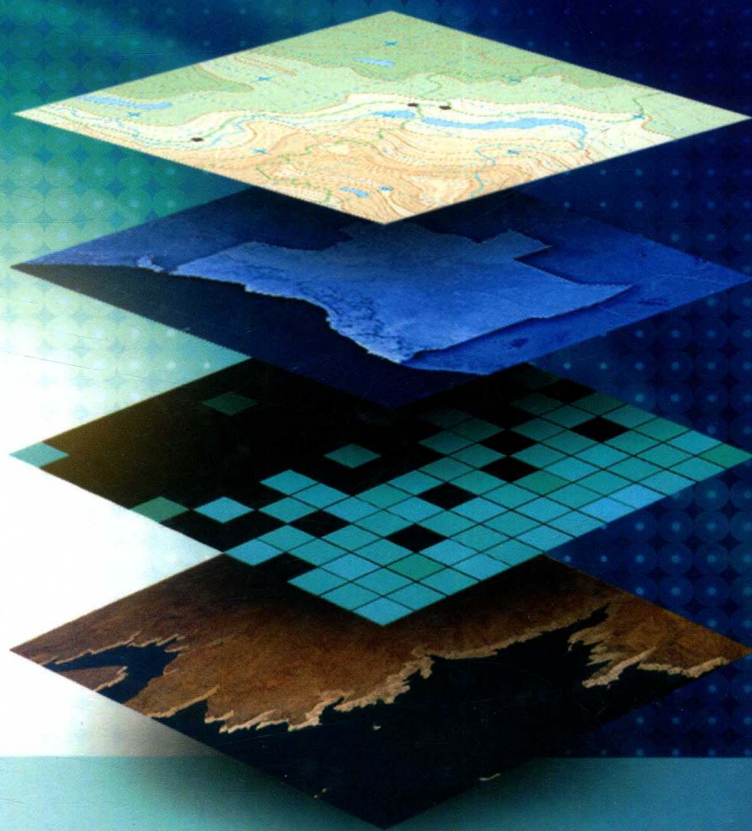


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GIS and Geocomputation for Water Resource Science and Engineering



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GIS and Geocomputation for Water Resource Science and Engineering

Barnali Dixon dedicates this book to her son, Edgar, her joyful challenge!!

Venkatesh Uddameri dedicates this book to three very special women—his grandmother (Late Sarojamma Kudthini), his mother (Late Lalitha Devi Uddameri), and his wife (Elma Annette Uddameri) for their love, support, and encouragement.

Preface

Geographic information systems (GIS) have had a tremendous impact on the field of water resources engineering and science over the last few decades. While GIS applications for water resources can be traced back to the 1970s, increased computational power, particularly of desktop computers, along with advances in software have made GIS widely accessible. Water resources engineers and scientists seek to model the flow of water, suspended and dissolved constituents in geographic entities such as lakes, rivers, streams, aquifers, and oceans. Geographic description of the system of interest is the first step toward understanding how water and pollutants move through these systems and estimating associated risks to human beings and other ecological receptors. As GIS deals with describing geographic entities, they are used quite extensively in conceptualizing water resources systems. GIS offer spatially coded data warehousing capabilities that are not found in regular database software.

In addition to data storage, retrieval, and visualization, a wide range of computations can be performed using GIS. Geoprocessing tasks such as clip, union, and joint can be used to slice, dice, and aggregate data, which facilitates visualization for pattern recognition and identification of hot spots that need attention. GIS can be used to delineate watersheds, the basic unit for hydrologically informed management of land resources. In addition to qualitative data visualization, GIS software come with a variety of geostatistical and interpolation techniques such as Kriging that can be used to create surfaces and fill in missing data. In addition, these tools can be used to map error surfaces and assess the worth of additional data collection. GIS software also come equipped with a wide range of mathematical and Boolean functions that allow one to manipulate attributes and create new information. Closed-form analytical expressions can be directly embedded into GIS systems to simulate system behavior and visualize the response of hydrologic systems (e.g., a watershed) to natural (climate change) and anthropogenic (urbanization) factors. Most of this functionality can be carried out using built-in functionality and without resorting to any programming. In addition, GIS software come with back-end programming support, which can be used to automate geoprocessing tasks, write new functions, and add additional capabilities for hydrologic analysis. The inclusion of time has been a holy grail of GIS research. Recent software enhancements and database models allow the inclusion of time stamped data and create animations that depict how the system has changed over time, allowing one to visualize over the entire space-time continuum. The idea of performing water resources computations and modeling within the GIS framework is referred to as **geocomputation** and is the primary focus of this book.

