.40=1.35ft (2.50)

B = 50ft (Road overpass)

Tr = 24 hours

Δy = 5-3 = 2 ft (for U.S.G. S. (maps)

Δy Δx = 15000 ft (reach measured)

Δy Δt = 24 hr.

From the above physical data the following parameters were determined:

$$S_0 = \frac{2}{15000} = 0.0001333 \tag{2.51}$$

$$\text{Kinematic celerity } = 0.740 \text{ ft/s } \left| c_k = \frac{dQ}{Bdy} = \frac{50}{50 \times 1.75} = 1.35 \right. \tag{2.52}$$

$$\Delta x \leq \frac{1}{2}\left(c_k \Delta t + \frac{Q}{BS_0 C_k} \right) = \frac{1}{2}\left(0.740 \times 24 + \frac{50}{1.33 \times 10^{-4}} \right) \tag{2.53}$$

$$\Delta x \leq \frac{42660}{2} = 21330 ft \tag{2.54}$$

Then

$$X = 0.5\left(1 - \frac{Q}{BS_0 C_f \Delta x} \right) = 0.5\left(1 - \frac{50}{1.33 \times 10^{-4} \times 0.240 \times 21{,}330} \right) = 0.184 \tag{2.55}$$

and θ the time constant is:

$$\theta = \frac{\Delta x}{C_k} = \frac{21330}{0.730} = 28824.3 \text{ or } 8 \text{ hrs} \tag{2.56}$$

and from Chow et al., the Taylor series coefficients become:

$$a_0 = \theta X = (8)(0.184) = 1.47 \tag{2.57}$$

$$b_0 = \theta(1 - X) = (8)(0.86) = 6.88 \tag{2.58}$$

then

$$\frac{Q(s)}{I(s)}=\frac{\frac{1}{6.88}}{S+\frac{1}{6.88}}-\frac{\frac{1.47}{6.88^2}}{S+\frac{1}{6.88}}+\frac{1.47}{6.88}(s) \tag{2.59}$$

$$\frac{Q(s)}{I(s)}=\frac{0.145}{S+0.145}+\frac{0.031}{S+0.145}+0.214S(s) \tag{2.60}$$

Taking the inverse transform

$$\frac{Q(t)}{I(t)}=0.145e^{-0.145t}-0.031e^{-0.145t}+0.214S(0) \tag{2.61}$$

Or

$$\frac{Q(t)}{I(t)}=\left(0.135e^{-0.145t}+0.214S(0)\right) \tag{2.62}$$

Comparing this equation to the one developed from the Taylor series expansion one observes:

The term

$$KXW= a_0 \tag{2.63}$$

and

$$K(1\text{-}X)W = b_0 \tag{2.64}$$

but

$$a_0=\frac{\partial f}{\partial I}\, and\, b_0=\frac{\partial f}{\partial Q} \tag{2.65}$$

and each is a function of time. Thus, a_0 and b_0 each have the dimension of time. These coefficients are determined from the actual data compiled from the hydrographs of the water shed.[17] The dimensions of a_0 and b_0 are measured in hours, the same as the Muskingum equation cited.

Much investigation has been exercised to determine the values of the X and K in the equations above. One source[18] states that the coefficients can be estimated by:

$$K = \frac{0.6L}{Vo} \tag{2.66}$$

and

$$X = 0.3(1 - \frac{4F^2}{9})\frac{yo}{SoL} \tag{2.67}$$

where

L = reach length
Vo = average velocity
yo = full flow depth
So = slope of the channel bottom
F = Froude number

For the watershed under study, estimates of a_0 and b_0 are 10 and 42 hours respectively. Figure 2.6 demonstrates the unit hydrograph using real-time data.

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[17] Ref. 3, Page 798.
[18] Ref. 19, Page 600.

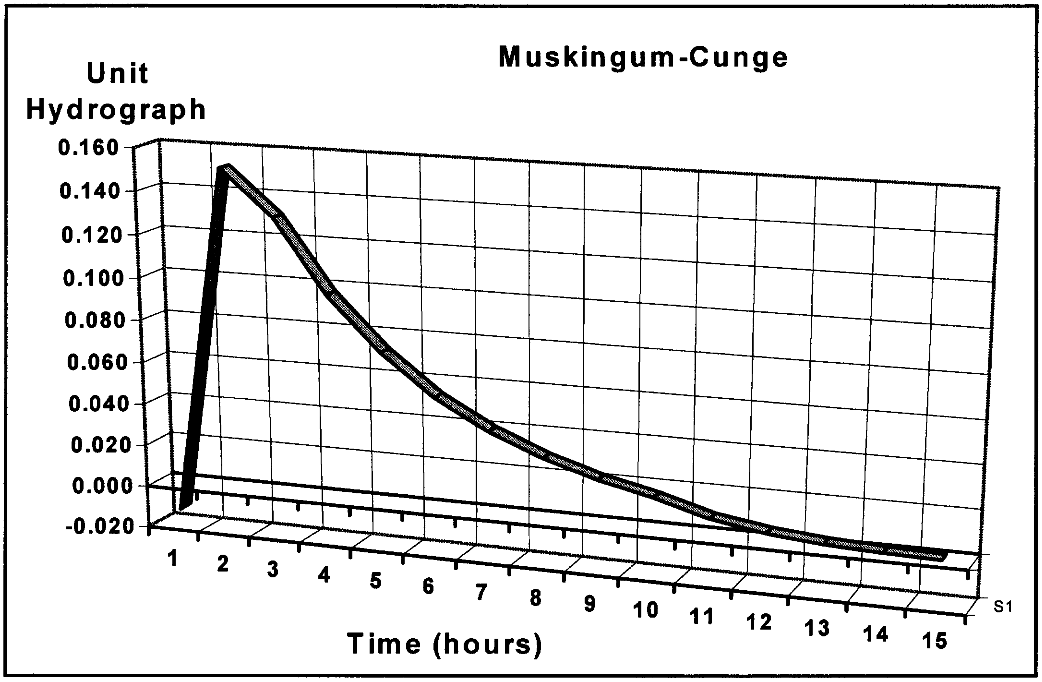

Figure 2.6 Unit Hydrograph using Real Time Data

2.4 Linear Reservoir

Another method of determining the routing hydrograph is the linear reservoir techniques. Taking a different assumption for the Taylor series expansion so that the polynomial

$$Q = \frac{M(D)}{N(D)} I \text{ with } N(D) = 1 \text{ and} \tag{2.68}$$

The terms represented by:

$$(-l)^{j-1} \frac{c^j}{j!} \text{ where j = 1,2, -m+1} \tag{2.69}$$

Using this relationship and dropping all terms beyond the first results in the following expression:

$$\frac{Q(t)}{I(t)} = \frac{1}{1+Ks} \tag{2.70}$$

The mathematical analysis follows:

$$\begin{aligned} &Q(1+Ks) = I \quad or \quad \frac{Q(s)}{I(s)} = \frac{1}{1+Ks} \\ &and \quad I - Q = sS \\ &\quad Q(1+Ks) - Q = Ss \\ &\quad S = KQ \end{aligned} \tag{2.71}$$

The relationship of output to input in terms of the inverse Laplace transform is

$$\zeta^{-1}\left[\frac{1}{1+Ks}\right] = e^{-Ks} \tag{2.72}$$

The same form as that obtained in Section 2.0 for the general polynomial case and consistent with the statement ".....will result in a model representing a series of linear reservoirs."[19]

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[19] Ref. 3, Page 794.

2.5 Infiltration Impact

The abstractions in the watershed are mainly from the infiltration from the precipitation.[20] The dominant factor for infiltration then becomes groundwater flow which then results as immediate deduction from the total watershed runoff and at some time later re-entering the watershed at some downstream point. Because of this, it becomes necessary to explore the impact of infiltration and how it may factor into the analysis of the previous section. The research will consider the Green-Ampt[21] model of infiltration (see Figure 2.7).

An aspect of infiltration and particularly as observed in sandy soils is that water tends to flow through the soils as a "slug"[16] so that a clean delineation exists between a wetting front at the unsaturated soil below and the saturated soil above. This front is the subject of the Green and Ampt analysis (see Figure 2.7).

From Darcy's law one obtains:

$$i = -K_s\left(\frac{-\Psi_f + L_f}{L_f} + l\right) \tag{2.73}$$

---

[20] Chow et al pg. 797.
[21] Ref. 16, pg. 186.

where

I = infiltration rate or specific discharge

Ψ_f = capillary – pressure heat at wetting front

L_f = depth to the wetting front

K_s = saturated conductivity

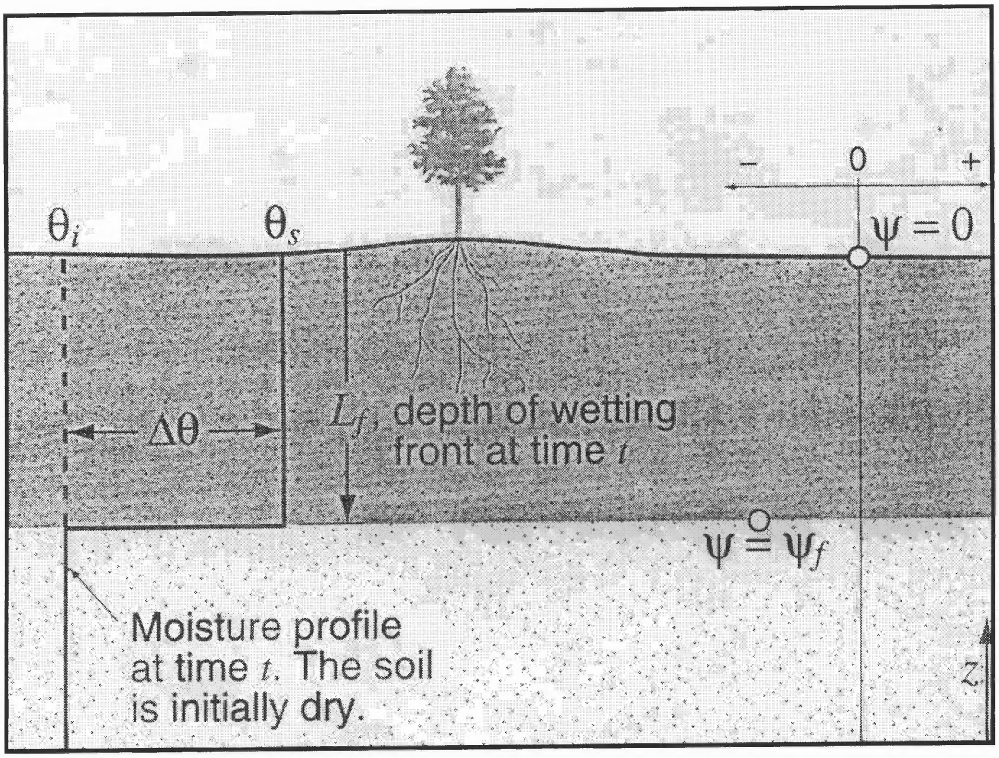

Figure 2.7 Schematic diagram of wetting front movement in the unsaturated zone, as conceptualized in the Green-Ampt model. The basic concept is that the soil surface is held at saturation and that water moves downward through the soil as a sharp "wetting front". Darcy's law can be applied under these idealized conditions to give an equation for calculating the rate of infiltration with time.

Rearranging the above equation yields

$$i = -K_s(\frac{-\Psi_f + L_f}{L_f}) \tag{2.74}$$

Define

I = total cumulative water infiltrated

Then

$$I = -\frac{dI}{dt} = -\Delta\theta \frac{dL_f}{dt} \tag{2.75}$$

and

$$\Delta\theta = \theta_s - \theta_i \tag{2.76}$$

where

θ_i = initial moisture content

θ_s = saturated moisture content

2.6 The Ekman Spiral

Another phenomenon that may occur in river channel is the Ekman Spiral[22]. The Ekman Spiral is caused by a horizontal force acting on the surface of the water and impacting near a pier or an abutment and causing a circular turbulence in the locale. The differential equations and boundary conditions representing this phenomenon are:

$$-fv = A\frac{\partial^2 u}{\partial z^2} \tag{2.77}$$

$$fu = A\frac{\partial^2 v}{\partial z^2} \tag{2.78}$$

---

[22] Ref.45, pg. 195.

Where

$$z \rightarrow 0 \text{ to } -\infty, \Im_s = \Im \left| z = \rho A \frac{\partial u}{\partial z} \right| z = 0 \tag{2.79}$$

And

u = flow velocity in x- direction

v = flow velocity in y- direction

$z =$ depth of channel

f = area/sec.

A = area in ft^3

$\rho =$ mass density

$\Im =$ lbs.sec./ft^2

From above, solve equations for u(z) and v(z)

$$v = -\frac{A}{f}\frac{\partial^2 v}{\partial z^2} \tag{2.80}$$

and

$$v = -\frac{A}{f}\frac{\partial^2 u}{\partial z^2} \tag{2.81}$$

then

$$\frac{A}{f}\frac{\partial^2 u}{\partial z^2} = -\frac{f}{a}V \tag{2.82}$$

and

$$\frac{A}{f}\frac{\partial^4 u}{\partial z^4} = -\frac{f}{a}\frac{\partial^2 v}{\partial z^2} \tag{2.83}$$

but

$$\frac{\partial^2 v}{\partial z^2} = -\frac{f}{a}u \tag{2.84}$$

so that

$$\frac{\partial^4 u}{\partial z^4} = -\frac{f^2}{A^2}u \tag{2.85}$$

$$\therefore \frac{\partial^4 u}{\partial z^4} + \frac{f^2}{A^2}u = 0, and \frac{f^2}{A^2} = a^4 \tag{2.86}$$

and

$$\mathcal{L}\left[\frac{\partial^4 u}{\partial z^4} + \frac{f^2}{A^2}u\right] = 0, \left(s^4 + a^4\right)u = 0 \tag{2.87}$$

The solution then rests on the four roots of -1:

$$s_1 = a\left(\cos 45^o + j\sin 45^o\right) \tag{2.88}$$

$$s_2 = a\left(\cos 135^o + j\sin 135^o\right) \tag{2.89}$$

$$s_3 = a\left(\cos 225^o + j\sin 225^o\right) \tag{2.90}$$

$$s_4 = a\left(\cos 315^o + j\sin 315^o\right) \tag{2.91}$$

Then by partial fraction expansion:

$$\begin{aligned}\frac{1}{\left(s^4 + a^4\right)} &= \frac{A_1}{\left(s - a(0.707 + j0.707)\right)} + \frac{\mathrm{A}_2}{\left(s - a(-0.707 + j0.707)\right)} \\ &+ \frac{A_3}{\left(s - a(-0.707 - j0.707)\right)} + \frac{A_4}{\left(s - a(0.707 - j0.707)\right)}\end{aligned} \tag{2.92}$$

Solving for each of the coefficients A's and using the identity:

$$e^{\frac{\pi}{4}} = 0.707 + j0.707 \tag{2.93}$$

$$e^{\frac{3\pi}{4}} = -0.707 + j0.707 \tag{2.94}$$

$$e^{\frac{5\pi}{4}} = -0.707 - j0.707 \tag{2.95}$$

$$e^{\frac{7\pi}{4}} = 0.707 - j0.707 \tag{2.96}$$

Now invoking the conditions $z \to 0 \;\; to - \infty$

$$u(z) = \frac{e^{0.707az}}{2a^3} \cos\left(0.707az - \frac{\pi}{4}\right) \tag{2.97}$$

From this:

$$\frac{\partial u}{\partial z} = \frac{e^{.707az}}{2\sqrt{2}a^2}\left[\cos\left(0.707az - \frac{\pi}{4}\right) - \sin\left(0.707az - \frac{\pi}{4}\right)\right] \tag{2.98}$$

$$\frac{\partial^2 u}{\partial z^2} = \frac{1}{2a} e^{.707az} \sin\left(0.707az - \frac{\pi}{4}\right) \tag{2.99}$$

At $z = 0$

$$\frac{\Im_s}{\rho A} = \frac{1}{2a^2} = \frac{\partial u}{\partial z} \quad \text{and } a = \sqrt{\frac{f}{A}} \tag{2.100}$$

and

$$u(z) = \frac{\Im_s}{\rho\sqrt{fA}} \; e\sqrt{\frac{f}{zA}} \; \cos\left(\sqrt{\frac{f}{A}} - \frac{\pi}{4}\right) \tag{2.101}$$

$$v(z) = \frac{T_s}{\rho\sqrt{fA}} \; e\sqrt{\frac{f}{zA}}^{\,z} \; \sin\left(\sqrt{\frac{f}{2A}} - \frac{\pi}{4}\right) \tag{2.102}$$

The solution requires several intermediate steps which have been skipped over in the interest of a more simplified presentation. Table 2.6 and Figure 2.8 show the data and graph of the Ekman spiral, respectively.

Table 2.6 Ekman Spiral

u	z	v
1.0	0.0	0.0
2.0	-1.0	-4.6
-0.6	-2.0	-2.0
-0.5	-3.0	0.0
-0.1	-4.0	0.1
0.0	-5.0	0.1

The Ekman Spiral is a phenomena that can occur in a river or channel and might impact the occurrence of erosion, or of the dynamic wave progressing downstream.

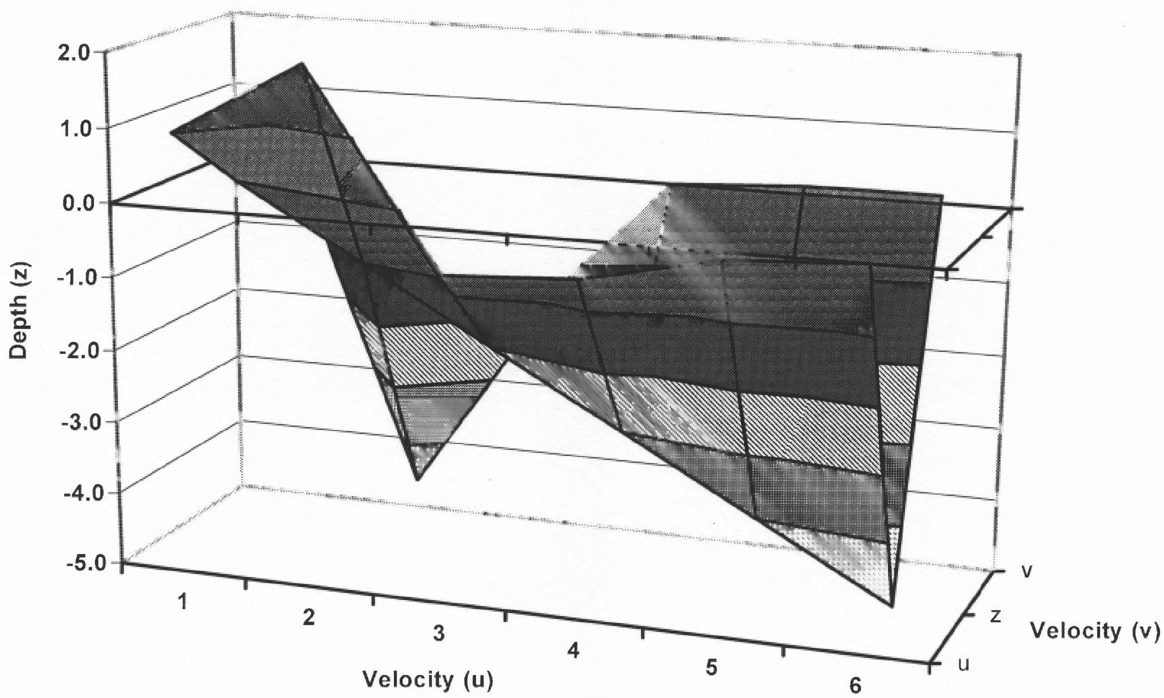

Figure 2.8 Ekman Spiral.

