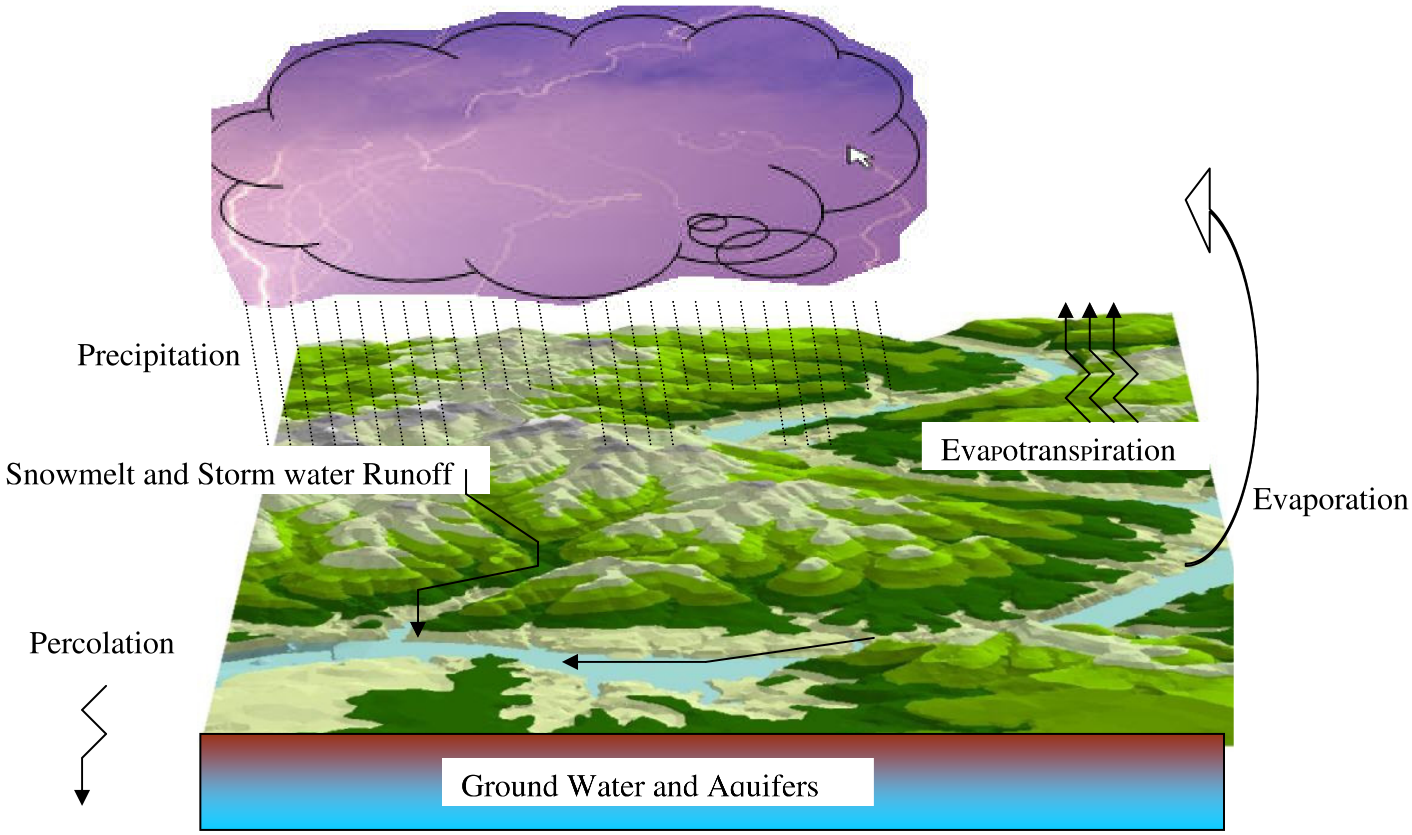
Applying ArcGIS in Water Resources Engineering

At this point the reader should have a feel for how ArcGIS technology may be applied in various real world examples, from business applications to science and engineering. However, this book is strictly focused on how the water resources and environmental engineer commonly employs ArcGIS in the solution of typical problems. The remainder of this chapter will be focused on what water resources is, and how ArcGIS is applied in the solution of important water resources and environmental engineering problems.