The book is written to be as self-contained as possible and is intended as a text for GIS-based water resources engineering or science courses suitable for upper-level undergraduate and early graduate students. It can also be used as a supplemental text in undergraduate and graduate level courses in hydrology, environmental science, and water resources engineering, or as a stand-alone or a supplemental text for an introductory GIS class with an understanding that the book's focus is strongly on water resources issues.

The book assumes some basic understanding of hydrologic processes and pollutant fate and transport that is covered in an introductory hydrology and environmental engineering/science class. Working knowledge of computers, particularly familiarity with spreadsheets, is also assumed on part of the reader. However, no prior experience in GIS is assumed. Elementary programming experience is desirable and will be beneficial to follow some advanced material in the book, but not required for the most part.

The book is arranged in three parts – The first part presents the fundamentals of geoprocessing operations and building blocks for carrying out geocomputations. The second part discusses the applied aspects of using GIS for developing water resources models. The third part is a compilation of case studies that illustrate the use of GIS in water resources and environmental applications. These case studies can be directly used as projects in classes or modified for other geographies. The case studies are also intended to help students transition from obtaining information from textbooks to that contained in the journal articles. Datasets for several exercises and case studies are provided on the website for the textbook, which serves as a useful companion to accompany this text.

While the focus of this textbook is largely on fundamental geocomputing concepts, we recognize the importance of software programs to implement these ideas in real-world applications. While we do not endorse any commercial product per se, we have adopted the ArcGIS software platform (ESRI Inc., Redlands, CA) for most examples in this book as it is widely used and generally accepted as the industry standard. We recognize the growing prominence of open-source GIS software and its importance in underdeveloped and developing nations. As such, we have presented a few examples of using such software as well. In particular, the availability of geospatial packages within the open-source R statistical and programming environment greatly helps with the integration of water resources modeling and GIS.

This book represents a true collaboration between an environmental scientist/geographer and a civil engineer focused on water and environmental issues. We both bring nearly two decades of

our experience with GIS and its use in water resources engineering and science. Our goal in writing this book was to blend the right amount of theory and practice into a single compendium. We each have taught classes on GIS in Water Resources and came to realize that while excellent texts exist on GIS as well as water resources engineering, there is not a text that blends the two. This limitation is often seen as a hindrance by students who are trying to grasp GIS (whose learning curve is admittedly steep) and trying to make connections to concepts learned in their introductory hydrology and environmental science classes. The book seeks to facilitate the learning process for water resources scientists and engineers by showing them the usefulness of GIS and geocomputation while reinforcing their concepts of hydrology and water resources. The book should also be useful to practitioners who are often required to learn GIS on the job.

We are greatly indebted to our teachers who taught us GIS and water resources and our students and research assistants who helped us learn new skills and techniques and showed us new ways of using GIS in our teaching and research. In particular, Drs. Vivek Honnungar, Sreeram Singaraju, and Annette Hernandez contributed significantly to several case studies and helped with organization of the material. Ms. Julie Earls and Mr. Stephen Douglas are thanked for their assistance with data download from public domain and background research when needed. Ms. Tess Rivenbarkt and Mr. Johnny Dickson are thanked for their comments on the material and their assistance with proofreading. We are also thankful to our collaborators in

industry and regulatory agencies who have helped us understand the role of GIS in real-world applications. In particular, Mr. Tim Andruss, at Victoria County Groundwater Conservation District, is acknowledged for his support and fruitful discussions on using GIS in real-world settings.

A great deal of information on GIS, particularly the use of software, can be found on the Internet. We want to salute those unsung champions who have shared their knowledge, answered queries, and presented solutions on GIS forums that are a great resource to those working in this area. The production team at Wiley-VCH deserves special recognition for their patience and support throughout the publication process. We are also thankful to an anonymous reviewer whose suggestions greatly improved this work. Finally, we cannot thank our families enough for putting up with our craziness before, during, and after writing this book. Their assistance with proofreading of the chapters and discussing ways to improve our presentation were invaluable to the process. We do however take the sole responsibility for any errors and omissions in the text. We hope you will find the information presented here useful and welcome your feedback and comments on ways to improve our content and presentation.