2.7 Spectral Signature

A hydrograph expressed in the time domain can be transformed to a frequency spectra through the Fourier transform. It is suggested that each channel with its own environmental parameters will have a unique spectral signature. The Fourier transform is defined by:

$$F(G(t)) = G(f) = \int_{t=-\infty}^{t=-\infty} g(t) e^{-j2\pi ft} dt \tag{2.103}$$

The analogy here is the Laplace transform except that the variable is in the frequency domain. In the case of the solutions expressed in section 2.2, the following transforms result:

Case I : $Q_p = 0.04$

$$g_1(t) = -0.271e^{-1.5t} \tag{2.104}$$

then

$$G_1(f) = \int_{-\infty}^{\infty} 0.271e^{0.15t} e^{-j2\pi ft} dt \tag{2.105}$$

or

$$G_1(f) = \frac{-0.271 \times 13.3}{1 + \left(\frac{2\pi f}{0.15}\right)^2} \tag{2.106}$$

$$g_2(t) = -0.308e^{-0.107t} \tag{2.107}$$

$$G_2(f) = \int_{-\infty}^{\infty} -0.308e^{-0.107t} e^{-j2\pi ft} dt \tag{2.108}$$

or

$$G_2(f) = \frac{(0.308)(5.76)}{1 + \left(\frac{2\pi f}{0.15}\right)^2} \tag{2.109}$$

qnd

$$g_3(t) = -0.032e^{-1.49t} \tag{2.110}$$

$$G_3(f) = \int_{-\infty}^{\infty} -0.032e^{-1.49t} e^{-j2\pi ft} dt \tag{2.111}$$

$$G_3(f) = \frac{-0.0429}{1 + \left(\frac{2\pi f}{1.49}\right)^2} \tag{2.112}$$

Summing the terms of the Fourier transform results in the frequency/amplitude curve showing in Figure 2.9. Note that this curve represents a peak "Q" of 0.04.

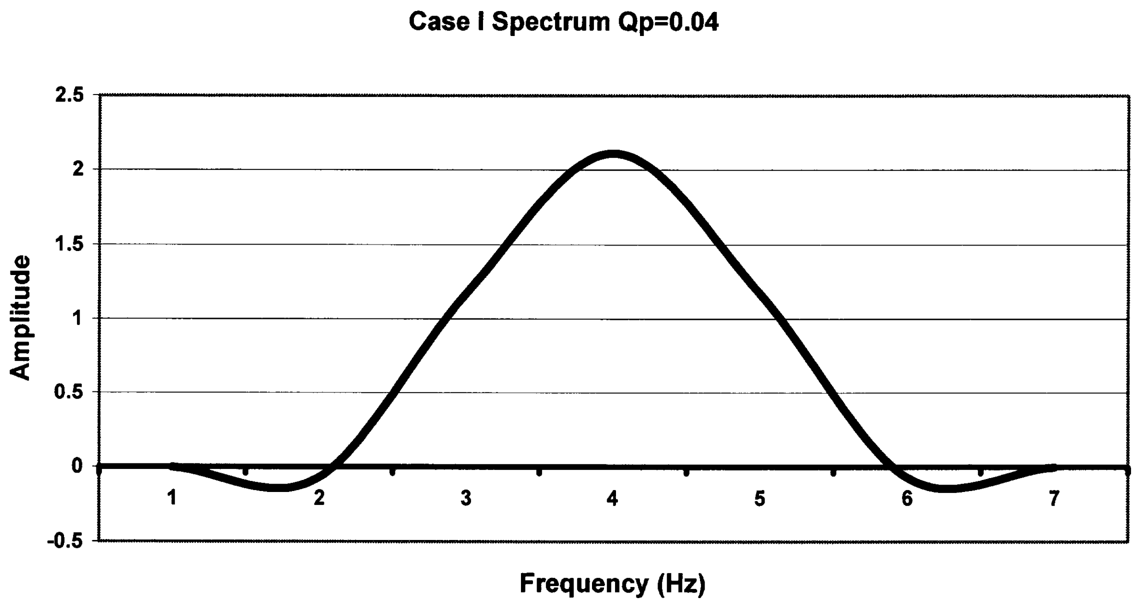

Figure 2.9 Case I Spectrum: Qp =0 .04.

Case II : $Q_p = 0.12$

The hydrograph response is represented by

$$\frac{Q(t)}{I_1(t)} = -0.114e^{-.104} + 0.146 - 0.032e^{-.358t} \tag{2.113}$$

The Fourier transforms resulting from each term follow:

$$\text{Term 1}: G_1(f) = \frac{-0.143}{1 + j7.85f} \tag{2.114}$$

$$\text{Term 2}: G_2(f) = \frac{-10.86}{1 + j68.2f} \tag{2.115}$$

$$\text{Term 3}: G_3(f) = \frac{-0.089}{1 + j17.2f} \tag{2.116}$$

A chart tabulating the amplitudes over a range of frequencies is shown below in Table 2.7, and a graph of the Spectrum is shown in Figure 2.10.

Table 2.7 Frequency/Amplitude Spectrum.

f	$G_1(f)$	$G_2(f)$	$G_3(f)$	ΣG
0	-0.143	10.86	-0.089	10.63
0.01	-0.143	7.41	-0.088	7.18
0.10	-0.112	1.72	-0.044	1.57
1.00	-0.018	0.159	-0.005	-0.136
-0.10	-0.112	1.72	-0.044	1.57
-0.01	-0.143	7.41	-0.088	7.18
-1.00	0.018	0.159	-0.005	-0.136

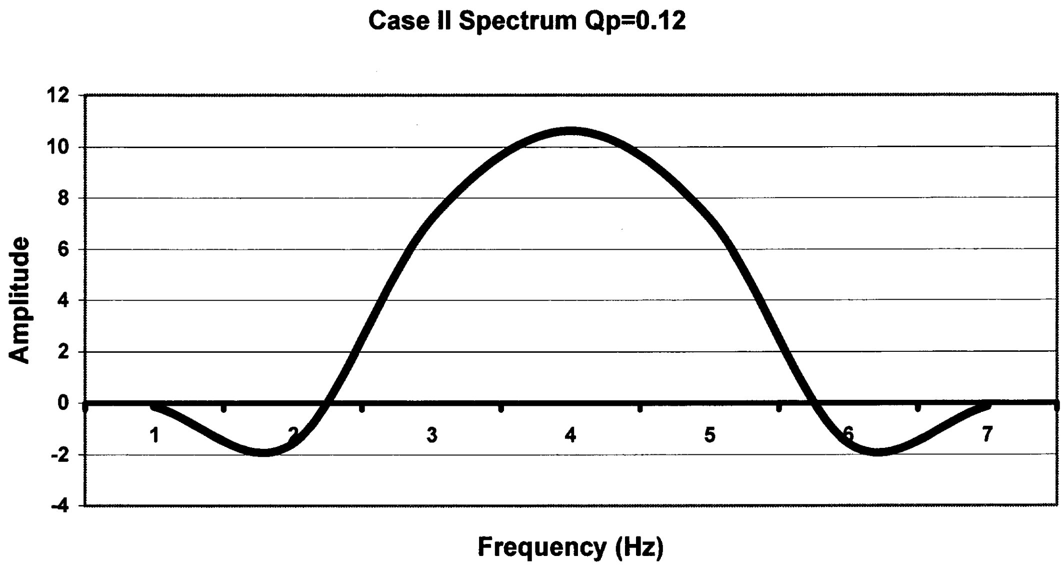

Figure 2.10 Case II Spectrum Q_p= 0.12.

Case III: $Q_p = 0.2$

$$\frac{Q(t)}{I_1(t)} = -0.103e^{-.13t} + \left(0.223\cos\left(0.315t + 297.5^0\right)\right) \tag{2.117}$$

The time response in this case represents a sinusoidal function. As such, the physical interpretation is the stream flow under analysis would be in an unstable state, such as several traveling waves.

$$\text{Term 1:} G_1(f) = \frac{-0.792}{1 + j48.3f} \tag{2.118}$$

$$\text{Term 2:} G_2(f) = \frac{1}{2}(0.462 - j0.887)\delta(f - 0.05) \times \ 0.112 \tag{2.119}$$

Here the transform is:

$$F(f) = \frac{1}{2} e^{j\phi} \delta(f - f_0) \tag{2.120}$$

$$e^{j\phi} = \cos\phi + j\sin\phi \tag{2.121}$$

A tabulation and graph of the function is shown in Table 2.8 and Figure 2.11, respectively. Note that the graph is a complex function and that phase shift occurs with frequency. It is observed from the different flows that a unique spectrum results, which can be an indication of the channel, state (i.e. a steady state to an unstable one).

Table 2.8 Case III Spectrum/ Phase Qp =0 .2

$f(H)$	$G(f)$	$\phi(f)$
-1.00	0.054	-78.20
-0.10	0.162	-0.71
-0.01	0.714	-0.16
0	0.791	0.19
0.01	0.712	0.08
0.10	0.162	-1.06
1.00	0.480	-88.70

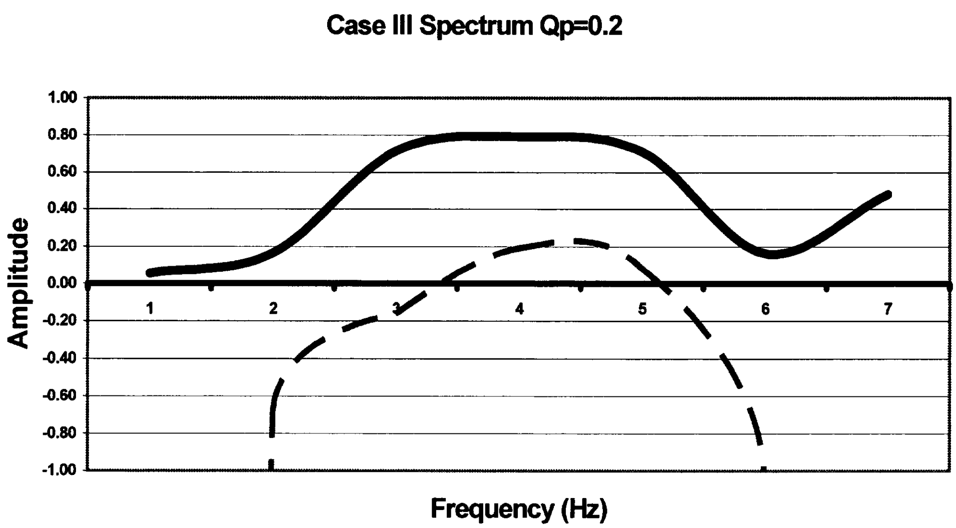

Figure 2.11 Graph of Case III Spectrum/Phase Qp=0.2.

CHAPTER 3

COMPUTER SIMULATION

3.1 General Approach

A fundamental need of any numerical model is a satisfactory quantitative description of the physical processes that are being modeled. The partial differential equations that govern two-dimensional surface-water flow in a horizontal plane are derived from equations that govern three-dimensional flow by considering fluid velocity in the vertical direction to be negligible. Therefore, pressure within the fluid is considered the same as in a hydrostatic condition.

The numerical techniques used to solve the governing equations are based on the Galerkin[23] finite element method. Application of the finite element method begins by dividing the area being modeled into smaller regions called elements. An element can be either triangular or quadrangular in shape. The type of shape used is one that can easily be arranged to fit complex boundaries. The elements are defined by a series of node points at the element vertices, midside points, and, for nine-node quadrilateral elements, at their centers. Values of dependent variables are approximated within each element using the nodal values and a set of interpolation functions (also called shape functions). Approximations of the dependent variables are substituted into the governing equations, which generally will not be satisfied exactly, thus forming a residual. The residual is weighted over the entire solution region. The weighted residuals, which are defined by

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[23] Ref. 11, Page 3-1 describes the method of weighted residuals to approximate solutions to partial differential equations.

equations, are set to zero, and the resulting equations are solved for the dependent variables.

In Galerkin's method, the weighting functions are chosen to be the same as those used to interpolate values of the dependent variables within each element. Galerkin's finite element method weights the governing equations over the entire solution domain. The weighting process uses integration, which is carried out numerically using Gaussian quadrature on a single element. Repetition of the integration for all elements that comprise a solution region produces a system of nonlinear algebraic equations when the time derivatives are discretized. Because the system of equations is nonlinear, an iterative solution procedure is needed. Newton iteration, or a variation of it, is applied, and the resulting system of equations is solved using an efficient frontal solution scheme.

3.2 Watershed Modeling Concepts

The study defines software methodology by addressing those issues required to characterize the watershed. The Watershed Modeling System (WMS©) utilizes the digital elevation model (DEM) to delineate watershed and sub-basin boundaries which are then integrated with Geographical Information System (GIS) data so that stream and confluence features can be used in the software simulation process. See Figure 3.1 for a watershed model flowchart of the process.

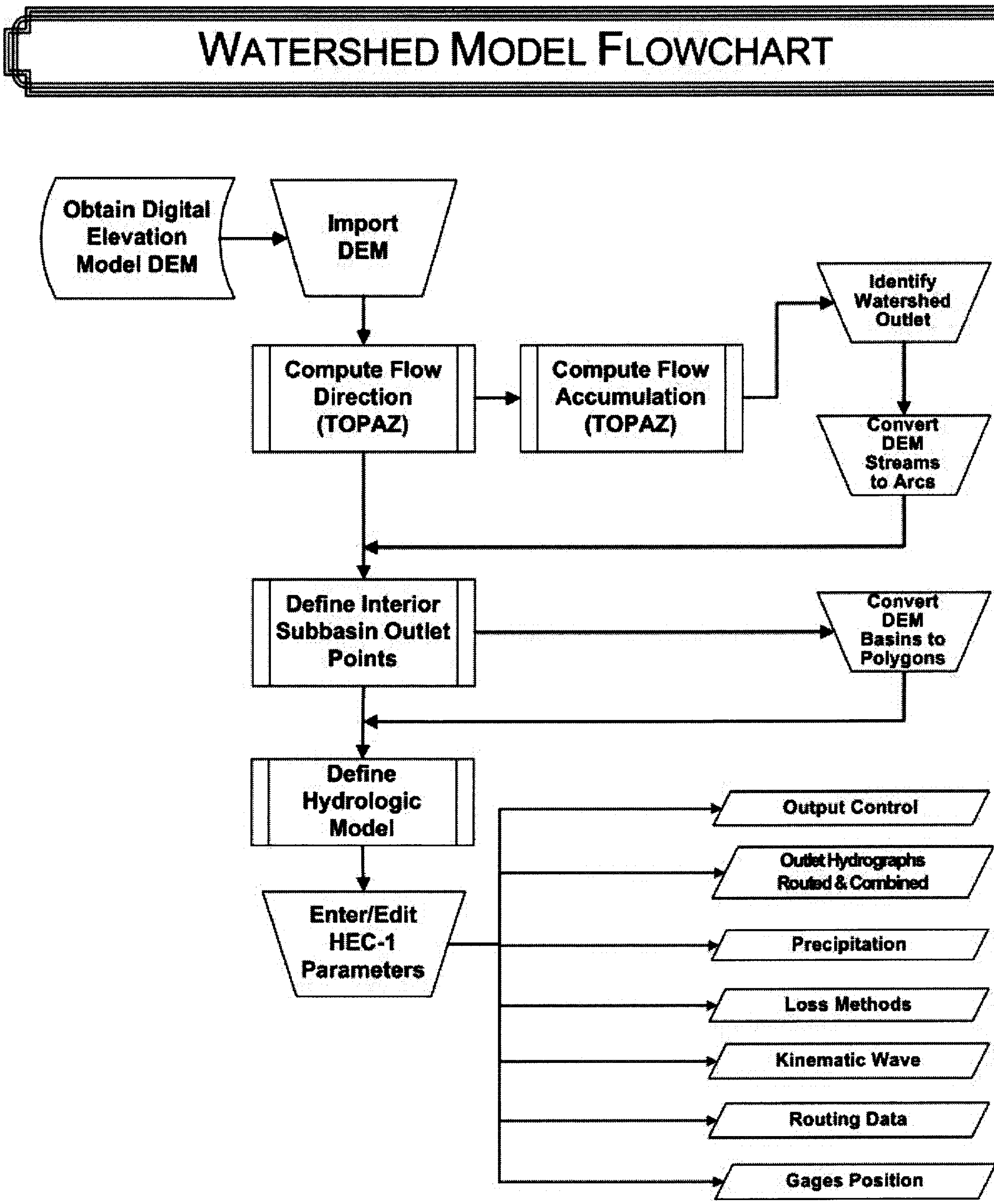

Figure 3.1 Watershed Model Flowchart.

The surface water modeling system creates models for simulating the hydrodynamic analysis. It permits flow velocities and water surface elevations through the use of mesh models. Bathymetric data obtained from the USGS is used in the surface water model.

No discussion of water supply would be complete without the discussion of a groundwater flow model. The ground water modeling techniques described includes software for the inclusion of data on the wells and the migration of pollutants through the soils.

WMS© [24] has evolved to the point that there are many tools and different ways to accomplish the same thing. For this reason it is a good idea to have an understanding of how WMS© can best be used to develop and run hydrologic models. The distinguishing difference between WMS© and other applications designed for setting up hydrologic models like HEC-l and TR-20 is its unique ability to take advantage of digital terrain data for hydrologic model development. WMS© uses three primary data sources for model development:

- Geographic Information Systems (GIS) Vector Data
- Digital Elevation Models (DEMs) or Gridded Elevation Sets
- Triangulated Irregular Networks (TINs)

Basin models are developed for a variety of engineering and management purposes, including the development of discharge frequency relationships for use in planning studies and project design, the analysis of the effects of urban development and other changes on runoff response, and the evaluation of the hydrologic impacts of alternative water development plans.