Water resources engineering in some form has been around throughout recorded history. Engineered irrigation systems date to as far back as 7000 years ago in Jericho and there are a number of example of ancient civilizations along the Indus, Tigris and Euphrates rivers harnessing water for agricultural endeavors. Rome built its first aqueduct in 312 B.C. with water from the Tiber river and surrounding springs as shown in the figure below.

Mankind has been engineering water delivery systems for thousands of years in order to bring water from where it is available to where it is needed, such as in this ancient aqueduct still standing in a public park in Rome.

Water resources (WR) draws primarily from the study of hydrology, hydraulics and environmental science in order to manage the quantity and quality of water. The study of hydrology is concerned with understanding the hydrologic cycle. The hydrologic cycle describes the mass balance transfer of water from one sphere of the environment to another. Water exists in the environment in the form of precipitation, groundwater, evapotranspiration and surface water.



Hydrology is most fundamentally the study of the hydrologic cycle which defines the movement or exchange of water between the atmosphere and the earth..

The mass balance transfer of water throughout the environment may be expressed by: inflow = outflow + change in storage. This is also known as the water budget which is commonly expressed with the below equation.

$$\Delta S = P - R - E - T - G$$

ΔS – Change in Storage
P – Precipitation
R – Surface Runoff
E – Evaporation
T – Transpiration
G – Groundwater Flow

Hydraulics on the other hand is concerned with the application of physics in determining the static and dynamic properties of water, such as in streams, rivers, storm sewers and pressurized piping systems. Concerns related to water quality are where water resources and environmental engineering overlap.

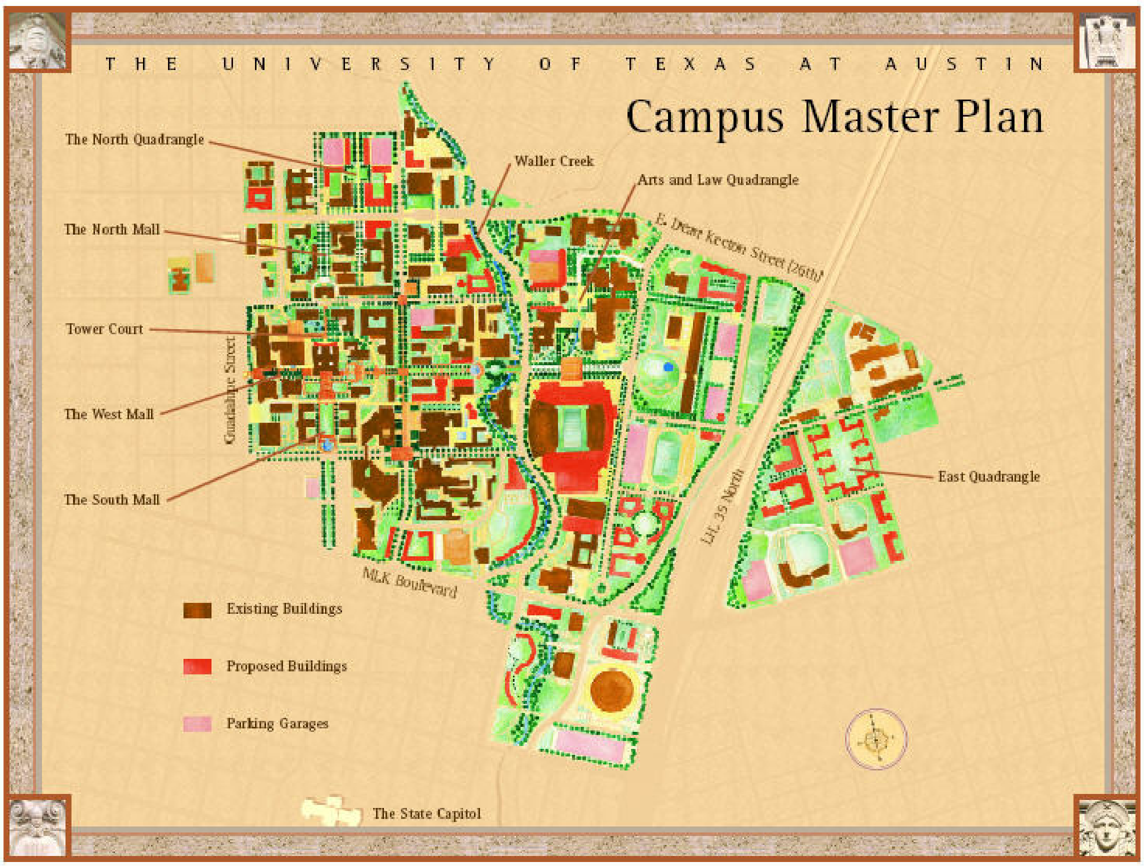
Hydraulics is commonly thought of as the study of water in motion..