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About the Companion Website

This book is accompanied by a companion website:

www.wiley.com/go/dixon/geocomputation

The website includes:

- Case studies
- Exercises

List of Acronyms

Abbreviation	Details
AAE	Average absolute error
ACRIMSAT	Active Cavity Radiometer Irradiance Monitor Satellite
ACWPP	Arroyo Colorado Watershed Protection Program
ADEQ	Arkansas Department of Environmental Quality
AF	Attenuation factor
AFC	Attenuation factor calculator
AFY	Acre-feet per year
AHP	Analytical Hierarchy Process
AI	Artificial intelligence
AIC	Akaike's information criterion
ANFIS	Artificial Neuro-Fuzzy Information Systems
ANN	Artificial Neural Networks
AOI	Area of interest
AP	Apparent color
ASCII	American Standard Code for Information Interchange
ASMC	Antecedent soil moisture conditions
ASR	Aquifer storage and recovery
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ASV	Autonomous surface vehicles
AVHRR	Advanced Very High Resolution Radiometer
AVIRIS	Airborne Visible InfraRed Imaging Spectrometer
AWRC	Arkansas Water Resources Center
BASINS	Better Assessment Science Integrating Point and Nonpoint Sources
BCF	Billions of cubic feet
BD	Bulk density
BGIS	Basin Geomorphic Information System
BIL	Band interleaved by line
BMPs	Best Management Practices
BOD	Biochemical oxygen demand
CAD	Computer Aided Design
CART	Classification and regression trees
CC	Correlation coefficient
CCN	Certificate of convenience and necessity
CEC	Cation exchange capacity
CERL	Construction Engineering Research Laboratory
CERP	Comprehensive Everglades Restoration Plan
CHIPS	Colonia Health, Infrastructure, and Planning Status
CI	Convexity index
CN	Curve number
COAV	Class-object-attribute-value
CSA	Clay settling area
CWA	Clean Water Act

DBMS	Database management system
DCIA	Directly connected impervious area
DEDNM	Digital Elevation Drainage Network Model
DEM	Digital elevation model
DFA	Discriminant function analysis
DGN	Design file
DGPS	Differential GPS
DLG	Digital line graphs
DO	Dissolved oxygen
DOM	Dissolved organic matter
DOQQs	Digital Orthophoto Quarter Quads
DOQs	Digital Orthophoto Quadrangles
DRASTIC	Aquifer vulnerability index: D epth to water table, R echarge, A quifer media, S oil type, T opography, I mpact of vadose zone, C onductivity
DSM	Digital surface model
DSS	Decision support systems
DTM	Digital terrain model
E/ET or ET/EV	Evaporation/evapotranspiration
EDAP	Economically distressed area program
EF	Ecological Fallacy
ELM	Everglade Landscape Model
EMC	Event mean concentration
EMR	Electromagnetic radiation
ENVI	Environment for Visualizing Images
EPA	Environmental Protection Agency
EROS	Earth Resources Observation and Science
ESA	European Space Agency
ESRI	Environmental Systems Research Institute
ESSP	Earth System Science Pathfinder Program
ESTDM	Event-based spatiotemporal data model
ET	Evapotranspiration
ETJ	Extraterritorial jurisdiction
ETM	Enhanced Thematic Mapper (Landsat)
ETM+	Enhanced Thematic Mapper Plus
FAC2	Fraction of predictions within a factor of two of observations
FAVA	Florida Aquifer Vulnerability Assessment
FAWN	Florida Automated Weather Network
FB	Fractional bias
FD	Fractal dimension
FDEP	Florida Department of Environmental Protection
FDOH	Florida Department of Health
FEMA	Federal Emergency Management Agency
FFNN	Feedforward neural network
FGDC	Federal Geographic Data Commission
FLUCCS	Florida land use and cover classification system
FMG Info Atlas	Info Atlas for Bay of Fundy, Gulf of Maine
FORTTRAN	Formula Translation
FWRI	Fish and Wildlife Research Institute (Florida)
GAM	Groundwater availability modeling
GCDs	Groundwater Conservation Districts
GCM	Global climate model
GCPs	Ground control points
GeoTIFF	Georeferenced Tagged Image File Format
GIRAS	Geographic Information Retrieval and Analysis System
GIS	Geographic Information Systems
GOCE	Gravity field and steady-state Ocean Circulation Explorer
GOES	Geostationary Operational Environmental Satellite
GPS	Global Positioning system
GRACE	Gravity Recovery and Climate Experiment
GRASS	Geographic Resources Analysis Support System