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[24] WMS - Watershed Modeling System Software is a product of the Environmental Modeling Research Laboratory of Brigham Young University

A river basin precipitation-runoff model, frequently called a watershed model, is a network of computational components programmed to simulate surface runoff and compute discharge hydrographs to locations of interest. An HEC-l model of a complex river basin has basic components for subbasin runoff, channel and reservoir routing, and hydrograph combining. Optional components include diversions and pumping. The number and location of components depend on basin conditions and modeling objectives. The subbasin runoff component represents runoff response from a subdivided part of the basin. Subbasin boundaries are delineated so that lumped parameters defining precipitation and precipitation loss give reasonable results. Input includes precipitation data, precipitation loss function parameters, and precipitation-runoff transformation function parameters (unit hydrograph or kinematic wave). The computed output consists of a discharge hydrograph at the subbasin outlet.

The routing component represents flood-wave movement through a channel reach or unregulated reservoir. The input consists of an inflow hydrograph and parameters defining the routing characteristics of the reach or reservoir. The output consists of an outflow hydrograph at the reservoir outlet or downstream end of the reach.

The hydrograph-combining component, essential to the operation of the system as a whole, performs the function of linking or combining the hydrographs from the other components.

A subdivision of the area of a large basin is necessary because of the size and complexity of the physical system, including the heterogeneity of basin characteristics and storms. A basin with major tributaries and a diversity of topography and land use must be broken down into smaller components to fit the constraints and assumptions in the model. A subdivision also may be necessary to obtain the information needed in terms of level of detail and location as dictated by the objectives of the study.

Sometimes it may be advantageous to subdivide the area in two phases: the first for parameter estimation and the second for developing an operational model of the complete system. The primary purpose of subdivision for calibration is to establish the conditions necessary for estimating parameters, including taking advantage of gage locations with historical data and defining areas with homogeneous conditions above the gages. In the operational model, other purposes related to the study objectives may come into play, and these may require altering subbasin boundaries to provide the output desired.

Existing data should be utilized as much as possible in developing a model. If a subbasin boundary is located so that the subbasin outlet coincides with a stream gage location, the program can compare observed hydrographs from the gage with computed hydrographs in estimating model parameters.

The subdivision should be consistent with the topography and the hydrologic system that exists in the basin. Subbasin boundaries must coincide with hydrologic boundaries, and the interrelationships of major hydrologic elements in the system need to be considered in deciding where boundaries are to be drawn. See Figure 3.2 for an example of subasin wartershed flowpaths from the WMS© software. For example, a subbasin encompassing more than one major tributary is not likely to provide the degree of resolution needed. Under these conditions of the individual tributaries to the runoff process would be lacking.

The uniformity of conditions in a subbasin is key to the validity of using lumped parameters in the model, and this generally limits the size of subbasins that can be used. Variation in loss rates, base flow, and other components of the runoff process obviously tends to increase with the size of the area involved.

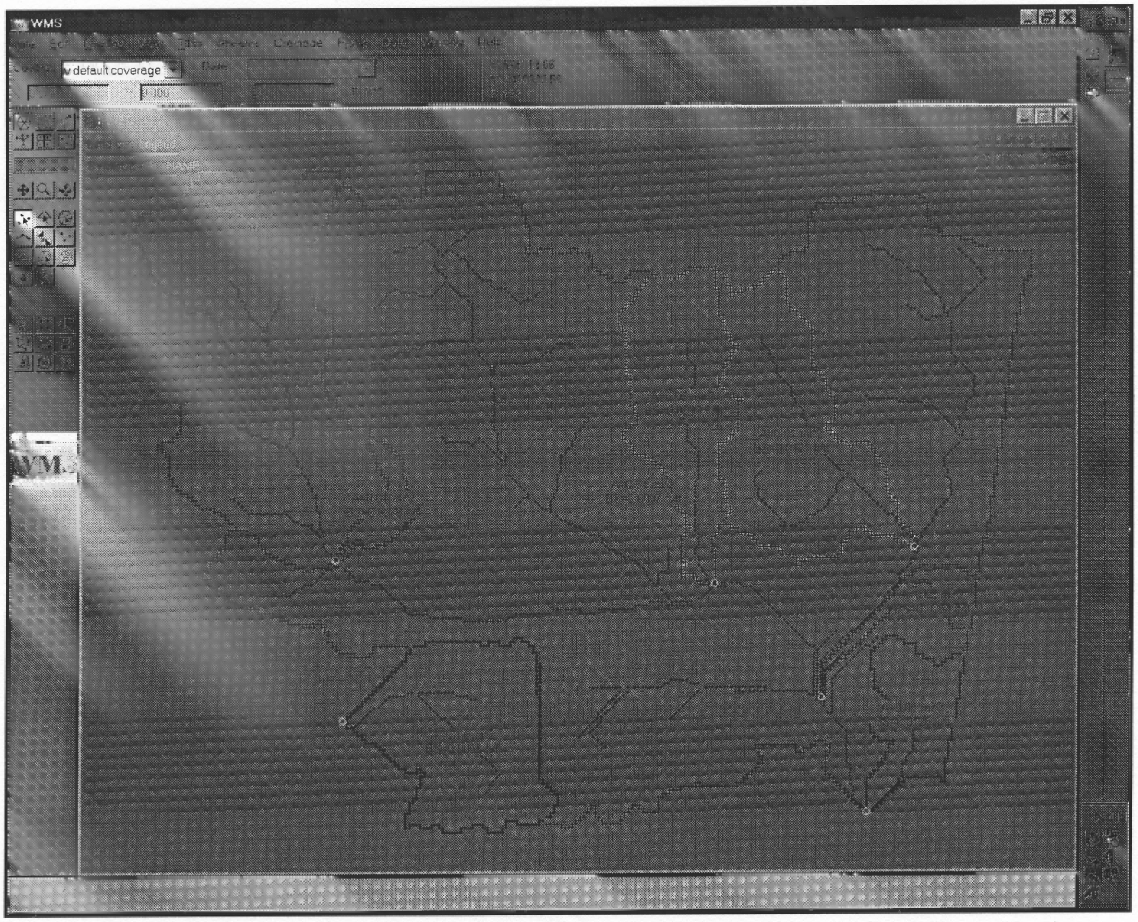

Figure 3.2 Watershed Flowpaths for subbasins from WMS© Software.

Slope is a significant factor in the runoff response of a basin. The slope of the main watercourse is frequently used in regression equations relating unit hydrograph parameters to basin characteristics. Thus, it is desirable to divide a basin into areas of relatively uniform slope, both for effective modeling and for facilitating the analysis of ungaged subbasins using regression relationships.

Since infiltration rates and other runoff response characteristics of a basin vary with soil type and cover, a model may be enhanced by the separation of areas with different soil and cover conditions. Generally, forested areas should be separated from unforested areas, and areas with permeable soils should be separated from areas with impermeable soils, other factors being equal.

Since mountains affect storm patterns and intensity due to orthographic effects, it may be appropriate to separate areas of high elevation from areas of lower elevation in some river basins.

The shape of a basin affects the configuration and timing of the runoff hydrograph. Because of time-area differences, a long, narrow basin generates in different hydrograph than a relatively square one of the same area. Since unit hydrograph methods, such as the Clark method, are based on typical basin shapes, irregular basins should be subdivided to conform to the assumed shapes if practical. For example, a basin area composed of a wide section and a long, narrow section normally would be divided to separate the narrow part from the wide part.

Usually, subdivisions are made at reservoir locations, both existing and planned, so that inflows to reservoirs can be computed and reservoir routing effects determined.

To evaluate the results of channel improvements, it may be necessary to isolate an improved section of a river as a routing reach, thus dictating where subbasin boundaries are located.

If an area of a basin is in the process of urbanization or future development is anticipated, it may be appropriate to separate this area in the model to facilitate revising basin parameters later to reflect changed conditions.

River basin models are frequently developed to evaluate potential damage and the effects of damage reduction measures at key damage centers, such as highly urbanized locations. Subdividing a basin to obtain essential data at such locations is an important consideration. When set up properly, the model can be run under different sets of conditions to predict peak flows and stages at these locations. This hydrologic data is translated into expected annual damage figures and benefits for evaluating alternative development plans.

Occasionally political boundaries influence the subdivision of a basin for modeling.

To investigate how these analysis tools can represent an integrated regional model, the Metedeconk River Basin in Ocean County, New Jersey is used. The utilization of digital elevation and bathymetry data imported into the software and the resulting analysis in computer generated images are presented. Other parameters in the database will be soil characteristics and land use.

Using the WMS software involves operations described in the following Sections.

3.3 Feature Object (GIS) Vector Data.

GIS vector data includes points, lines, and polygons that are used to represent basins, streams, and key points such as outlets or culverts (see Figure 3.2). This GIS data is identified as Feature Objects, and tools for using them are included in a Map Module. Feature object data can be used by itself to create a watershed models for hydrologic DEMs[25,26].

Many times it is not practical to obtain digital elevation data and perform an automated watershed characterization prior to setting up a hydrologic model. Watershed and sub-basin boundaries may already be known as stored as part of a GIS or CAD database, or it may be straight-forward to trace an existing map to define streams and basins. With WMS software, properly structured hydrologic models can be created automatically from points, lines, and polygons.

3.4 Digital Elevation Models

The second method that can be used in this investigation of the WMS for defining watershed models and developing hydrologic data involves the use of digital elevation models or DEMs. A DEM (as defined in WMS) is simply a two-dimensional array of elevation points with a constant x and y spacing. While a DEM results in data redundancy for surface definition, its simple data structure and wide-spread availability have made them a popular source for digital terrain modeling and watershed characterization[27].

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[25] TIN – Triangular Irregular Network
[26] DEM – Digital Elevation Model
[27] Several researchers, including Pueker and Douglas (1975) and Garbrecht and Martz (1995) have developed methods to extract watershed geomorphology for DEMs.

The two primary data sets that must be obtained to perform watershed delineation with DEM elevations are the USGS digital maps. Other sources of elevation data may include federal, state, and local government agencies, universities, or private data publishers.

The flow direction grid can be computed from the active DEM region using a custom version of the TOPAZ[28] computation within the WMS software. With the flow directions assigned for each DEM point, the flow accumulation at each DEM point can be computed (see Figure 3.3). The flow accumulation for a given DEM point is defined as the number of DEM points whose flow paths eventually pass through the point. For example, DEM points that are part of a stream have high flow accumulation value greater than a user-defined threshold. Flow accumulations are computed in WMS from the flow directions. With the aid of the flow accumulations, the location of the watershed outlet needs to be determined and an outlet feature point created. A minimum threshold is then defined and all of the DEM points "upstream" from the defined outlet(s) are connected together to form a stream network of feature lines. Stream feature arcs can be created in any fashion. For example, in an urban area the streams will not likely be well-defined from the DEM elevations and flow directions. The flow directions for the DEM are then used for basic overland flow whereas the stream vectors are used for conveyance channels. Practically, one can think of WMS modifying the flow directions of the DEM points underlying the stream vectors so that flow always follows the defined stream vectors.

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[28] TOPAZ – Topographic Parameterization program developed by the USDA-ARS, National Agricultural Water Quality Laboratory under direction of Dr. Jurgen Garbrecht.

If one wishes to further subdivide the watershed into sub-basins then nodes along the stream feature arcs should be converted to "outlet" nodes by using the feature point/node attributes dialog. As these nodes are converted the hydrologic modeling tree is automatically updated.

Using the outlets on the stream network and the flow directions, the contributing DEM points for each outlet are assigned the proper basin identification.

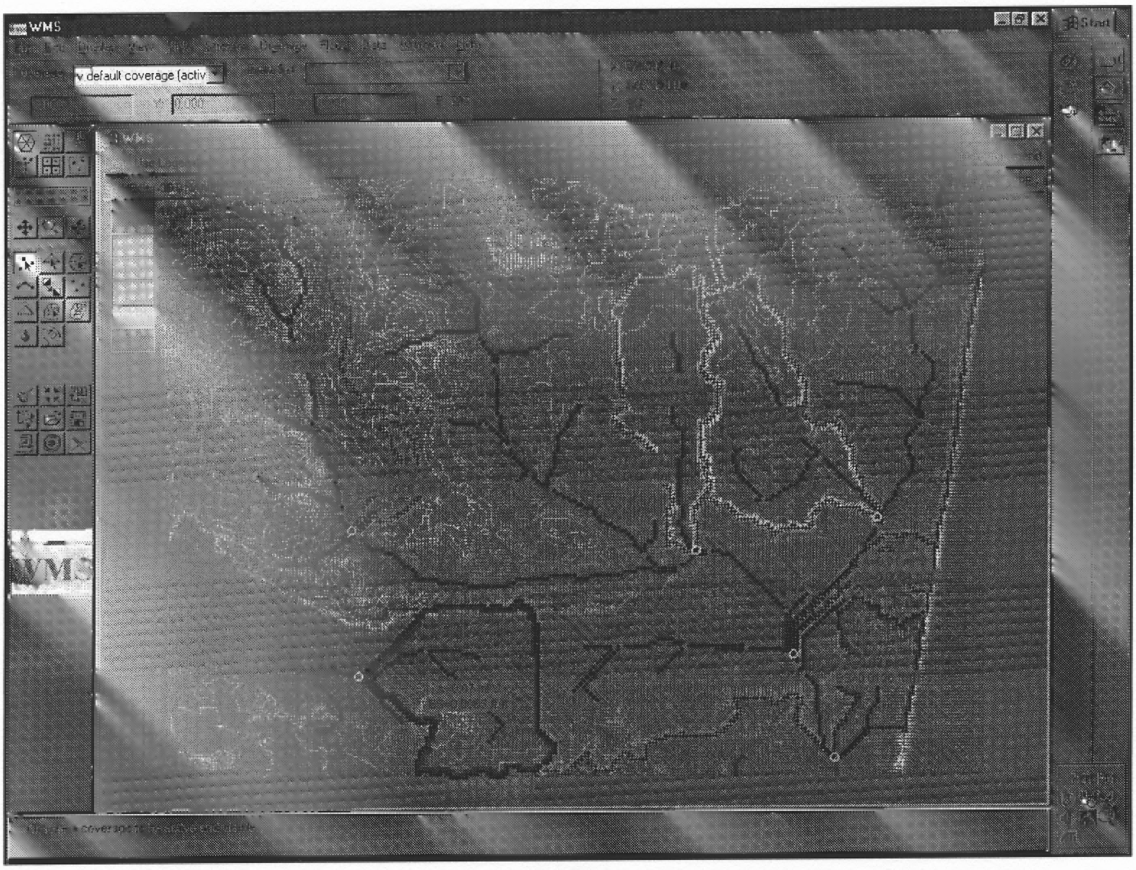

Figure 3.3 Watershed Delineation from Digital Elevation Model in WMS© Software.

Similar to how flow accumulations were converted to stream arcs, the boundaries between DEM points with different basin identification can be converted to feature polygons. Storing a basin as a single polygon rather than several hundreds (or thousands) of DEM cells is much more efficient.

Once the boundaries of the sub-basins have been determined geometric properties important to hydrologic modeling (area, slopes, runoff distances, etc.) can be computed from the DEM data . At this point a model as described in the previous section, where watersheds are defined strictly from the feature points, lines (arcs), and polygons. The computed data is automatically stored in the appropriate locations for hydrologic model definition, and the remaining parameters for the desired hydrologic model can be entered using the appropriate interface dialogs.

3.5 Guidelines for Using TIN Data

The third method, which has been a traditional approach in WMS for defining watershed models, is through the use of TINs[29]. Developing watersheds from TINs often involves the use of both feature objects and DEMs. The following steps can be used as a guideline for watershed characterization with TINs.

An elevation source is required for creating a TIN. An existing TIN whose triangle edges already conform to key drainage features such as streams is useful. An existing TIN data source can be used as a background elevation source to create a new TIN from it. A background elevation source can be a DEM, TIN, or both. If you use data already developed in a GIS then you may have to do some editing. This will depend

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[29] TIN/s are Triangular Irregular Networks.

on how well the data being imported matches with the required data for watershed model development. In WMS three primary layers are used. A point layer representing the watershed outlet and any sub-basin outlet or confluence points, 2) a line layer representing a stream network, and 3) a polygon layer representing watershed boundaries. If all three layers exist then construction of the watershed model topology can proceed, but if one or more of the layers are absent, they must be created manually from within WMS. For example if you only had a file that contained sub-basin boundaries, you would need to digitize the stream network and define the outlet locations of the sub-basins.

An important point to remember in WMS is that lines used to define a stream network have direction. For each line (arc) there is a beginning and en ending node and "flow" along the line is defined in this direction. When interactively creating lines in WMS you should always create streams from downstream to upstream.

3.6 Surface Water Modeling

A modular set of computer programs, FESWMS-2DH is developed to simulate surface-water flow where motion is essentially horizontal and is well described by a two-dimensional approximation.

Three separate, but interrelated, programs comprise the core of the modeling system: (1) the Data Input Module (DIN2DH), (2) the Depth-Averaged Flow Module (FL"O2DH), and (3) the Analysis of Output Module (ANO2DH).

A data preprocessor, DIN2DH performs in the modeling system. The primary purpose of DIN2DH is to generate a two-dimensional finite element network (also called a finite element grid) that is error free. See Figure 3.4 for Finite Elements Mesh Output from SMS© software. DIN2DH functions include editing of input data, automatic generation of all or part of the finite element network, refinement of an existing network, ordering of elements to enable an efficient equation solution, and graphic display of the finite element network. Processed network data can be stored in a data file for use by other FESWMS-2DH programs.

The finite element method, FLO2DH is applied to solve the governing system of equations using the defined network. FLO2DH can simulate both steady and unsteady (time-dependent) two-dimensional (in a horizontal plane) surface-water flow to obtain depth-averaged velocities and flow depths. The effects of bed friction and turbulent stresses are included, as are, optionally, surface wind stresses and the Coriolis force.