Water is the most precious mineral on earth, it is as important to life as the air we breath. Although it is true that water is the most abundant mineral on earth with some 70 percent of the Earths surface covered in water, less than 3 % of the this water is fresh water and the vast majority of that figure is frozen in the polar ice caps (by volume). Therefore, less than 1% of Earth's available water is accessible from fresh surface and ground water sources. Increasingly issues associated with the quantity and quality of water abounds with the challenges of coping with population growth, urbanization and industrialization.

Water Resources engineering utilizes the power of ArcGIS as much or more than any other professional application; and WR is more fully integrated into ArcGIS than any other civil engineering sub-discipline in terms of its assimilation of the ArcGIS Desktop with WR modeling software. By harnessing ArcGIS for WR model development, the engineer or scientist may efficiently and accurately create hydrologic, hydraulic and environmental models that add value to the technical solution given the data management and results visualization capabilities inherent within ArcGIS.

Water resources engineers commonly employ computer modeling software to simulate the movement of water throughout the environment. These computer models are built with an understanding of the physical characteristics describing the environment. ArcGIS may be used to extrapolate and manage the numeric parameters that compose the input to environmental models. But more importantly, ArcGIS offers an array of geospatial analysis tools that may be scaled to fit the needs of most any water resources or environmental engineering problem. Below are a few examples of some of the important ways that ArcGIS is applied to common WR design and study applications.

Master Plans (MP) *are* developed in order to create a strategy for addressing a perceived long term problem. There are two principle types of master plans: development master plans and study master plans. Development MP are performed in order to layout and design land development projects such as neighborhoods and college campuses. Study MP are developed to address environmental issues such as land use planning and drainage. In either case, ArcGIS at a minimum is an excellent tool for mapping the spatial extent of proposed alternatives and calculating spatial attributes.



This is a draft figure. A more descriptive ArcGIS based figure will be shown here in the final publication.

Water Availability analysis is perhaps the most important application of ArcGIS in water resources engineering, as the availability of water is vital to sustaining life. The average person will consume some 16,000 gallons of water over a lifetime; and many times more than that is consumed per capita in various other industrial and household uses.

The availability and distribution of water has growing political implications with water increasingly being thought of as a valuable commodity. The fair and equitable distribution of water throughout a region is a key factor in economic development. There are numerous examples of communities growing in size such that they outstrip the availability of water from their traditional water sources. This situation requires the design of innovative water delivery systems based on complex alternatives analysis using various environmental and economic constraints.