GRDC	Global Runoff Data Center
GRS	Geodetic Reference System
GUI	Graphical User Interface
GUS	Groundwater ubiquity score
GWVIP	Groundwater Vulnerability Index for Pesticides
HABs	Harmful Algal Blooms
HAL	Health advisory level
HEC	Hydrologic Engineering Center
HEC-RAS	Hydrologic Engineering Center River Analysis System
HMS	Hydrologic Modeling Systems
HRUs	Hydrologic Response Units
HSG	Hydrologic soil group
HUC	Hydrologic unit code
HUC#	Hydrologic Unit Catalog number
I&O	Index and overlay
ICA	International Cartographic Association
IDL	Interactive Data Language
IDW	Inverse distance weighted
IFOV	Instantaneous field of view
IFSAR	Interferometric synthetic aperture radar
IGWV	Intrinsic groundwater vulnerability
IR	Infrared
IRS-1C or IRS-1D	Indian Remote Sensing satellites
ISCGM	International Steering Committee for Global Mapping
IT	informational technology
JPEST	Java-based Pesticide Screening Toolkit
KDD	knowledge discovery in a database
KNRIS	Kentucky National Resource Information System
LAI	Leaf area index
LHS	Latin-hypercube sampling
LiDAR	Light Detection And Ranging
LPI	Leaching potential index
LR	Logistic regression
LRGV	Lower Rio Grande valley
LSU	Louisiana State University
LU	Land use
LULC	Land use/ Land cover
MADM	Multiattribute decision making
MAGI	Maryland Automated Geographic Information System
MAUP	Modifiable Area Unit Problem
MB	Mega Bytes
MCDM	Multi-criteria decision making
MCL	Maximum concentration limit, maximum contaminant level
MDM	Minimum discernible mark
MF	Membrane filter
MG	Geometric mean bias
MGD	Million gallons per day
MISR	Multi-angle Imaging SpectroRadiometer
MLMIS	Minnesota Land Management Information System
MLPs	Multilayer perceptrons
MMC	Modular Modeling Systems
MML	Module Markup Language
MMU	Minimum mapping unit
MODFLOW	Modular Flow or Modular Three-Dimensional Finite-Difference Groundwater Flow Model
MODIS	Moderate Resolution Imaging Spectroradiometer
MODM	Multimultiobjective decision making
MOS	Modular Optical Scanner
MPN	Most probable number
MRLCC	Multiresolution land characteristics consortium
MS	Management science

MSA	Metropolitan statistical area
MSL	Mean sea level
MSW	Municipal solid waste
MUIR	Map Unit Interpretations Record
NAD27	North American Datum 1927
NASA	National Aeronautics and Space Administration
NASDA	National Space Development Agency (Japan)
NASIS	National Soil Information System
NAVSTAR	Navigation System by Timing and Ranging
NCDC	National Climatic Data Center
NCDCDS	National Committee for Digital Cartographic Data Standards
NDVI	Normalized difference vegetation index
NED	National Elevation Dataset
NGIA	National Geospatial Intelligence Agency
NGMC	National Geospatial Management Center
NGOs	Nongovernmental organizations
NGP	National Geospatial Program
NHD	National Hydrographic Dataset
NI	Non-irrigated
NLEAP	Nitrate Leaching and Economic Analysis Package
NMAS	National Map Accuracy Standards
NMSE	Normalized mean square error
NNRMS	National Natural Resource Management System (India)
NOAA	National Oceanic and Atmospheric Administration
NPS	nonpoint source
NRCS	National Resource Conservation Service
NSSDA	National Standard for Spatial Data Accuracy
NSSH	National Soil Survey Handbook
NTU	nephelometric turbidity unit
NWIS	National Water Information System
NWS	National Weather Service
O&I	Overlay and Index
OC	organic carbon
OCTS	Ocean Color and Temperature Scanner
ODE	ordinary differential equation
OGC	Open Geospatial Consortium
OK	ordinary kriging
OLS	ordinary least squares
OO	object-oriented
OODM	Object-oriented data model
OOP	Object-oriented programming
OR	Operations research
ORSTOM	Office de la recherche scientifique et technique outre-mer
OSF	Open-source software
PAR	Perimeter-area ratio
PCA	Principal component analysis
PCB	Polychlorinated biphenyl's
PCs	Principal components
PCSs	Permit compliance systems
PDA	Personal Digital Assistant
PDF	Probability density function
PDOP	Positional Dilution of Precision
PHABSIM	Physical (Fish) Habitat Simulation Model
PLASM	Prickett Lonquist Aquifer Simulation Model
PLM	Patuxent Landscape Model
PLSS	Public Land Survey System
PNT	Position, navigation, and timing
POR	Period of record
PP	Point Profile
PRISM	Parameter-Elevation Regressions on Independent Slopes Model