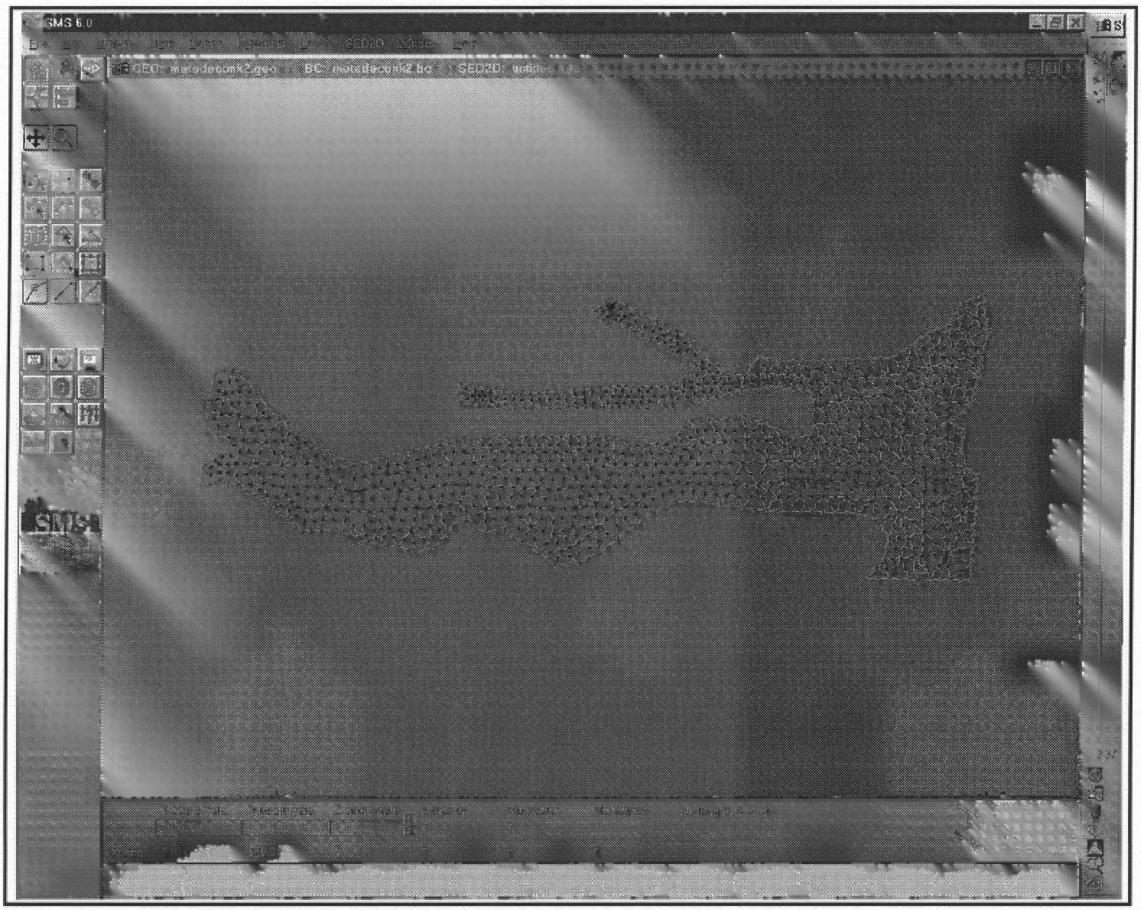

Figure 3.4 Triangular Finite Elements Mesh from SMS© Software

Pressure flow through bridges is considered if the water is in contact with the bottom of the bridge deck defined by a "ceiling" elevation at a node point. Flow over weirs, or weir-like structures (such as highway embankments), and flow through culverts can also be modeled. Clear-water general scour can be calculated along with local scour at bridge piers. The computed two-dimensional flow data can be written to a data file and stored for future use.

Results of flow simulations are presented graphically and as reports by ANO2DH (see Figure 3.5). Graphic plots of velocity and unit-flow vectors; ground-surface and water-surface elevation isolines; and velocity, unit flow, or stage (water-surface elevation) time-history plots at a computation point can be created. Thus, ANO2DH acts as a postprocessor in the modeling system.

The three-dimensional nature of flow is unimportant in many surface-water flow problems of practical engineering concern, particularly when the width-to-depth ratio of the water body is large. In such cases, the horizontal distribution of flow quantities might be the main interest, and two-dimensional solutions based on depth-averaged flow approximations can be used to great economic advantage. Shallow rivers, flood plains, estuaries, harbors, and even coastal seas are examples of surface-water bodies where the two-dimensional depth-averaged flow equations will provide an accurate description of fluid motion.

Flow is assumed to be strictly two dimensional throughout this manual, except the special cases of weir and culvert flow. A two-dimensional flow description is obtained by integrating the governing three-dimensional flow equations with respect to the depth

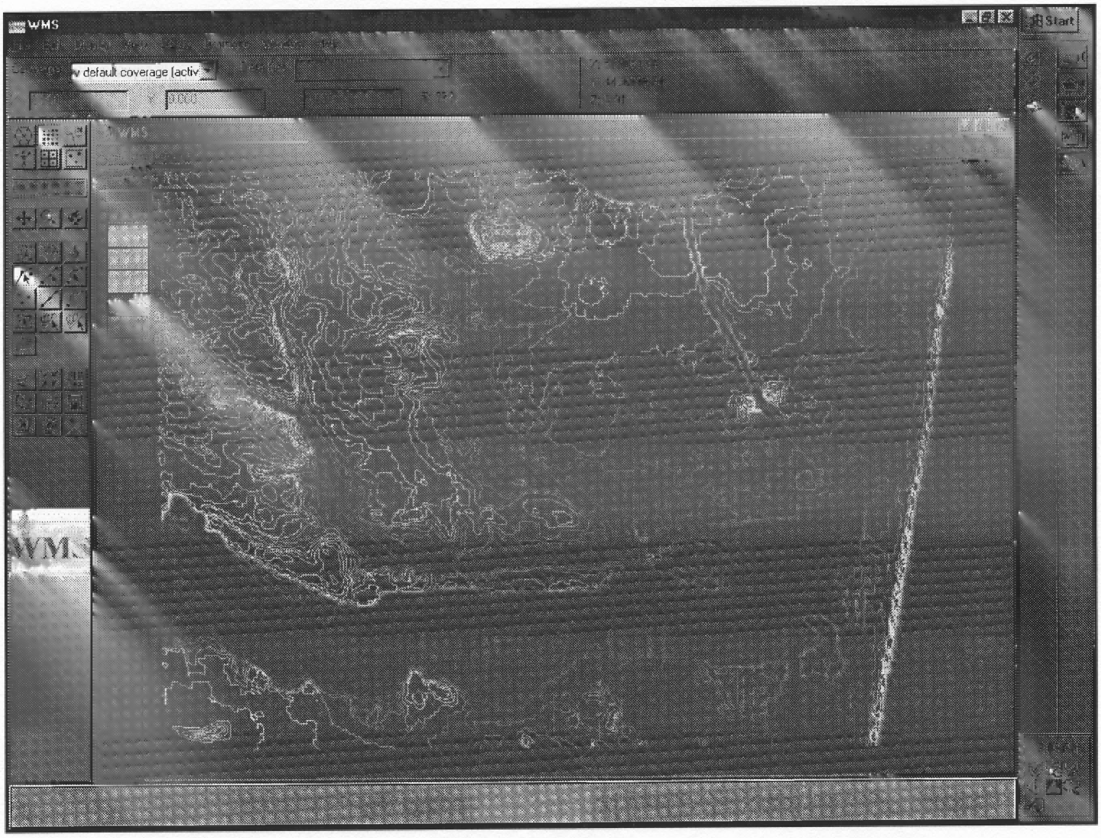

Figure 3.5 Bathymetry Chart from WMS© software

of flow. Velocity in the vertical direction is assumed to be negligible; therefore, pressure in a column of water is considered hydrostatic. Flow depth and the resulting depth-averaged velocities are variable in a horizontal plane.

Depth-averaged horizontal velocities and water depth, as well as the time-derivatives of these quantities are calculated with FESWMS-2DH if a time-dependent flow is modeled. Equations that describe depth-averaged surface-water flow account for the effects of bed friction, wind-induced stress at the water surface, fluid stresses caused turbulence, and the effect of the Earth's rotation. Because velocity in the vertical direction is not modeled, evaluation of phenomena such as stratified flow is beyond the scope of the modeling system. Also, because water density is assumed constant, flows resulting from horizontal density gradients cannot be evaluated.

Flow in water bodies that have irregular topography and geometrical features, such as islands and highway embankments can be simulated with FESWMS-2DH. Flow over dams, weirs, and highway embankments, and through bridges, culverts, gated openings, and drop inlet spillways can also be modeled. Boundary stresses (bed friction and surface stresses caused by wind) and stresses caused by turbulence are accounted for using empirical relations.

Flow through bridges and culverts can be modeled as either one-dimensional or two-dimensional flow. One-dimensional flow is described by an empirical equation that gives the flow rate through a bridge or culvert based on water-surface elevations at the upstream and downstream sides of the structure. When two-dimensional flow through a bridge is modeled, additional flow resistance that results from contact between the bridge deck and water surface is considered. Although it is usually not practical to model bridge piers directly, the effect of bridge piers can be accounted for indirectly by including in the momentum calculations the drag force exerted by a pier on water flowing past it.

Flow over highway embankments can be modeled as either one-dimensional or two-dimensional flow. For reasons that are described later, modeling flow over highway embankments as one-dimensional flow using empirical weir-flow equations is usually more accurate. When water flows over a bridge deck and pressure flow exists within the bridge opening (combined weir and pressure flow); flow over the bridge needs to be modeled as one-dimensional weir flow. However, flow through the bridge can be modeled as either one- or two-dimensional flow.

The effect of changes to the system can be forecast by modifying the input data that describe an existing physical system. Thus, FESWMS-2DH can be used to study the consequences of designed works and operations.

3.7 Groundwater Flow

A finite-difference model and its associated modular computer program simulates flow in three dimensions. The modular structure consists of a Main Program and a series of highly independent subroutines called "modules." The modules are grouped into "packages." Each package deals with a specific feature of the hydrologic system which is to be simulated, such as flow from rivers or flow into drains, or with a specific method of solving linear equations which describe the flow system, such as the Strongly Implicit Procedure or Slice-Successive Overrelaxation.

3.8 Groundwater Model

The primary features of the ground-water flow model were to produce a program that could be readily modified, was simple to use and maintain, could be executed on a variety of computers with minimal changes, and was relatively efficient with respect to computer memory and execution time. See Figure 3.6 for the graphical user interface for the Visual Modflow Program©.

The model program documented in this report uses a modular structure wherein similar program functions are grouped together, and specific computational and hydrologic options are constructed in such a manner that each option is independent of other options. Because of this structure, new options can be added without the necessity of changing existing subroutines. In addition, subroutines pertaining to options that are

Figure 3.6 Groundwater Equipotential from Visual Modflow© Software.

not being used can be deleted, thereby reducing the size of the program. The model may be used for either two- or three-dimensional applications. Input procedures have been generalized so that each type of model input data may be stored and read from separate external files. Variable formatting allows input data arrays to be read in any format without modification to the program. The type of output that is available has also been generalized so that the user may select various model output options to suit a particular need.

The major options that are presently available include procedures to simulate the effects of wells, recharge, rivers, drains, evapotranspiration, and "general-head boundaries". The solution algorithms available include two iteration techniques, the

Strongly Implicit Procedure (SIP) and the Slice-Successive Overrelaxation method (SSOR).

3.9 Input and Output Data

Input data are classified broadly as one of the following categories: (1) program control data, (2) network data, or (3) initial and boundary condition data. Program control data govern the overall operation of a program. This data includes codes that define tasks to be carried out by the modeling system, and constant values used as coefficients in equations and apply to the entire finite element network.

Network data describe the finite element network (grid). These data include element connectivity lists, element property type codes, node point coordinates, and node point ground-surface elevations. Also included, as network data are sets of empirical coefficients that apply to a particular element property type. Initial condition data are starting values of the dependent variables and their time derivatives at each node point in the finite element network. Boundary condition data are values of dependent variables prescribed at particular node points along the boundary of the network.

Output from the modeling system consists of processed network data, computed flow data (depth-averaged velocities and water depth at each node point, and the derivatives of these quantities with respect to time for unsteady flow simulations), and plots of both network data and flow data.

3.10 Graphic Output

For transportation and long-term storage of graphical information, graphic output from FESWMS-2DH is written in a specified format to a data file called a plot file. A utility program that displays the graphic output on a specific hardware device can read a plot file. Graphic output stored in a plot file can be processed afterward as often as necessary, stored for future used, or transported from one place to another.

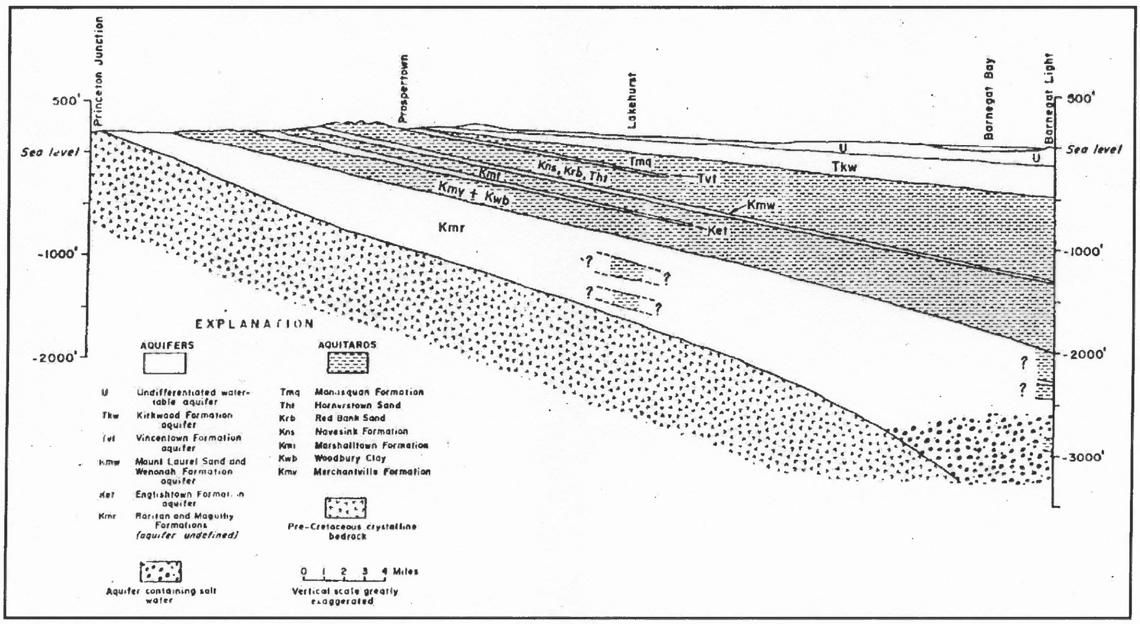

Figure 3.7 Stratiography.

CHAPTER 4

GEOGRAPHICAL INFORMATION SYSTEMS

4.1 General Approach

Recent developments in data base technology promoted by such organizations as ESRI[30] in their recent publication Arc Hydro: GIS for Water Resources have advanced the ability to integrate both geospatial and temporal data into an organized system for producing a water resource analytical model. This model would incorporate various thematic layers into a framework to support the hydrologic analysis. The relationship of this structure is shown in Figures 4.1 through 4.8, where the elements of the hydrologic information system are linked to the time series and geospatial data with the hydrologic analysis.

The hydrologic cycle and the resulting physical phenomena form the base for the development of the watershed model. While hydrographic phenomena are relatively static in time hydrology can vary rapidly in time. These properties are portrayed in Figure 4.9, the Hydrologic Cycle Superimposed on Hydrographic Spatial Information.

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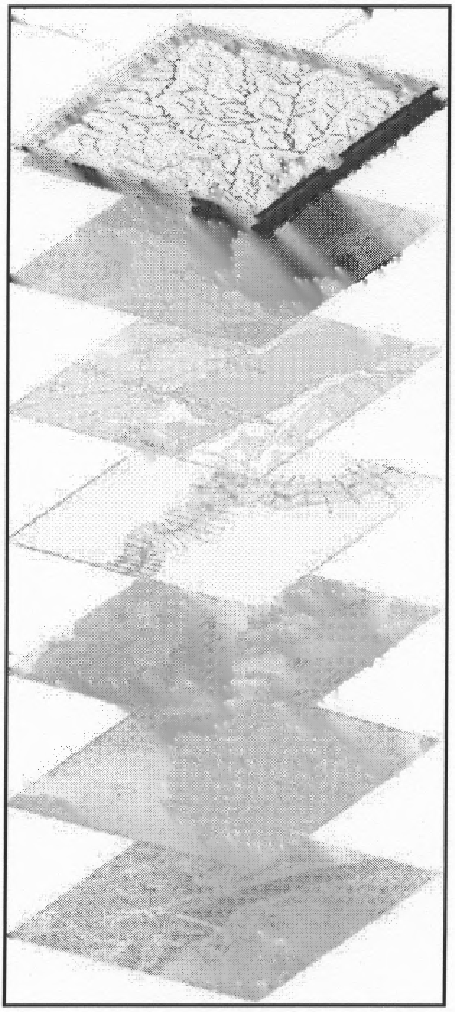
[30] Ref. 44.

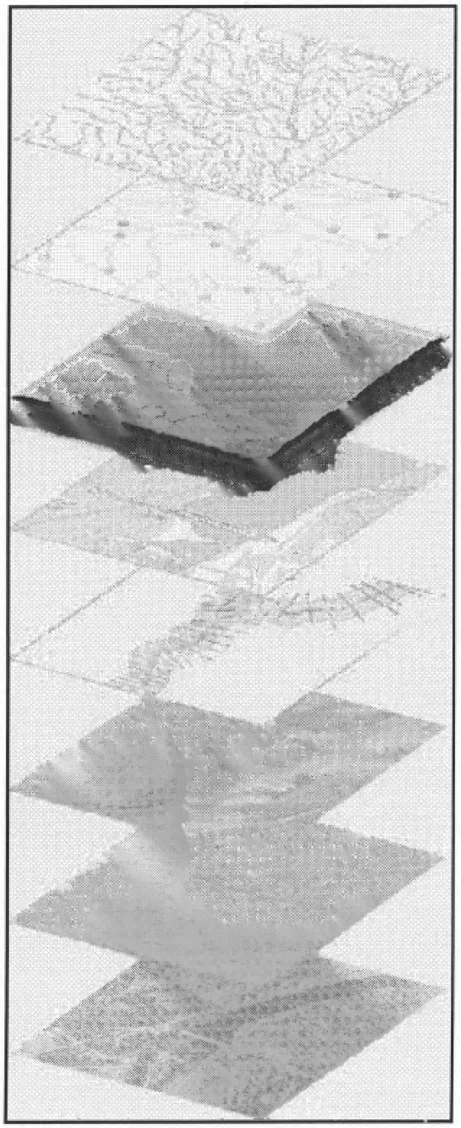


Layer:	Streams
Map Use:	Cartography and stream analysis
Data Source:	Usually mapped by government mapp and resource agencies
Representation:	Edges and nodes for network , polygo for lakes
Spatial Relationships:	Each edge has a flow direction and flo another edge or sink
Map Scale and Accuracy:	A typical map scale is 1:24,000 and locational accuracy is about ten meters.
Symbology and annotation:	Streams are drawn with blue lines wit varying weights with patterns, color, v and style.

Figure 4.1 Streams Layer.

Layer:	Hydrographic points
Map Use:	Gage stations on a stream network and features such as dams.
Data Source:	Usually mapped by government mapping and resource agencies.
Representation:	Junctions, network flags, and points on a stream network.
Spatial Relationships:	Points can be related to junctions on the network.
Map Scale and Accuracy:	A typical scale is 1:24,000, locational accuracy is about ten meters.
Symbology and annotation:	Typically drawn with colored circle markers by type.

Figure 4.2 Hydrographic Points Layer.