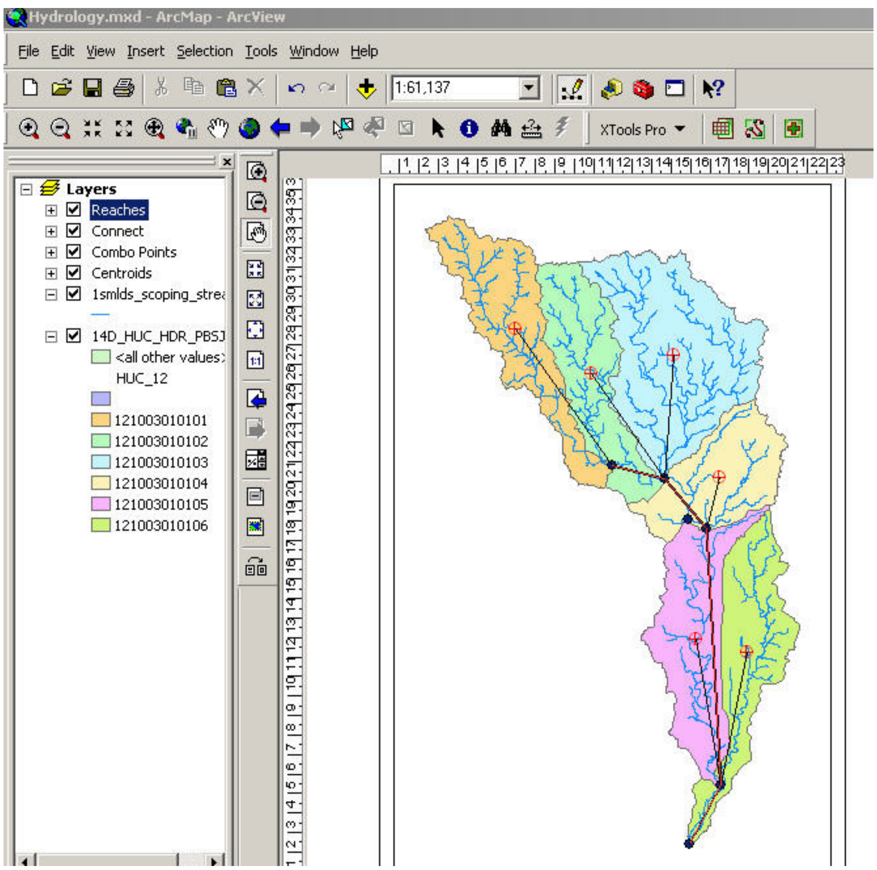
Regional water master plans are developed in order to preempt future critical water supply shortfalls with water supply solutions that may be implemented as needed over time. This analysis is performed using time based water mass balance modeling in order to determine a region's long term water viability from a combination of surface and ground water. ArcGIS may be employed to determine the severity of a region's water needs and to evaluate alternatives for addressing long term water shortages. In this way, policy maker can manage the availability of water from a regional to a local scale.

ArcGIS can greatly facility in reservoir site selection and water availability modeling

WRAP† Hydro is an example of an ArcGIS based data model that may be used to organize and store water availability parameters such as historical stream flow, water well logs, evaporation, abstraction, water demand, waste water return and reservoir storage, population projections, land use and climatic considerations.

† Water Rights Appropriation Package

Drainage Analysis is the process of evaluating the existing hydrologic characteristic of a watershed and determining the storm water runoff potential under various storm intensities. This information is then used to calculate floodplain boundaries and evaluate the effectiveness of existing drainage infrastructure or to design new drainage systems. There are a number of well developed ArcGIS applications such as HEC-GeoHMS and PrePro that are used to preprocess the development of HEC-HMS (Hydrologic Engineering Center's - Hydrologic Modeling System) models used to calculate storm runoff. These applications automate the delineation of watersheds and catchments, as well as produce the schematically correct drainage systems attributed with basic hydrologic characteristics such as longest flow paths, slopes and drainage areas.



ArcGIS can greatly facility in reservoir site selection and water availability modeling.

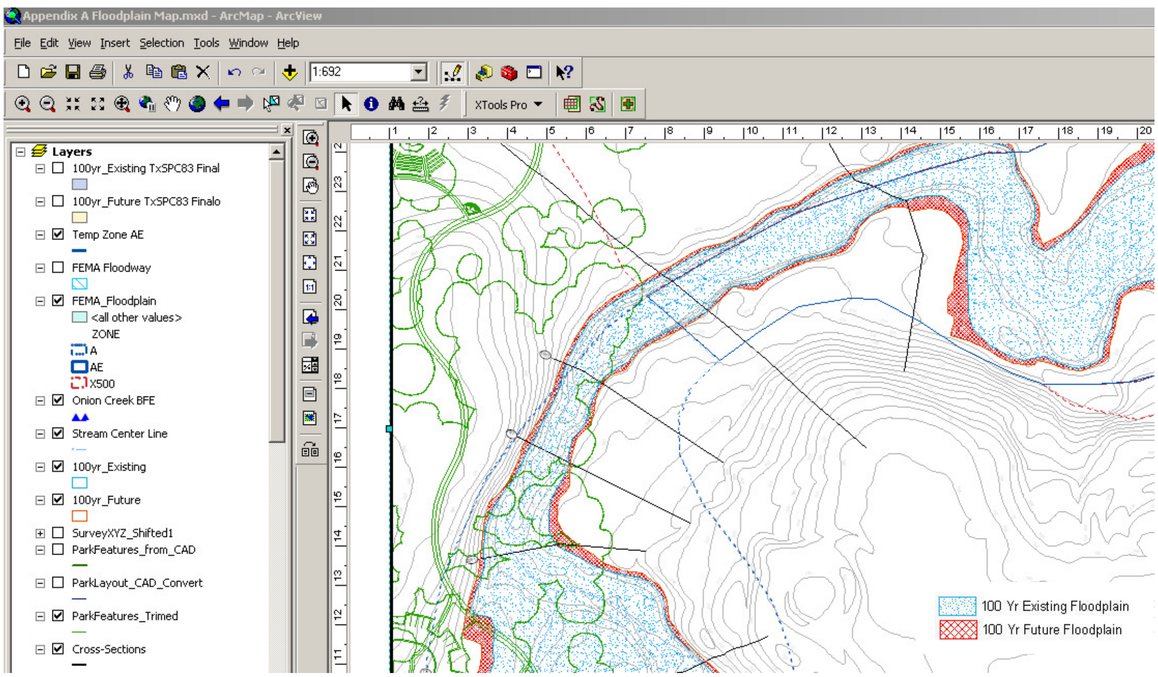
The basic ArcGIS Desktop tools provide an excellent platform for calculating watershed characteristics. Simply by pulling together all of the relevant watershed data, such as publicly available topography, soils, and land use information, the engineer may easily calculate basic hydrologic characteristics, from which modeled or empirically estimated storm flows may be calculated. Finally, ArcGIS is well suited for drafting drainage construction plan sheets for anything from storm sewer layout to regional flood control ponds.