PROMET	Process-oriented model for evapotranspiration
PRZM	Pesticide root zone model
PSI	Pathogen sensitivity index
PWS	public water system
QA/QC	Quality assurance and quality control
QGIS	Quantum GIS
R&O	Reclassification and overlay
RADARSAT-1	Radar Satellite
RBF	Radial basis function
RGB	Red-green-blue
RMSE	Root mean square error
ROI	Radius of influence
RPE	Raster Profile and Extension
RS	Remote Sensing
RTK	Real-Time Kinematic
RUSLE	Revised Universal Soil Loss Equation
SAC-SMA	Sacramento Soil Moisture Accounting
SCADA	Supervisory control and data acquisition
SCAN	Soil Climate Analysis Network
SCS	Soil Conservation Service
SCS-CN	Soil Conservation Survey Curve Number
SDM	Spatial data mining
SDTS	Spatial Data Transfer Standard
SHP	Southern High Plains
SI	Shape index
SMOS	Soil Moisture and Ocean Salinity Satellite
SOM	self-organizing maps
SPCS	State Plane Coordinate System
SPOT	Satellite Pour l'Observation de la Terre
SQL	Structured query language
SRTM	Shuttle Radar Topographic Mission
SSE	Sum of squared error
SSM/I	Special Sensor Microwave Imager
SSURGO	Soil Survey Geographic Database
STATSGO	State Soil Geographic Database
STC	Selecting Threshold Criteria
STORET	STORage and RETrieval data warehouse
SVAT	Soil-vegetation-atmosphere transfer
SVM	Support vector machine
SWAT	Soil Water Assessment Tool
SWFWMD	Southwest Florida Water Management District
SYMAP	Synagraphic Mapping System
TAC	Texas Administrative Code
TauDEM	Terrain Analysis Using Digital Elevation Models
TCEQ	Texas Commission on Environmental Quality
TDS	Total dissolved solids
TFN	Triangular fuzzy number
TGWV	True groundwater vulnerability
TIN	Triangular Irregular Network
TKN	Total Kjeldahl nitrogen
TM	Thematic Mapper
TMDL	Total Maximum Daily Load
TMS	Temporal map sets
TNP	Transportation Network Profile
TOPAZ	Topographic Parameterization
TOT	Time of travel
TPWD	Texas Parks and Wildlife Department
TQLs	Temporal query languages
TRMM	Tropical Rainfall Measuring Mission
TSS	Total suspended solids

TVP	Topological Vector Profile
TWDB	Texas Water Development Board
UAV	Unmanned automated vehicles
UK	Universal kriging
UML	Unified modeling language
USDA	US Department of Agriculture
USDA-NRCS	US Department of Agriculture National Resource Conservation Service
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
VB Script	Visual Basic Script
VBA	Visual Basic for Applications
VC	Visual Complexity
VG	Geometric variance
VI	Vulnerability index
VIP	Very important points
VPF	Vector Product Format
WAAS	Wide Area Augmentation System
WAF	Waste application field
WAHS	Watershed Hydrology Simulation
WBD	Watershed boundary database
WBNM	Watershed Bounded Network Model
WGS84	World Geodetic System 1984
WHP	Well head protection
WHPA	Well head protection analysis
WHPR	Well head protection radius
WQ	Water quality
WQP	Water Quality Portal
WQSDB	Water Quality Standards Database
WRA	Water Resources Agency
WSC	Water supply corporation
WSN	Wireless sensor networks
WSRP	Water Supply Restoration Program
WWTP	Wastewater treatment plants
ZOI	Zone of influence

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