Layer:	Drainage areas
Map Use:	Drainage areas are used to estimate water flow into rivers
Data Source:	Derived from digital elevation models.
Representation:	Polygons with points at drainage outlets.
Spatial Relationships:	Each drainage area covers a stream region.
Map Scale and Accuracy:	A typical scale is 1:24,000 locational accuracy is about ten meters.
Symbology and annotation:	Shaded polygons can depict catchments or watersheds.

Figure 4.3 Drainage Areas Layer.

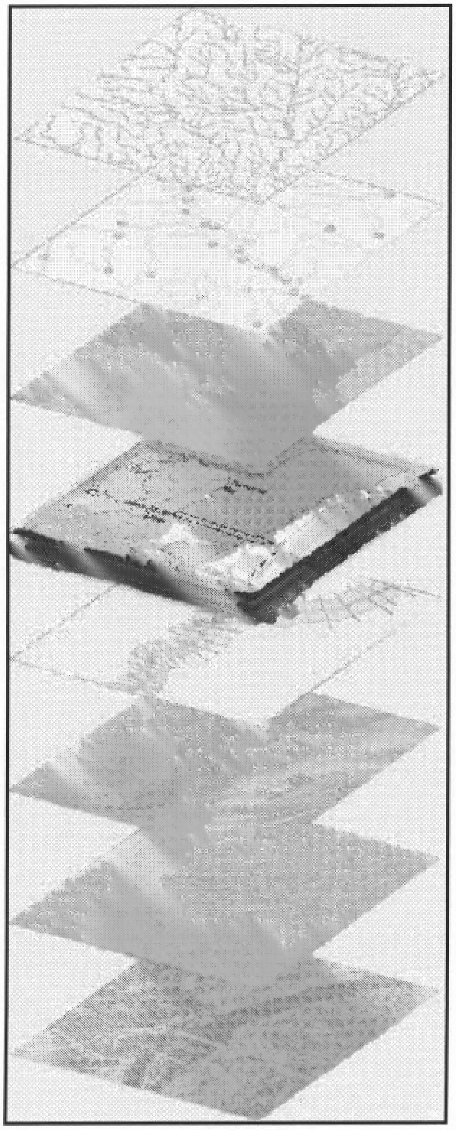
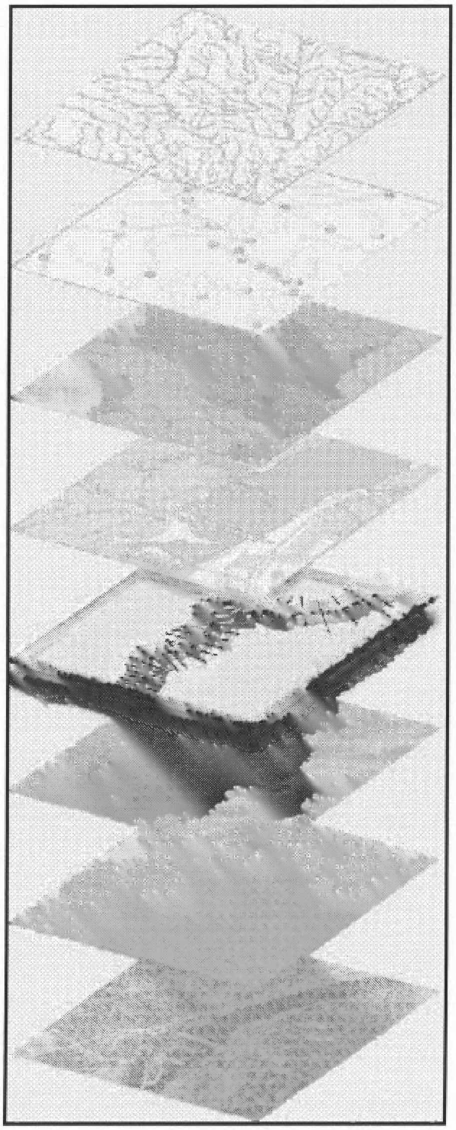


Figure 4.4 Hydrography Layer.

Layer:	Hydrography
Map Use:	The hydrographic layer in topographic maps
Data Source:	Mapped by government mapping Agencies.
Representation:	Point, line, polygon and annotation for water features
Spatial Relationships:	Streams feed rivers, rivers flow into lakes or streams.
Map Scale and Accuracy:	A typical scale is 1:24,000 locational accuracy is about ten meters.
Symbology and annotation:	National cartographic standards are applied to water features.



Layer:	Channel
Map Use:	Hydraulic Analysis
Data Source:	Derived from surface model or land surveying.
Representation:	Cross sections and longitudinal profiles along a river channel.
Spatial Relationships:	Cross sections are perpendicular to flow lines.
Map Scale and Accuracy:	A typical scale is 1:24,000 locational accuracy is about one meter.
Symbology and annotation:	Channels flow lines and cross sections shown with graphs.

Figure 4.5 Channel Layer.

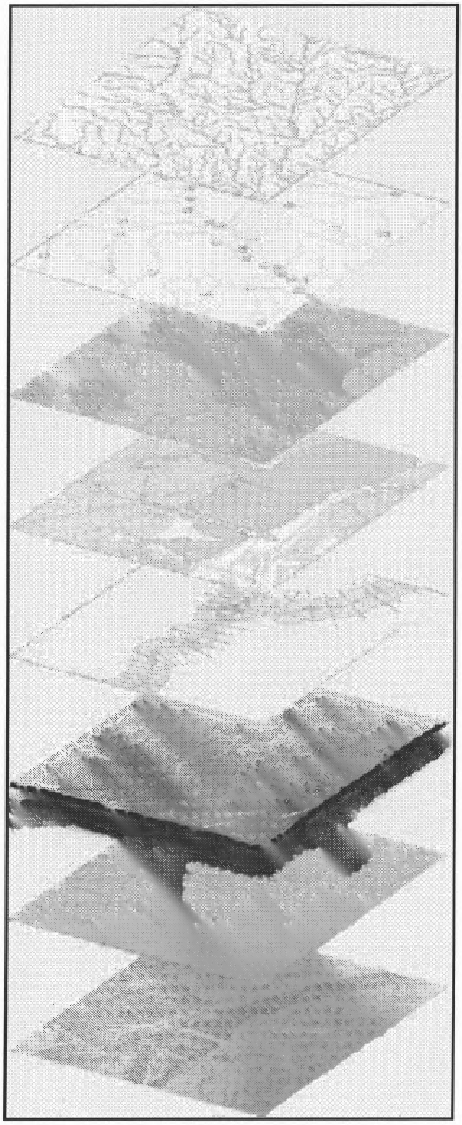
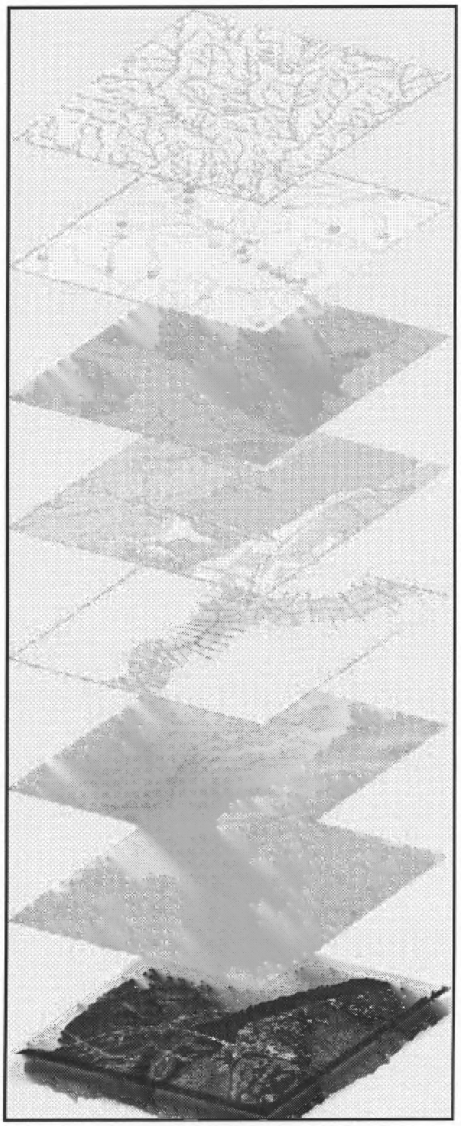


Figure 4.6 Surface Terrain Layer.

Layer:	Surface Terrain
Map Use:	Deriving streams and drainage ares, also cartographic backround
Data Source:	Digital Elevation Models.
Representation:	TIN surface model or raster with elevations.
Spatial Relationships:	If raster, each cell has an elevation,if TIN, each face joins to form surface.
Map Scale and Accuracy:	A typical scale is 1:24,000 locational accuracy is about one meter.
Symbology and annotation:	Elevation is shown with contours or graduated colors..

Layer:	Rainfall Response
Map Use:	Overlaid with rainfall grid to estimate flood or drought conditions
Data Source:	Derived from combining layers such as soil, vegetation and land use polygon
Representation:	Polygon
Spatial Relationships:	Polygons tesselate on area
Map Scale and Accuracy:	A typical map scale is 1:24,000 , locational accuracy is about ten meters
Symbology and annotation:	Polygons can be shaded to proportion to rainfall response values or local hydrographs for areas

Figure 4.7 Rainfall Response Layer.



Layer:	Digital Orthophotography
Map Use:	Map backround
Data Source:	Aerial photogrammetry and satellite collection
Representation:	Raster
Spatial Relationships:	Pixels tesselate the area imaged
Map Scale and Accuracy:	Tone, contrast and balance of gray scale or color presentation
Symbology and annotation:	

Figure 4.8 Digital Orthophotography Layer.

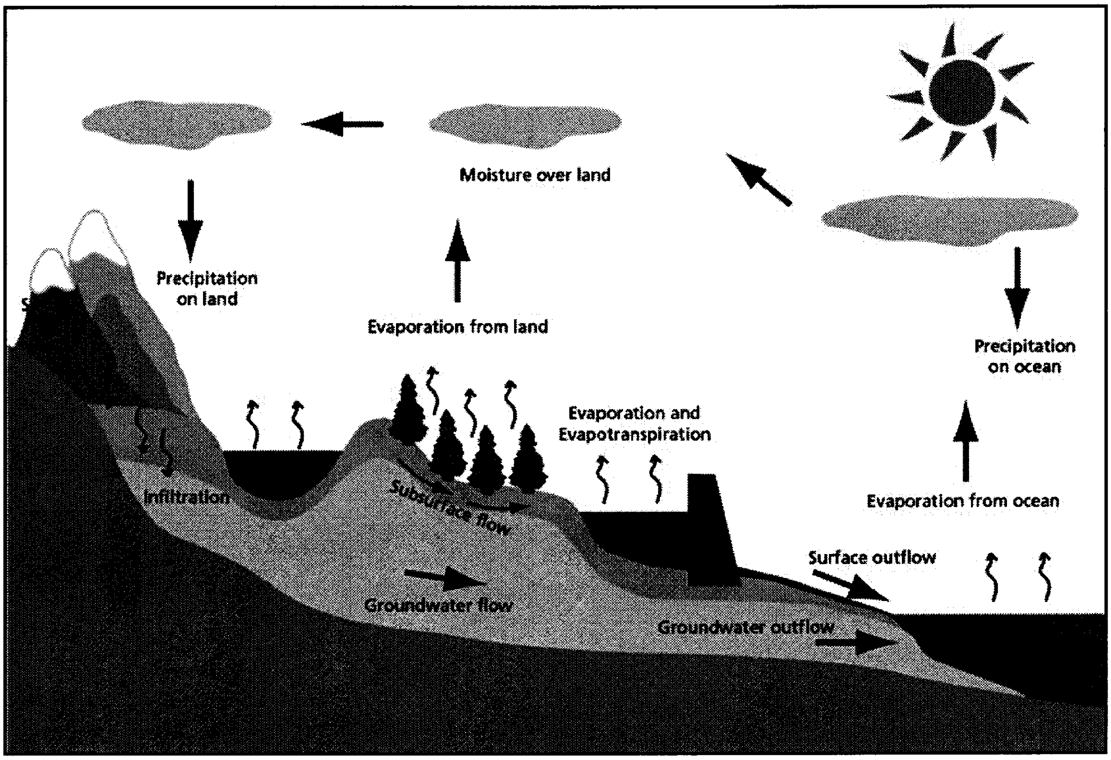


Figure 4.9 Relationships in the Hydrologic Information System.

4.2 Geodata Bases

Recent technological trends have permitted large amounts of storage to be integrated with the desktop computer. This accompanied with the ability to access the Internet has allowed vast amounts of data to be compiled. This capability of storage ranging in the gigabytes makes the defining of the watershed model practical for widespread accessibility. Because the dimensionality of the data contained in the thematic layers typically focus on a geographical region the data organization is usually based on a relational database. A relational database contrasts to "flat" files in that the data is linked by relationships - associations between records in connected tables through values in fields that tables share. A user for example can view or copy a table or set of tables in a relational database. Since the relational database supports permanent relationships between its tables, feature-to-feature connections can be established among the thematic data layers.

Developments in software have lead to object modeling. This has promoted the popularity of software such as Microsoft Word, Excel, Access, and Powerpoint 0R. Thus, objects interact with one another in complicated ways- therefore software must be designed to accommodate object oriented programming. The Arc Hydro software developed by ESRI claims this ability.

In Arc Hydro a set of Arc GIS object classes are used:

- Objects- data tables to store only attributes; such as a time series data table
- Features - data tables that store both spatial coordinates and attributes {points, lines, and areas such as streamflow gage locations.
- Network Features- special points and lines called junctions and edges where data tables store the connectivity between junctions and edges.

An overview of the data model framework is shown in Figure 4.10. Thus, the modeling software enables one to combine basic data sets into a watershed or subbasin as shown in Figure 4.11. The Arc Hydro data model then is made up of five components:

- *Network*: Connected sets of points and lines showing pathways of water flow
- *Drainage*: Areas and streamlines delineated from surface topography
- *Channel* : 3-D lines representing shape of river and streamlines
- *Hydrography*: Base data from topographic maps and tabular data inventories
- *Time series*: Tabular attributes describing time varying water properties for a water feature.

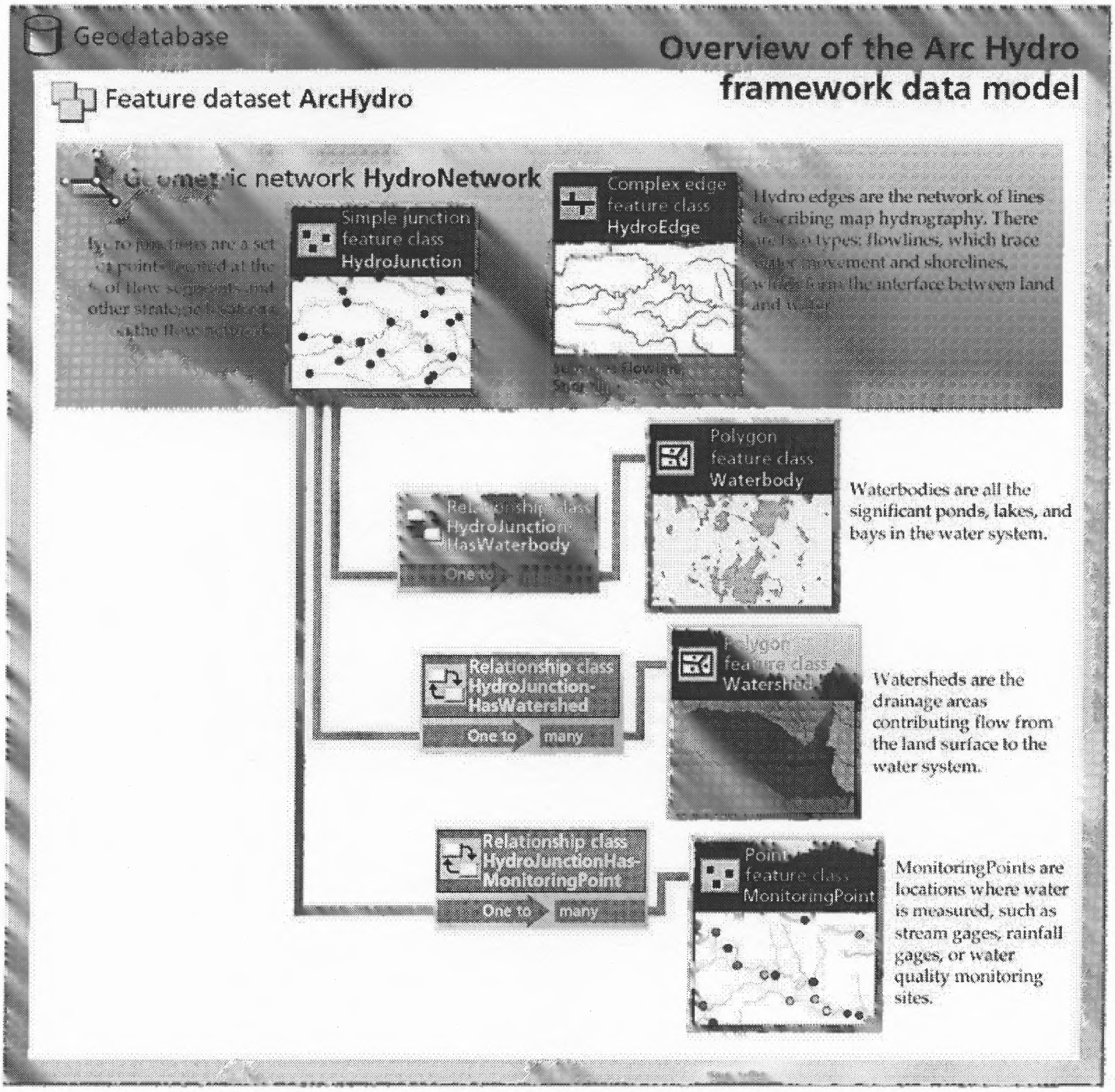


Figure 4.10 Overview of the Arc Hydro Framework Data Model.