Floodplain Analysis is an important responsibility for water resources engineers since people have historically settled close to sources of water prone to flooding. Some 7% of the land area of the United States is within a flood hazard area. The United States has been devastated by floods numerous times throughout its history. Most notably the Mississippi River has flooded with devastating consequences for the inhabitants of its floodplains.

Statistical criteria are used to define the potential extent of flooding. The "100-year" flood is the most common type of flood hazard boundary, because it is used to set flood insurance rates. But there is a lot of confusion surrounding the meaning of this term given the fact that it is not uncommon for the 100-year floodplain boundaries to be exceeded by floodwaters several times over a significantly shorter period than 100-years. Therefore, this boundary represents the 1 in 100 chance that limits of maximum inundation will be equaled or exceeded in a given year.

The accurate mapping of flood prone areas is of obvious importance to all stakeholders such as regional planners, local governments, and home owners. It has been reported that some 30% of the flood insurance claims come from outside of the 100-year floodplain. ArcGIS is well suited to address the cartographic and technical analysis associated with defining a floodplain boundary. The Federal Emergency Management Agency (FEMA) has made available in digital format many of the nation's Flood Insurance Rate Maps. This information may be readily displayed on custom maps next to any other desired spatial information and used for land use planning or development activities.

ArcGIS is more than just a cartographic tool, as it is also a hydraulic model "pre-processor". The delineation of floodplain boundaries are derived from numerous sources of geospatial information, such as channel geometry and roughness. HEC-GeoRAS is an ArcGIS extension that may be employed assimilate relevant geospatial information necessary to create HEC-RAS (River Analysis System) riverine geometry input files that may be used in hydraulic modeling to calculate floodplain elevations that are used in floodplain boundary delineation.



ArcGIS has well refined tools for floodplain model development and flood hazard boundary mapping.

Outline of This Book

This book will provide a quick start tutorial for anyone wanting to learn how to apply ArcGIS technology in water resources engineering. It will provide a number of step-by-step tutorials designed to highlight the fundamental uses of ArcGIS and the nuances of using ArcGIS technology that only comes with the experience of applying this software in water resources engineering. This book is not intended to replace existing users' manuals but rather to supplement them in order to make for a more direct understanding of how water resources solutions are executed inside ESRI-based GIS software.

Chapter TWO

Introduction to GIS Concepts and Methods in Water Resources Engineering

This chapter will introduce the reader to the basic concepts and definitions that one should be aware of in the study of geographic information systems, both in general and as it technically relates to the science and engineering of water resources. This chapter will give the reader a foundation of knowledge concerning geospatial data types and sources from which specific ArcGIS-based water resources applications may be built. However, specific step-by-step instructions on how to apply ArcGIS technology will not be given. This chapter will be focused on the "what" not the "how." An introduction to basic GIS concepts such as data gathering, geospatial file types, database file types and projections will be given here.