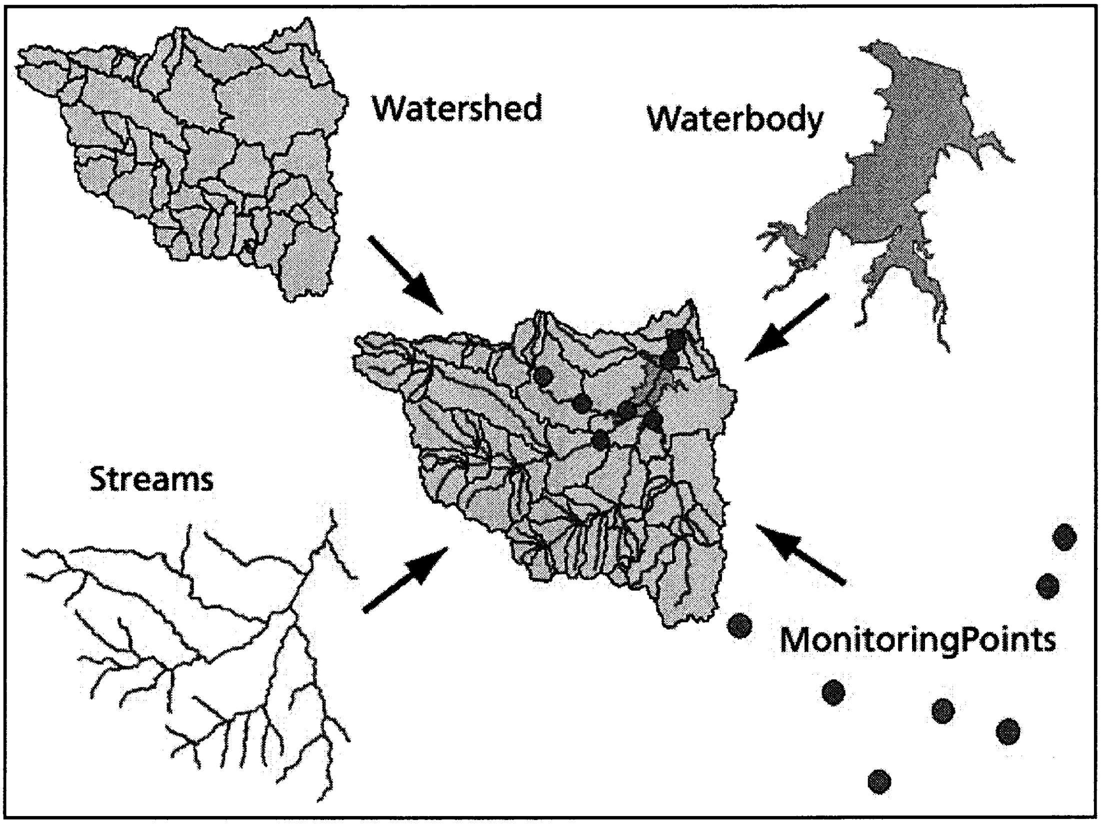


Figure 4.11 Simplified Version of Data Model.

CHAPTER 5

ENVIRONMENTAL DATA

5.1 Importance of Environmental Data

Environmental data is essential to identifying the patterns in the data to determine the flow paths, topographical features and environmental characteristics. The research will discuss these aspects and produce examples drawing from USGS digital elevation models and from NJ State data. See Satellite Image of area of investigation in Figure 5.1.

Figure 5.1 Satellite Image of Area Under Investigation.

The important role that GIS can play in investigations of the watershed will be amplified in the study with emphasis on its mappable capabilities of geographical information overlaid on a topographical base. Data required to complete the study is drawn from many sources. These sources would include but not be limited to information obtained from the Internet, The United States Geographical Service, United States Department of Agriculture, and the National Oceanic Service.

5.2 Graphical Description

Recent software developments provide as its output a series of graphs of the region as the model is developed. This graphical portrayal of the watershed would include soil types, well locations, depth and pumping rates, river current vectors, and topology. These forms of data are discussed with the assumption that, in many situations, the graphic or picture is an improved format for data analysis. It is suggest that the geographical picture is an excellent way to provide the juxtaposition of the various watershed components.

5.3 Environmental Factors

The watershed basin analyzed in this investigation is at location 40° 05' 09" latitude and longitude 74° 11' 09" and its drainage area is 27.5 square miles. The boundaries of the investigation encompass a lesser sub basin which include the communities of Point Pleasant Boro, Bay Head, Mantoloking and Bricktown of Ocean County, New Jersey. The land surrounding the river basin is comprised of woodlands, beaches and urban developments. It is in this area that the watershed model will be developed.

5.4 Data Analysis

Data analysis continues the pattern of the GIS theme by presenting the software results in geo-graphical form. This will provide a final overlay showing ground water flow, the basin network of flow, river flow and pollution flumes over the watershed. It is emphasized that the representation of the study in the geo-graphical format conveys the results of a watershed study in most comprehensive way. See Figure 5.2 Quad Area Map of Analysis.

Figure 5.2 Quad Map Area of Analysis.

Table 5.1 Statistics for Barnegat Bay.

01408168 BARNEGAT BAY AT MANTOLOKING, NJ

LOCATION - Lat 40° 42' 24", Long 74° 03' 25", Ocean County, Hydrologic Unit 02040301, at east end of Downer Avenue in Mantoloking and 0.1 mile south of Bridge on State Route 528.

PERIOD OF RECORD - Tidal crest-stage gage 1979-85, 1993, June 1993 to current year.

GAGE - Water-stage recorder. Datum of gage is 10.00 ft. below sea level. Gage-height record converted to elevation above or below (-) sea level for publication.

REMARKS - No gage-height or doubtful record, Jan. 13-24 and Mar. 7-11. Summaries for months with short periods of no gage-height record have been estimated with little or no loss of accuracy unless otherwise noted. Some periods cannot be estimated and are noted by dash (--) lines.

EXTREMES FOR PERIOD OR RECORD – Maximum elevation known, 4.93 ft., October 11. 1992, from crest-stage gage; minimum recorded, -0.42 ft., Oct. 8, 1996.

EXTREMES FOR CURRENT YEAR – Maximum elevation recorded, 3.71 ft., Oct. 19; minimum recorded, -0.42 ft., Oct. 8.

Summaries of tide elevations during the year are as follows:

TIDE ELEVATIONS, IN FEET, WATER YEAR OCTOBER 1996 TO SEPTEMBER 1997

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
Max. Elevation	3.71	3.36	2.91	2.94	2.37	2.86	2.91	2.74	2.52	2.52	3.42	2.85
High Tide												
Date	19	9	8	25	5	26	25	3	6	3	21	29
Min. Elevation	0.42	0.25	0.1	0.06	0.08	0.23	0.36	0.47	0.61	0.5	0.38	
Low Tide												
Date	8	27	21	30	25	4	9	22	2	24	12	24
Mean High Tide	1.89	1.68	1.78	--	1.36	1.5	1.77	1.55	1.72	1.59	1.75	0.168
Mean Water level	1.62	1.39	1.49	--	1.12	1.2	1.49	1.29	1.46	1.37	1.5	1.45
Mean Low Tide	1.33	1.13	1.24	--	0.86	0.194	1.23	1.05	1.2	1.11	1.24	1.21

METEDECONK RIVER SUMMARY STATISTICS

SUMMARY STATISTICS	1996 CALENDAR YEAR		1997 WATER YEAR		WATERYEARS 1992-1997	
Annual Total	25030		24031			
Annual Mean	68.4		65.8	56		
Highest Annual Mean					65.8	
Lowest Annual Mean					36.4	
Highest Daily Mean	359	21-Jan	330	21-Oct	514	12-Dec-92
Lowest Daily Mean	5.2	4-Sep	10	17-Oct	5.2	4-Sep-96
Annual 7-Day Minimum	20	30-Aug	27	22-Sep	13	29-Aug-95
Instantaneous Peak Flow			401	21-Oct	652	12-Dec-92
Instantaneous Peak Stage			2.97	21-Oct	3.38	12-Dec-92
Instantaneous Low Flow			10	17-Oct	4.5	4-Sep-96
Annual Runoff (CFSM)	2.49		2.39		2.05	
10 Percent Exceeds	115		110		99	
50 Percent Exceeds	60		57		44	
90 Percent Exceeds	28		30		24	

5.5 The River

The reach under investigation is the eastern most length of the Metedeconk River, which empties into Barnegat Bay, a major estuary along the New Jersey coastline. See Table 5.1 for statistics on Barnegat Bay. Approximately seven miles of the river is incorporated into the analysis terminating at the gaging station located at the Mantoloking Bridge in Barnegat Bay.

5.6 Geographic Province

The region under consideration is located within the Gulf and Atlantic Coastal Plain Province. This province is composed entirely of undisturbed sedimentary strata consisting mostly of loosely consolidated sands and gravels. Much more area than is visible today was exposed during Pleistocene glaciation when the sea level stood considerably lower. The plain is relatively flat, sloping gently to the ocean, with some low, hilly sections. The Coastal Plain, for 2000 miles from Long Island to Mexico consists of three well-defined geological belts. The geological belt of interest being the outermost shore belt of quaternary sands.

5.7 Cretaceous Beds

The Cretaceous beds dip very gently seaward at about 40 feet per mile. On the geological map the Lower and Upper Cretaceous are not differentiated. Their combined thickness along the Atlantic coast is about 1700 to 2000 feet at a maximum. Because of the subdued relief of the crystalline surface upon which the Cretaceous beds rest, there are almost no instances of inliers of these crystallines projecting through the Cretaceous cover. However, the crystalline rocks outcrop along the valleys of the streams, and this accounts for the crenelate inner margin of the Coastal Plain. On Long Island the Cretaceous rocks occur only in the cliffs along the north shore, being elsewhere entirely concealed under glacial drift and outwash. In New Jersey they form the well-known clay belt or inner lowland.

5.8 Soils Survey

The Ocean County USDA Soil Conservation Service identifies the proposed site to be in the Evesboro, Psamments, and Urban Land categories of soils classification (see Figure 4.3).

5.9 Evesboro Sand

Evesboro sand, EvC contains 5 to 10 percent slopes. This sloping, excessively drained soil occurs on side slopes. Slopes are convex and range from 50 to 200 feet in length. Most areas are long and narrow and range from about 5 to 5 acres. Some small areas are round or oval.

Typically, the surface layer is brown sand about 7 inches thick. The subsoil is yellowish brown sand 20 inches or more. Included with this soil are areas of gently sloping Evesboro sand and sloping Lakewood sand that make up about 10 percent of this association.

The permeability of this soil is rapid in the subsoil and substratum. Available water capacity is low. Organic matter content and natural fertility are low. Unless the soil has been limed, the surface layer is extremely acid and the subsoil and substratum are very strongly acid. Runoff is medium. Tilth is good, and the soil is easily worked.

Where irrigation is available this soil is suited to vegetables and fruits. The soil has a moderate erosion hazard, which can be controlled by planting cover crops and farming on the contour. Tilth and organic matter can be maintained by controlling erosion, planting cover crops, and plowing under crop residue.

Although most of the acreage of this soil is wooded, the soil is not well suited to commercial trees. pitch pine, chestnut oak, post oak, blackjack oak, white oak, and black oak are the common species. Controlled burning is the major woodland management practice used to control wild fires.

Slope and the loose, sandy surface limit the soil for urban uses, especially for playgrounds and recreation areas. The soil is in capability subclass Vlls.

5.10 Evesboro Series (EvC)

The soils of the Evesboro series are Mesic, coated Typic Quartpsamments. These deep, excessively drained soils formed in acid, sandy Coastal Plain sediments. Evesboro soils are on divides and side slopes. Slopes ranges from 0 to 15 percent but is dominantly 2 to 5 percent. The natural vegetation includes chestnut oak, post oak, blackjack oak, white oak, black oak, and pitch pine and an understory of lowbush blueberry and bracken fern.

Typical pedon of Evesboro sand, 0 to 5 percent slopes, in Jackson Township, 1.1 miles northwest of the intersection of Brewers Bridge Road and Cooks Bridge Road, 30 feet northeast of Cooks Bridge Road with soil horizons typically:

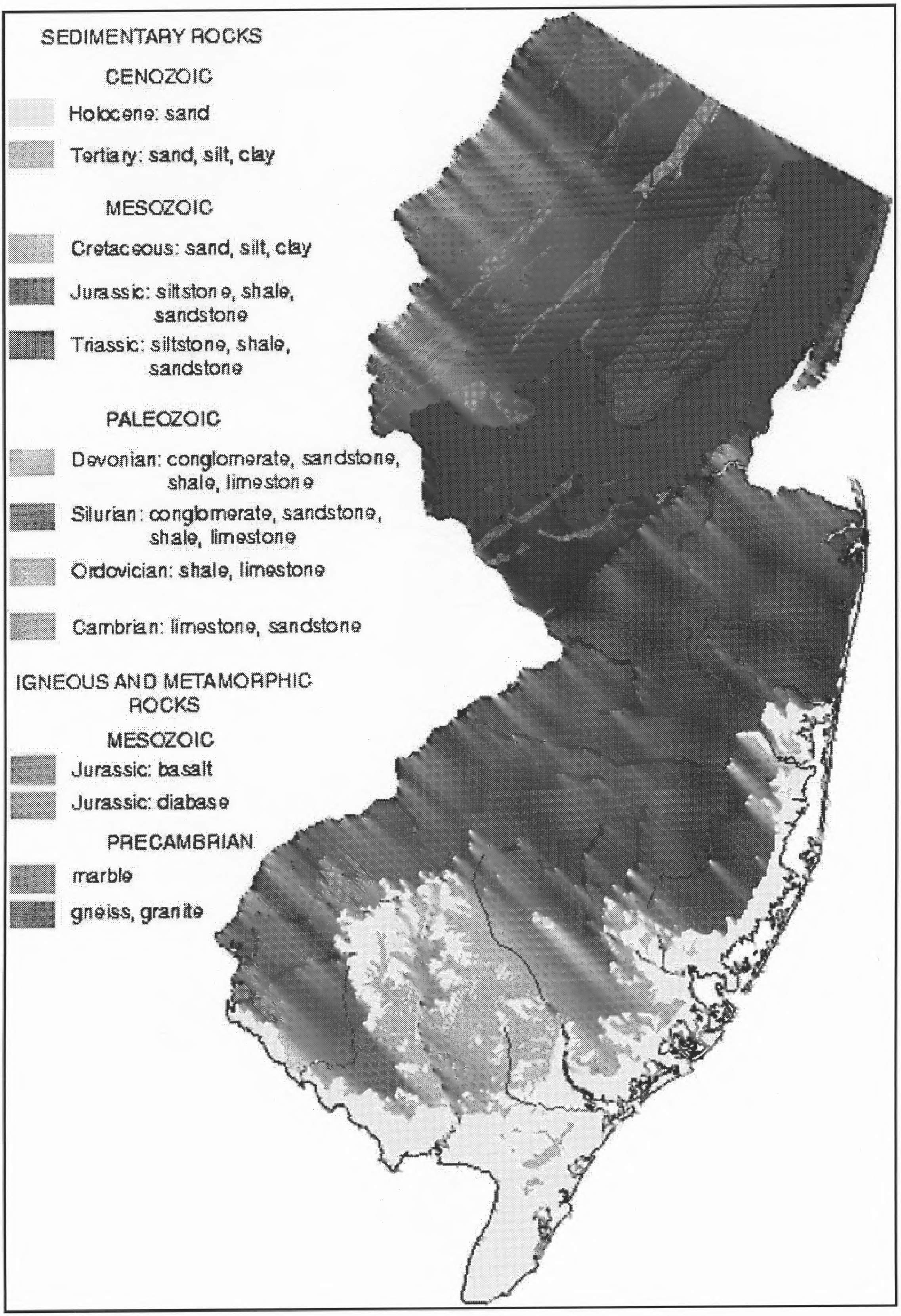


Figure 5.3 USGS Geologic Map of New Jersey.

A1- 0 to 1 inch, grayish brown (10YR 5/2) sand; single grain; loose; many fine roots, extremely acid; abrupt smooth boundary.

A2 - 1 to 9 inches, brown (10YR 5/3) sand; single grain; loose; many medium roots, extremely acid; clear smooth boundary.

B - 9 to 33 inches, yellowish brown (10YR 5.6) sand; single grain; loose; common medium roots; very strongly acid; gradual smooth boundary.

C - 33 to 60 inches, yellow (10YR 7/6) snad; single grain; loose; few medium roots; very strongly acid.

The solum thickness ranges from 32 to 44 inches and averages about 40 inches. Coarse fragments of rounded quartzose pebbles make up 0 to 10 percent of the solum. Unless the soils have been limes, reaction is extremely acid in the A horizon and very strongly acid in the B and C horizons. In Jackson and Plumstead townships, Evesboro soils have a profile of loamy fine sand and fine sand.

All parts of the A horizon have hue of 10YR. The A1 horizon has value of 2 to 5 and chroma of 1 or 2. The A2 horizon has value of 5 or 6 and chroma of 2 or 3. Where the soil is cultivated, the Ap horizon has value of 4 or 5 and chroma of 2.

The B horizon has hue of 10YR, value of 5 or 6, and chroma of 6 or 8. It is sand or loamy sand.

The C horizon has hue of 10YR, value of 6 or 7, and chroma of 3, 4, or 6.

5.11 Psamments (PN)

Psamments (PN) are nearly level. This unit consists of excessively drained to well drained soils that are dominantly made up of mainly yellowish brown, sandy fill placed in low, poorly drained or very poorly drained areas. The surface has been smoothed, and the areas are nearly level. The thickness of the fill ranges from 24 to 48 inches but is dominantly 36 inches. The material has a gravel content that ranges from 0 to 50 percent put is typically 5 to 20 percent. See Figure 4.3.

Included with this unit in mapping are areas of Sulfaquents and Sulfihemists and Atsion, Berryland, and Mullica soils that make up about 20 percent of the association. The permeability of the fill material is rapid. Available water capacity is low. Organic matter content is low, and the reaction is mostly very strongly acid.

Because of the variation in the amount of fill and the nature of the filled area, onsite investigation is needed to make reliable interpretations for this unit. This unit is not assigned to a capability subclass.

5.12 Urban Land (UL)

This unit consists of areas where more than 80 percent of the surface is covered by asphalt, concrete, buildings, or other impervious surfaces. Examples are parking lots, shopping centers, airports, industrial parks, and schools. These areas are throughout the survey area, but are more common in the northern part of the county and east of the Garden State Parkway. The areas generally range from 10 to 100 acres and are nearly level or gently sloping.

Included with this unit in mapping are areas of Downer, Evesboro, Klej, and Lakehurst soils. The proportion of these included areas ranges from almost none in the urban centers to 15 percent in less developed areas.

Onsite investigation is needed to determine the suitability of this unit for any proposed use. The unit is not assigned to a capability subclass.

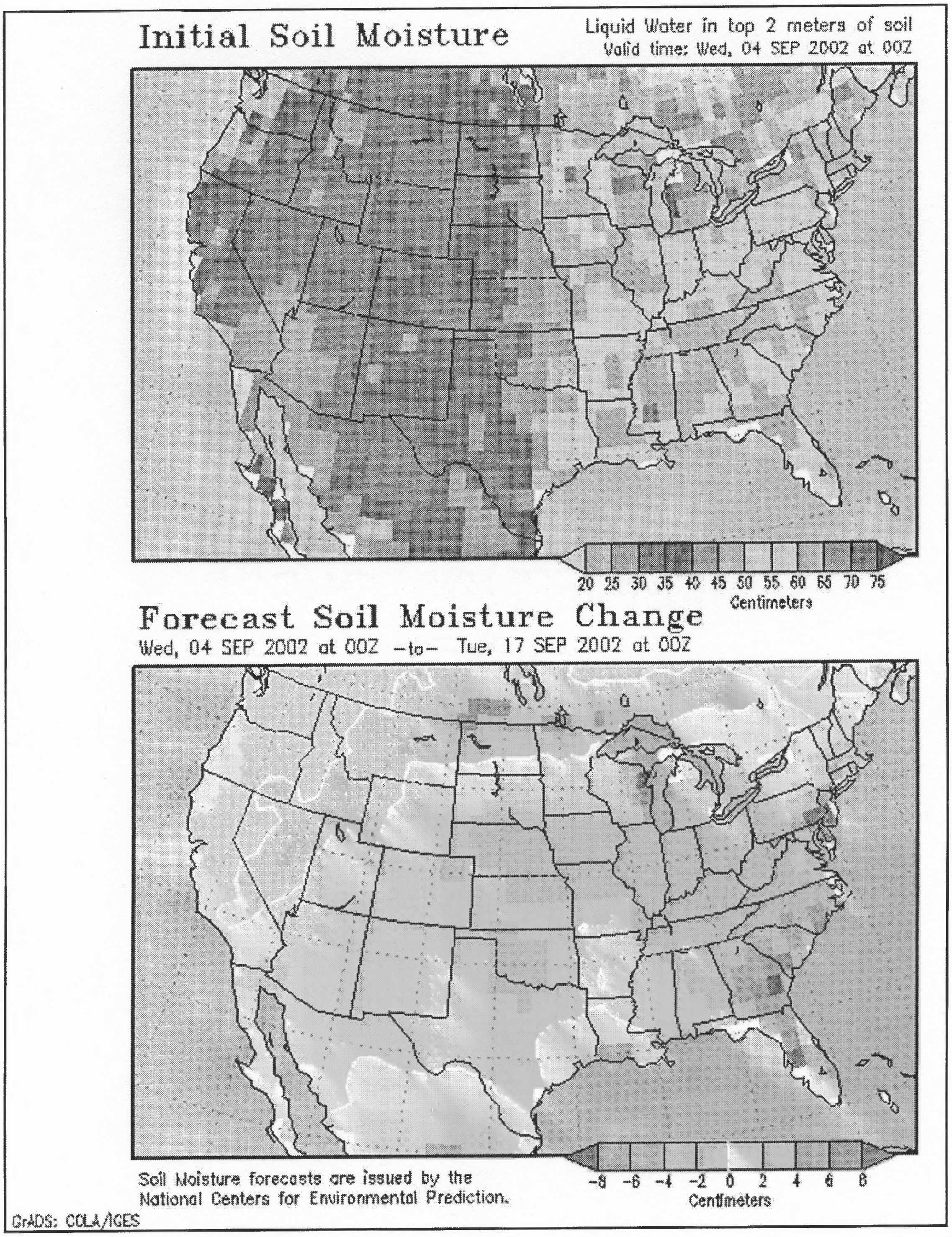


Figure 5.4 Soil Moisture in United States.

5.13 Environmental Considerations

A survey of the region provides the following observations.

The northern and eastern sections of the area consisting of wetlands and wooded sections provide breeding grounds and sufficient space for ruffled grouse, woodcock, thrushes, woodpeckers, squirrels, raccoon and deer. Woodland areas attract ducks, geese, muskrat, and beaver.

Woodland plants both annual and perennial wild herbaceous plants are found which grow on moist wet sites. Examples are; smart weed, wild millet, wild rice, salt grass, cord grass, rushes, sedges and reeds. Coniferous plants such as cone-bearing trees, shrubs are found. Pine, spruce, fir, cedar, and juniper are examples. Upland one can find hardwood trees which both provide cover for wild life and produce nuts or other fruit, buds, catkins, twigs, bark of foliage the wildlife eat. Examples of native plants are oak, poplar, cherry, sweet gum, apple, hawthorn, dogwood, hickory, blackberry and blueberry.

5.14 Engineering Properties

Engineering considerations are mostly concerned with the soils and groundwater. Sandy soils are prevalent on the site. The soils found on the site will generally have the following characteristics:

- Sand – to depths of tem feet and more
- Permeability – 1.0 to 20 inches per hour
- Water Capacity – 0.04 to 0.09 inches per inch
- Soil reaction – 3.6 to 5.0 pH
- Erosion factor - .17, wind category 1
- shrink swell potential – low

- High water table – greater than 6 ft., no flooding
- Corrosion – uncoated steel, low; concrete, high

5.15 Groundwater

The basin groundwater is derived from precipitation, draw from well water and flow at the river soil interface. Potable water in the region comes primarily from the groundwater aquifers. In recent years, upper reaches of the Metedeconk have been diverted to form local reservoirs so that the communities forming the basin receive supplementary water. Some of this diversion was to prevent further salt-water intrusion into existing wells and the additional supply needed to meet the demands due to increasing populations. See Figures 5.5 and 5.6 for data on aquifers in the state of New Jersey.

Major Aquifers in New Jersey[31]

General Setting

The Coastal Plain is the largest physiographic province in New Jersey. It lies southeast of the Fall Line, where it intersects the Piedmont province in a series of falls along river courses. The geology of the Coastal Plain is characterized by unconsolidated sand, gravel, silt, and clay thickening seaward from a featheredge at the Fall Line to more than 6,500 feet (ft) thick in southern Cape May County (Gill and Farlekas, 1976). The highly permeable beds of coarse material form aquifers that differ in areal extent and thickness. Slightly permeable interbeds of silt and clay form confining beds, which restrict the vertical flow of water.

North of the Fall Line, areal boundaries of aquifers roughly correspond to the physiographic divisions of the State. Aquifers in the Newark Group underlie the Piedmont province, upland crystalline rocks underlie the Highlands province, and Paleozoic sedimentary rocks form the Valley and Ridge province. See Figure 5.6.

New Jersey receives an average of 44 inches (in.) of precipitation annually, of which approximately 15 to 39 in. recharge the ground-water reservoir.

Principal Aquifers

The principal aquifers of New Jersey are classified into two groups-Coastal Plain aquifers south of the Fall Line and non-Coastal Plain aquifers north of the Fall Line. The aquifers areal distribution is shown in Figure 4-6.

Coastal Plain Aquifers

The five principal Coastal Plain aquifers are the Kirkwood-Cohansey aquifer system, the Atlantic City 800-foot sand, the Wenonah-Mount Laurel aquifer, the Englishtown aquifer, and the Potomac-Raritan-Magothy aquifer system. All but the Kirkwood-Cohansey are confined except where they crop out or are overlain by permeable surficial deposits. The aquifers are recharged directly by precipitation in outcrop areas, by vertical leakage through confining beds, and by seepage from surface-water bodies.

More than 75 percent of the freshwater supply in the New Jersey Coastal Plain is from ground water. In the Coastal Plain, high-capacity production wells used for public supply commonly yield 500 to 1,000 gallons per minute (gal/min), and many exceed 1,000 gal/min. Water quality is satisfactory except for local excessive iron concentrations [as much as 460 milligrams per liter (mg/L)] in several aquifers, including the Potomac-Raritan-Magothy, and for local contamination from saltwater intrusion and waste disposal. In the unconfined Kirkwood-Cohansey aquifer system water is brackish or salty in some coastal areas. In confined aquifers, salinity generally increases with depth in the southern and southeastern parts of the Coastal Plain.

Figure 5.5 Description of Major Aquifers from USGS Website.

[31] USGS Website at http://nj.water.usgs.gov/gw/aquifer.html

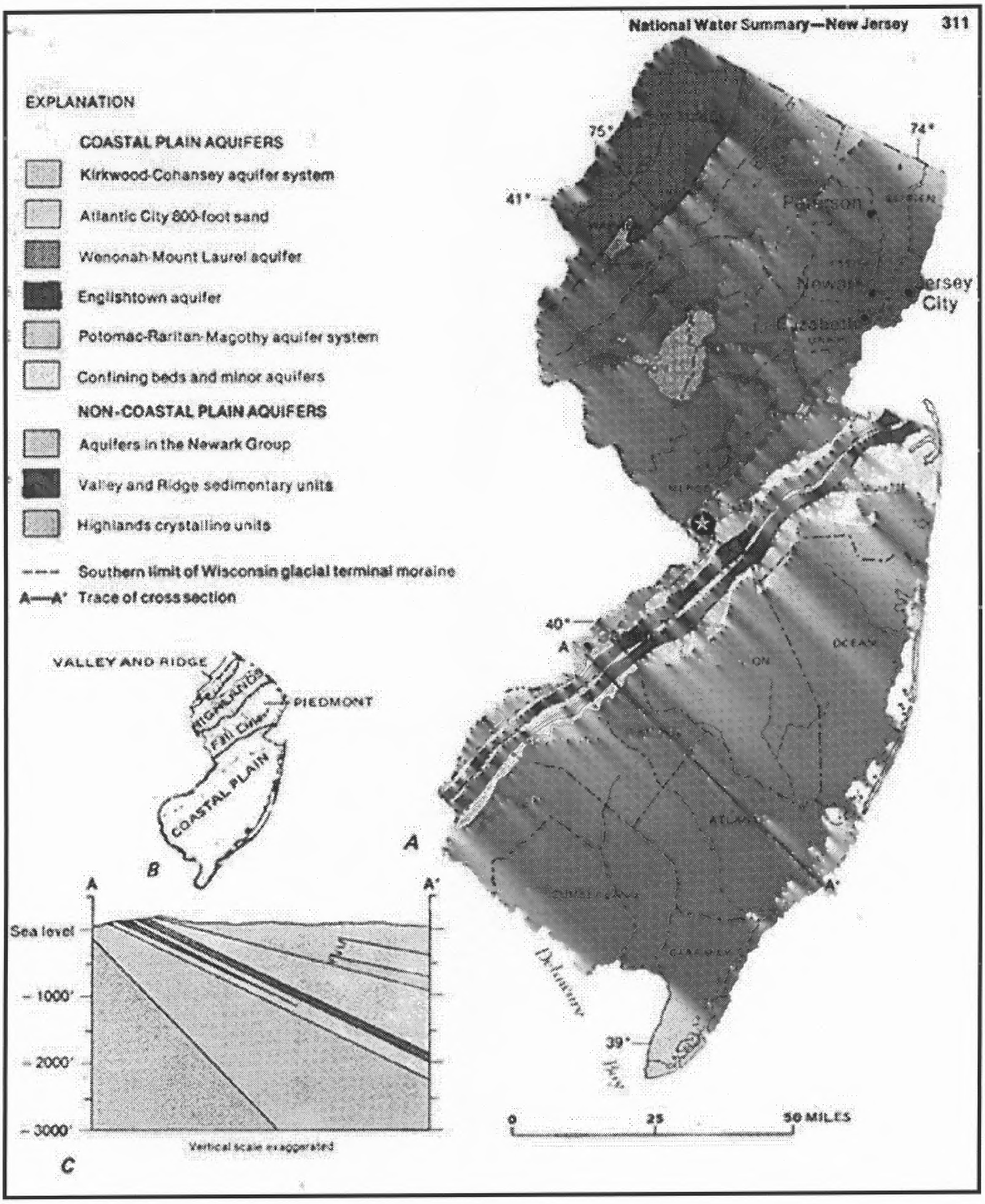


Figure 5.6 Principal aquifers in New Jersey.
A. Geographic distribution
B. Physiographic diagram and divisions.
C. Generalized cross section (A-A) of the Coastal Plain. (Sources *A*, *C*, compiled by O.S. Zapecka from U.S. Geological Survey files. *B*, Owens and Sohl, 1969; Ralsz, 1954.)

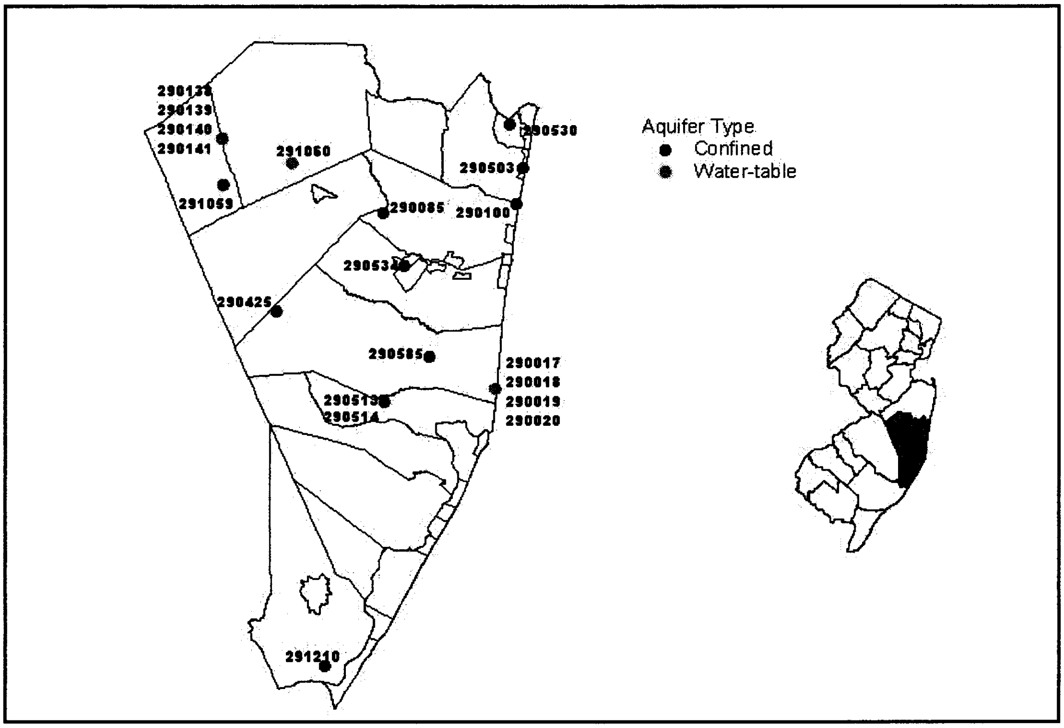


Figure 5.7 Wells Located in Watershed.

Data on the wells locations shown in Figure 5.7 can be determined from Table 5.3 through the UID code. A generalized schematic of well construction is depicted in Figure 5.8.

Table 5.2 Wells located in watershed.

UID	LOCAL NUMBER	TOWNSHIP	WELL DEPTH	ACQUIFER	START YEAR
290017	Island Beach 1 OBS	Lacey Twp.	397	CKKD	1977
290018	Island Beach 2 OBS	Lacey Twp.	474	PNPN	1962
290019	Island Beach 1 OBS	Lacey Twp.	2760	MRPA	1977
290020	Island Beach 1 OBS	Lacey Twp.	12	CKKD	1962
290085	Toms River 84 OBS	Dover Twp.	1480	MRPA	1968
3E+07	Normandy 3	Dover Twp.	1480	MRPAU	1999
290138	Colliers Mills 1 OBS	Jackson Twp.	427	EGLS	1964
290139	Colliers Mills 1 OBS	Jackson Twp.	171	VNCN	1977

5.16 Precipitation

Precipitation is the source for the ground water in the Metedeconk Basin. Approximately 40% of the precipitation falling on the area infiltrates on the zone of saturation. The sandy surface materials are highly permeable allowing rainfalls to infiltrate rapidly. As water seeps into the ground, some is evaporated, some is taken into the roots of plants and trees and eventually transpired while some is held by surface tension and capillary forces in pore spaces of the zone of aeration. These properties are data required to develop the models. Precipitation information is available on the internet. Samples of this kind of information are shown in Figure 5.9.

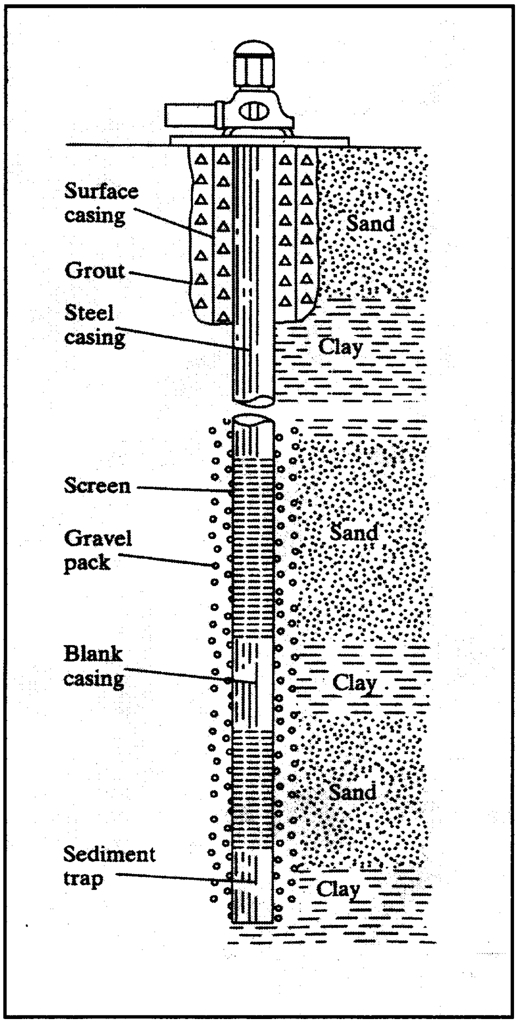


Figure 5.8 Generalized diagram of a water well, showing relationship of annular materials and casing. (From Heath, 1983, p. 53)

5.17 Future Developments

The study will finish with a brief discussion of watershed modeling and its place in the national and state monitoring of the water environments. The predictive possibilities of the modeling in planning and forecasting the impact of natural disasters will be reviewed with some suggestions for further research.

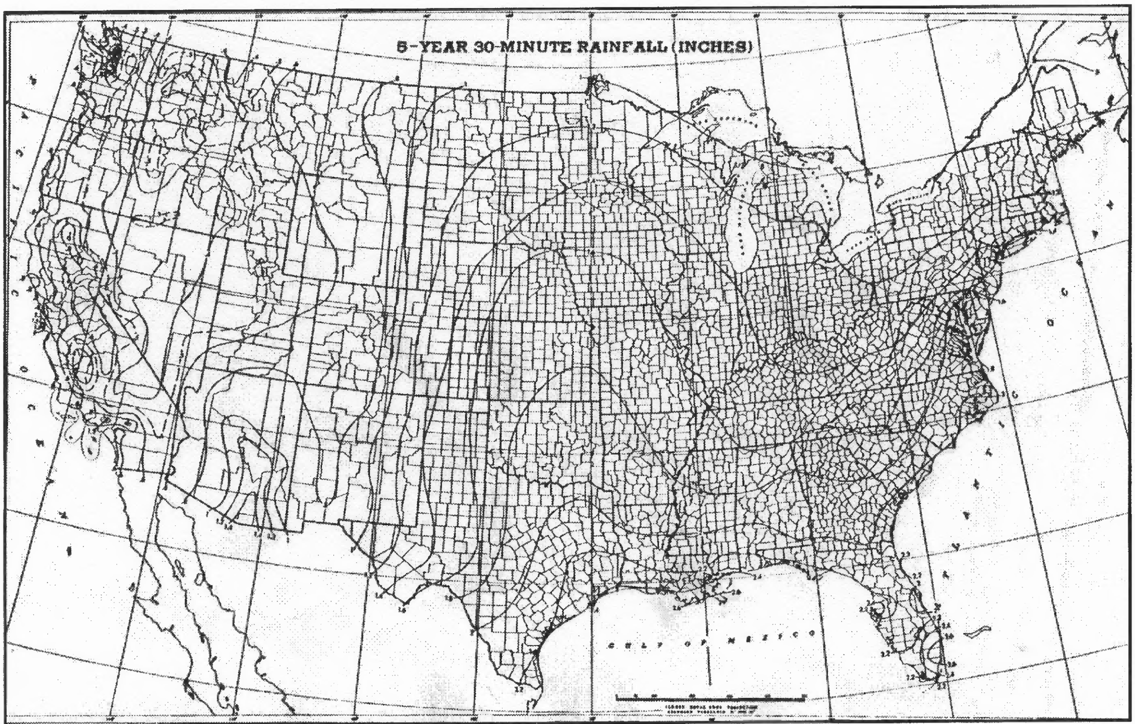


Figure 5.9 Five year 30 minute rainfall.