Chapter THREE

ArcGIS the Basics

In this chapter, the "how" will be explored in greater detail. The reader will be given specific instructions for how to perform some of the most important ArcGIS tasks presented in the context of civil and water resources engineering problems. The reader will be presented with 8 example problems (exercises) that will give concisely instructions on how to execute specific ArcGIS tasks such as exploring for geospatial data, creating shapefiles, creating map layouts, geoprocessing and working with

CAD files (among others). Important extensions such as Spatial and 3D Analyst and X-Tools as will also be introduced here. Two case examples are presented at the end on this chapter which will tie together all of the previously presented concepts and exercise into concise quick start tutorials that will step the user through series of ArcGIS tasks that are commonly employed within civil and water resources engineering.

Chapter FOUR

Applied Hydrology with ArcGIS

This chapter will give a brief description of the hydrologic cycle and will define the sort of parameters that are typically used in performing hydrologic calculations and how these parameters are derived using ArcGIS. Important concepts related to geospatial hydrologic data such as Digital Elevation Models (DEMs), soils, land use, reservoirs and gauging stations will be covered. These concepts will introduce the reader to issues associated with calculating hydrologic parameters and developing Hydrologic Response Units (HRU, areas of homogeneous hydrologic characteristics). Additionally, the nuances of developing lumped and distributed (gridded rainfall and land-use) HEC-HMS with ArcGIS will be discussed here.

Two case examples will be given in this chapter. The first example will explain how to modify existing DEMs to represent manmade topographic features so that automated catchment delineation may be carried out on a "hydrologically-corrected" DEM. The second case example will explain how to create a distributed HEC-HMS model using the National Weather Services' NEXRAD rainfall data. Finally, a troubleshooting section will be included to help the engineer overcome typical issues related to the development of HMS models using automated model development tools such as HEC-GeoHMS and PrePro.

Chapter FIVE

Applied Hydraulics with ArcGIS

The basic principles of hydraulics and the parameters and geospatial file types used to develop hydraulic models will be discussed here. Detailed instruction regarding how to develop HEC-RAS models and use ArcGIS to estimate hydraulic modeling parameters will be covered. Two case examples will be presented. The first example will explain how to develop HEC-RAS models and floodplain maps using HEC-GeoRAS. The second example will show how an existing, HEC-RAS model without geospatial attributes may be georeferenced and made compatible for automated floodplain mapping using HEC-GeoRAS. Finally, a troubleshooting section will be included to help the engineer understand what a given HEC-GeoRAS error message might mean.

Chapter SIX

Applied Hydrologic Information Systems

Hydrologic Information Systems (HIS) is perhaps at the forefront of GIS-based, water resources applications. HIS describes the application of the GIS in order to integrate hydrology, hydraulics and water quality modeling data into a concise data management and modeling framework. Therefore, in this chapter the concepts of developing watershed data models such as Arc Hydro will be covered. Key concepts related to geodatabases such as feature datasets, feature classes, geometric networks, relationships and schemas will be discussed and formulated in the context of Arc Hydro and Arc Hydro Compliant data models. This chapter will conclude with a discussion of how HIS technology may be used to develop a basin-wide information system. In all, this chapter will give an overview of how geodatabases are customized to suit a particular project need within watershed master planning, and how these geodatabases are interfaced with hydrologic and hydraulic (H&H) modeling engines inside an ArcGIS-based HIS.

Chapter SEVEN

Extending ArcGIS: Model Builder and VBA

Perhaps the most exciting improvement of ArcGIS 9 over ArcGIS 8 is the ModelBuilder application. There are a number of civil engineering geospatial analysis applications that could make use of this tool.

For instance, large Storm Water Pollution Prevention Plans (SWPPPs) may require estimates of soil loss using the universal soil loss equation to help the engineer determine erosion potential and specify appropriate erosion controls. The universal soil loss equation is a function of spatial attributes such as surface slope, soil erodibility, and annual rainfall. This section will give a case example regarding how to use ModelBuilder and the universal soil loss equation to calculate soil loss potential across a construction site (such as a neighborhood land development project).

An understanding of the Visual Basic (VB) programming language and how this language is used in Arc-9 represents the pinnacle of ArcGIS-based engineering professionalism. And although this topic slightly exceeds the scope of this book, one could not consider the publication truly “complete” without a brief explanation of how to develop custom Model Builder and VB application for ArcGIS.