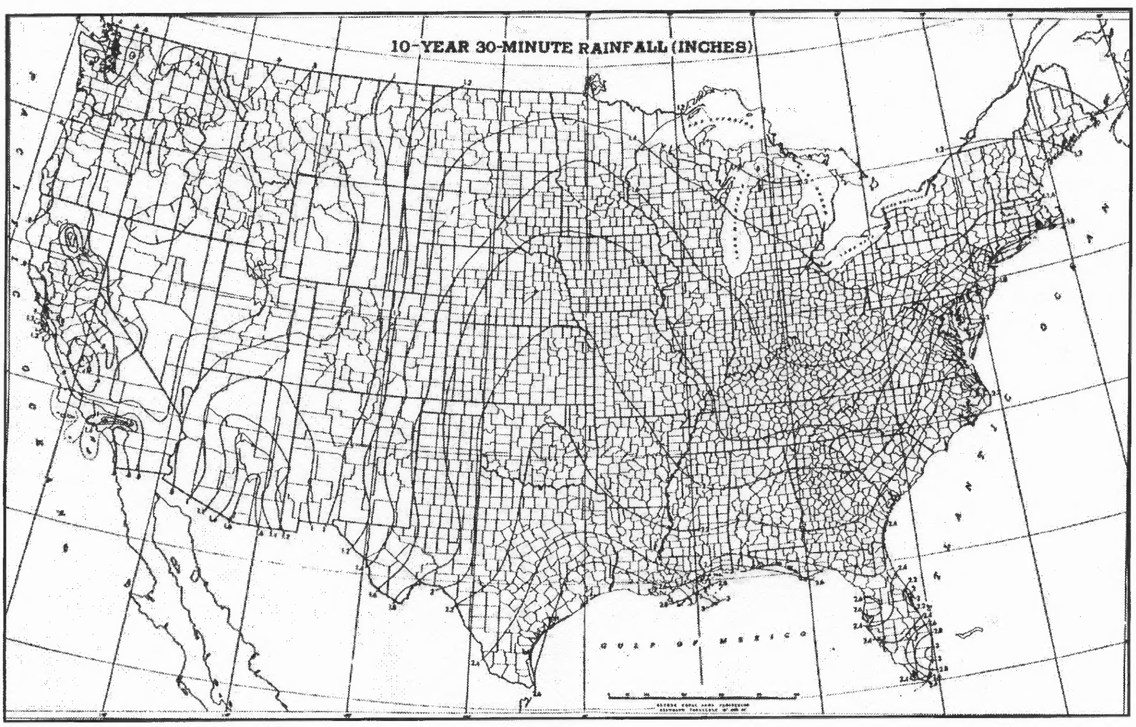


Figure 5.10 Ten year 30-minute rainfall.

CHAPTER 6

WATERSHED MANAGEMENT

6.1 Importance of Watershed Management

Current wisdom is placing increasing emphasis on the health of the watershed. A watershed is defined as the surface and ground water flowing in and over an area. Many physical and biological phenomena are involved in the process of analyzing these interactions and their impact on the state of the watershed. Thus, the management of these resources becomes important.

These environmental interactions range from conditions of drought to severe storms, as well as pollution arising from the use of pesticides, fertilization and urbanization. In recent years, a realization that the preservation of the watershed areas is vital to the quality of the nations water sources has resulted in the formation of regulatory agencies at the State and National levels. Statutes resulting from these agencies' activities have filtered down to local governments. In addition, civic groups have formed to promote a greater public awareness of the fragile nature of the watershed. It is suggested that much of the efforts expended are fragmented and, for the most part, are "invisible" to the populace at large. This fragmentation sometimes leads to conflicting goals and implementation. Recent developments by the Federal Government in conjunction with State Agencies strive to strengthen efforts to protect the watershed.

6.2 Management Approach

Key components of the local, watershed approach to protecting natural resources will serve as a guide to evaluate groundwater management approaches and how they may be used in a particular situation. The most critical component to the watershed management approach is the involvement and consensus of all key members (or organizations representing them) at each step in the process. Key components include, but are not limited to:

- Assessment of all natural resources-water (including groundwater), soil, air, animals, plants and people.
- Identify and give priority to identified problems.
- Develop objectives that are measurable -based on local environmental, economic and social goals.
- Identify and agree upon strategies for reaching objectives.
- Implement strategies and assess results.

Some of the activities, as they pertain to groundwater, are described as follows:

- Determining boundaries of the groundwater and watershed areas - part of a reassessment effort.
- Discussing existing and future uses of the watershed - part of setting goals.
- Defining pollutants and sources - part of assessment, goal setting and solution identification.
- Understanding various tools - part of identifying and implementing solutions.

Some special issues to be considered in the management efforts may be that water quality use designations may not always reflect the presence of groundwater intakes for drinking water, and quality criteria and drinking water maximum contaminant levels (MCLs). Sometimes these are not consistent in terms of chemical specific values and parameters while minor dischargers and permitted management measures national guidelines may not sufficiently reduce the risk to drinking water intakes. Where agriculture activities are reducing drinking water quality, changes in management practices may take a long time to result in water quality improvements depending on weather and geography. Additionally, source water areas for groundwater drinking supplies (wellhead areas) generally do not coincide with surface water drainage areas. Contaminant sources and the size of the contributing area may dictate the need for long-term drinking water treatment in certain public water supply systems.

6.3 Management Tools

Tools in current practice can be used to manage groundwater resources to identify zoning regulations to segregate different, and possibly conflicting, activities into different areas of a community. This approach may be limited in its ability to protect groundwater due to "grandfather" provisions. Another tool may be to overlay Water Resource Protection Districts. This is similar to zoning regulations in that the goal is to define the resource. Ordinances and bylaws would provide map zones of contributing boundaries and enact specific legislation for land uses and development within these boundaries. An important step could limit some land uses. Prohibiting land uses such as gas stations, sewage treatment plants, landfills, or the storage/transport of toxic materials is a first step towards the development of a comprehensive groundwater protection strategy. Special permitting could also be employed to regulate uses and structures that have the potential to degrade water and land quality. Another technique might be the use of large lot zoning to limit groundwater resource degradation by reducing the number of buildings and septic systems within a groundwater protection area. In more rural areas, septic system problems can be reduced or eliminated by extending or developing community sewage treatment systems. Another tool that might be used is a government plan designating land parcels from which development rights can be transferred to other areas. This allows land uses to be protected while assuring that these uses are outside sensitive areas. Controls may be used to slow or guide a community's growth, in combination with its ability to support growth. An important consideration is the availability of groundwater. Additionally, any given resource has a threshold, beyond which it deteriorates to an unacceptable level. Performance standards assume that most uses are allowable in a designated area, provided they will not overload the resource. It is important to establish critical threshold limits as the bottom line for acceptability.

Additional protection measures are often adopted to enhance local water resource protection such as; (1) Prohibit new residential underground storage tanks; (2) Remove existing residential underground storage tanks; and (3) Prohibit all new underground storage tank installation in groundwater and surface water management areas. Frequently, a septic system will not function properly, causing "breakout" of solids at the surface, leading to bacterial contamination. Also, when systems fail, any additives used can become contaminants.

Land owners can donate some land to the community or to a local land trust. Conservation easements can allow for a limited right to use the land., and effectively protect critical lands from development. Many communities purchase selected parcels of land that are seen as significant for resource protection. Wells need to be monitored because they are a direct conduit to groundwater. Standards for new well construction, as well as closure of abandoned wells, can prevent groundwater from being contaminated.

6.4 Defining Waters to be Monitored

The Federal Government, through its various acts, has delegated the management of watersheds to the states. The Federal Government regulates this by requiring the states to:

- Define its waters
- Monitoring systems to support decisions
- Implementation of monitoring program to achieve objectives

A suggested method[32] is to use a map or GIS coverage of the river or stream network, wetland areas, groundwater aquifers and coastal areas. This will establish a sampling frame. This frame will have both spatial and temporal characteristics. The spatial characteristics are fundamental to the design of the monitoring design while leaving the temporal characteristics for the target population.

Monitoring design scenarios are part of the overall monitoring strategy, including defining target populations, selecting sampling locations, selecting indicators to measure, defining how samples are collected and analyzed, and analyzing and presenting data and results.

6.5 Management Plan

An important goal of watershed management is to plan and work toward an environmentally and economically healthy watershed that benefits all who have a stake in it.

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[32] Monitoring Network Design and Implementation Scenarios - First Edition July, 2002

A plan can be developed once all the information about the watershed has been obtained. The process can be broken into three parts.

1. Discuss concerns, gather and analyze data, define challenges/opportunities, develope objectives, and document data and decisions.
2. Develop a plan for addressing the objectives, select the best watershed management alternative(s), list strategies for implementing the selected alternative(s), and determine how to measure progress.
3. Implement and evaluate efforts based on the best available assessment of the natural, economic and social aspects of the watershed. Acknowledge, note and assess missing information throughout the planning process.

The planning process can then proceed when all the interested parties are involved. The group should have detailed information and maps on:

- Boundaries, terrain and water bodies
- Soil types, roads and land uses
- Recreational uses, fish and game surveys
- Development , employment and education trends

The group should also meet regularly at a neutral location and have a technical advisory team to assist them.

Geographic Information System (GIS)[33] maps containing the information required for the plan can be obtained from a local Natural Resources Conservation Service, planning and zoning, Department of Transportation, environmental consultants and others. Maps can show multiple items by using an overlapping technique. During the

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[33] GIS(Geographic Information System) - A computerized system designed to support the retrieving, compiling, storing and display of data for addressing management, planning and environmental decision making.

first stage the group will begin identifying concerns/problems, seeking data, analyzing data and establishing objectives.

The team will need to identify and address concerns about the water and other natural resource systems, local economy and social structure. These concerns will be perception-based as well as have a scientific basis for concern.

Other important aspects to consider are some of the major economic forces, including major employers and their locations, as well as economic trends. The team's investigation may have an impact on the economic future, and the future of the watershed. Economic, social and natural resources are interrelated and may have influences on each other. The role of education needs to be evaluated for the present, as well as the future

The state's water quality agency has designated for a specific use most water bodies (stream, lake, estuary, wetland, aquifer[34]). These uses include:

- Drinking water supply
- Aquatic life
- Fish for consumption
- Agricultural (irrigation/livestock)
- Swimming and other high contact recreation
- Boating and other minimal contact recreation
- Industrial

Once the team has listed all concerns, it will need to combine similar subjects. The next step is to seek information and data about the concerns.

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[34] A geologic formation of porous rock, gravel or sand containing groundwater.

Assistance from a team of experts should include representatives of water departments and conservation districts. Planning and zoning, and chambers of commerce could be included in the group of experts as resources. In addition, it will be useful to include fish and game departments, forestry agencies, natural resource agencies and conservation groups. In order to represent to socio-economic faction, universities, bank officials, science and economic teachers, and industrial leaders should be included.

After listing concerns and exploring them by gathering and analyzing data, challenges and opportunities will surface. Priorities must be set that target efforts to the most critical problems and opportunities.

The management plan team will need to strive for consensus on prioritizing which problems and opportunities to pursue.

Critical areas within a watershed have the greatest impact. Looking at the landscape can help determine critical areas, such as areas next to a stream or lake. Another area might be determined by major water uses such as water supply locations, recreational areas and fragile wildlife habitats. The team may identify areas with vulnerable characteristics such as unstable streambanks or shallow groundwater.
Water quality in critical areas may be affected by “point source” and/or “nonpoint source” discharges. Point source discharges can come from a pipe or ditch connected to an industrial facility, storm sewer or feedlots. When the team determines critical areas they must match resource needs with targeted efforts to get the greatest benefits.

One of the most important steps in watershed protection is to correctly identify and document challenges and opportunities. A challenge is an obstacle that prevents positive changes on parts of society, the economy, or the environment. An opportunity is a condition that can be created to make a positive affect on society, the economy or the environment.

It is important to document both the resource being affected and the existing condition (quantity or quality). Also, describe damage in both economic and resource terms . Include who, how, where and what is affected.

In addition to problem/opportunity statements, all data and other information, including maps, gathered during this initial phase needs to be included.

The maps and other data will be needed later when you are developing brochures and other educational tools for implementing your team's plan. In addition, if the team needs to obtain outside financial assistance, the documentation will be needed to support the request for funding.

Documentation makes it easier to put together a proposal on short notice as when a new funding source is located. It is also useful for creating informational brochures and other educational materials. Documentation is essential for reporters and other media developing stories about the team's efforts.

Once everything has been defined and documented, establishing objectives will clarify the goals of the team. Important points when establishing objectives are:

- All views of those on the watershed team must be considered and consensus reached on how the team envisions the health of the watershed to be in the future.
- Existing legal constraints need to be considered.
- Describe the objective in measurable terms.

Some watershed management alternatives the team can explore with the goal of selecting one or more are:

- Contour strips/Conservation tillage/Construction site control.

- Filter or buffer strips/Reduced dumping of chemicals in storm sewers/terraces.
- Nutrient management/Pest management.
- Tree plantings/Irrigation water conservation.
- Irrigation water conservation/Home water conservation.
- Septic system maintenance/Roadside erosion control.
- Alternative livestock watering sources/Rotational grazing.
- Enterprise zones/Riparian zone management.
- Private rural road maintenance/Streambank stabilization.
- Storm water management/Constructed wetlands.

These are the ways the team promotes the use of the management alternatives selected. Examples could include workshops, demonstration plots and watershed tours. Other methods may also include an information campaign, cost sharing and local ordinances or zoning.

This will enable the team to look at the objectives and measure the progress. A baseline for doing this includes activities such as secchi disc readings[35] and nitrate strip tests, stream and wildlife inventory, fishing and hunting licenses, bacterial surveys, acres management, and land use inventory.

The team should develop a list of management alternatives that could help achieve the objectives, possibly assisted by the advisory team. A unranked list should be developed to assess the effectiveness for with as many alternatives as possible. Economic, social and environmental factors should be considered when evaluating the alternatives.

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[35] Flat disc lowered into a lake or still water until it disappears. The distance it is lowered is the reading (usually in inches).

Watershed models[36] will help the team to understand the cause and effect relationships within a watershed. The model can represent a real watershed allowing the study of different features of the watershed such as surface runoff of nutrients, pesticides, and the economics of different management practices. The results of the models will aid in decision-making.

A vision statement results from the team efforts, providing a set of objectives and alternatives for achieving the goals set by the team. An Action Plan implements the objectives by providing an implementation list, the people responsible for carrying out the action, as well as a timeframe for completion.

Some of the actions will require little money to accomplish; others, will require donated time or materials from local individuals, organizations, business and industry. Some actions require funding and this is where the team needs to explore funding options. Most watershed teams make obtaining financial assistance an action.

Because of the time and paperwork associated with federal and state funding, most teams start by looking for funding locally. Some local utilities, non-profit organizations and others have funded watershed management actions. Now is the time to put together a workshop on grant proposals. Invite state and local specialists to work with the team on grant writing.

The team should now look at its plan and ask tough questions, such as: Does the need still exist to do this? What else can be done? Has the vision remained the same? Has new information changed the objectives? What part of the plan has been the most successful? What part of the plan needs to be changed? This is a daunting task.

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[36] A tool that represents a view of reality to depict watershed management alternatives.

6.6 Conclusion

The environmental watershed management team is a relatively new concept, requiring careful attention by all bodies concerned. Identifying the appropriate participants for the team may not be initially apparent. Furthermore, each of the interested parties may not realize the scope and range of technologies involved. Because of the overlapping of the political bodies existing within the watershed, the process will be difficult to initiate. It is suggested that the coordination required is best done at the state level. This recognition may not be evident and adequate budgeting for the initiatives to begin may not have been allocated. It is time, however, for this important effort to begin.

CHAPTER 7

SUMMARY

7.1 Summary and Conclusions

The investigation suggests an approach to determining the status of the watershed. In the last year or so, the geophysical and ecological health of the watershed has gained increased attention as newer technology is applied. As this technology progresses, so does the modeling become more advanced.

The investigation results in several innovations. A framework for describing a watershed through improved modeling techniques and database management is outlined. This has been augmented by the feedback concept to produce a realtime dynamic simulation of the watershed. Selected differential equations were subjected to LaPlace transformation techniques. The resulting time domain equations were then transformed to the Fourier form to realize a spectral signature of the channel hydrograph.

Software organization has been described as being composed of two major components: (1) mathematical models, and (2) dynamic realtime databases containing the environmental as well as the physical parameters of the watershed. The database software relies heavily on the application of Geographical Information Systems (GIS) technology for its construction.

Much work in developing a dynamic watershed model utilizing the latest technological advancement remains. The process will be an evolutionary one.

7.2 Future Research

Future research is needed to produce a real time dynamic model of the watershed. The Federal Government, in cooperation with State Government is participating in the construction of a real time streamgaging network. In the future, this network may provide a dynamic, on-line simulation when linked to the watershed model, rather than the current static models. In addition, it will be possible to program on-line scenarios to display consequences of dynamic situations.

Data concerning land use and ecological conditions will enable the assessment of the seasonal impact on the watershed. Newly developed software such as the ESRI ARCHydro© will allow this kind of database to be developed.

These recent developments require a new assessment of the past practice of routing equations, such as the Muskingham model, to represent the profile of stream wave. The interrelations of the streamgage network and the models need to be explored further. Streamgage data needs to be linked directly to the dynamic database. In addition, it is necessary to develop spectrum analysis techniques to provide early warnings as to the state of the watershed. Specific tasks to be undertaken in future research are:

- Real time links from stream gage to the watershed data base.
- Establish the distance needed between stream gages necessary to define the reach.
- Test the adequacy of the feedback model to characterize the watershed.
- Develop a dynamic GIS database for each watershed.

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