# **BRIEF CONTENTS**

- Chapter 1 Introduction to GIS 1
- Chapter 2 Georeferencing 25
- Chapter 3 Data for GIS 55
- Chapter 4 Data Quality 107
- Chapter 5 Spatial Data Models and Databases 125
- Chapter 6 Spatial Analysis of Vector and Raster Data 149
- Chapter 7 Network Analysis 195
- Chapter 8 Statistics and Spatial Data Measurements 233
- Chapter 9 Spatial Analysis of 3-Dimensional Data 257
- Chapter 10 Cartography Using a GIS 279
- Chapter 11 GIS Hardware/Software and Programming 321
- Chapter 12 Future Considerations 339
- Appendix 361
- Glossary 379
- Index 389

# CONTENTS

# PREFACE XX

# ABOUT THE AUTHORS XXV

# CHAPTER 1 INTRODUCTION TO GIS



# What Are Spatial Data? 1

## Spatial Questions 4

## How Are Spatial Data Organized in a GIS? 4

Discrete Geographic Features 4 Continuous Geographic Features 6 Features Summarized by Geographic Area 6

#### Vector and Raster Data Structures 6

Vector Data Structure 6 Raster Data Structure 6 Spatial Data Infrastructures 7

## Formal and Informal Definitions of GIS 8

## Misconceptions about GIS 10

Misconception: A GIS Is Simply a Modified Graphics Arts or Computer-Aided-Design (CAD) Program11Misconception: A GIS Is Simply a Cartographic Mapping Program11Misconception: A GIS Is Simply a Software Package without Theoretical Foundation11Misconception: Traditional Paper Maps Are Just as Useful as a GIS12Misconception: A GIS Is No Different Than Any Other Information System12

## Components of a GIS 12

GIS Hardware 12 GIS Software 12 Humanware (Liveware) 16 GIS Data 16

# Trends in GIS 17

## The Business of GIS 17

GIS Software Development Industry 17 GIS Data Acquisition Industry 17 GIS Value-added Service Industry 18 Careers in GIS 18 Investing in GIS 19 Book Organization 20 Summary 20 Review Questions 20 Glossary 21 References 22

# CHAPTER 2 GEOREFERENCING



Overview 25

Datums 25

Ellipsoids 25

#### Geoids 27

Horizontal Datums 27 Vertical Datums 28

#### Coordinate Systems 29

Cartesian Coordinate Systems 29 Latitude and Longitude 29 Measuring Distance Using Latitude and Longitude 30

#### The Globe 32

#### Map Projections 33

Developable Surfaces Used in Map Projections 35 Cylindrical Map Projections 36 Mercator 36 Universal Transverse Mercator 38 Space Oblique Mercator 39 Mollweide 39 Azimuthal (Planar) Map Projections 40 Perspective Azimuthal Map Projections 41 Lambert Azimuthal Equal-area 41 Azimuthal Equidistant 42 Conical Map Projections 42 Albers Equal-area Conic 42 Lambert Conformal Conic 42 Other Projections and Coordinate Systems 45 State Plane Coordinate Systems 46 Custom Map Projections 47 Implementation in a GIS 47

# Tissot's Indicatrix 48

Summary 50

**Review Questions** 50

Glossary 52

References 52

# CHAPTER 3 DATA FOR GIS

#### **Overview 55**

#### In Situ Data Collection 55

Global Positioning System (GPS) 55 GIS Applications of GPS 56 History of the GPS 56 GPS System Components 57 Space Segment 57 Control Segment 57 User Segment 58 GPS Selective Availability 62 Other Global Navigation Satellite Systems 62 In Situ Land Surveying 62 Surveying Instruments and Techniques 62 Traditional Land Surveying 62 Surveying Using a Total Station 65 Surveying Using a SmartStation 66 In Situ Data Sampling or the Taking of a Census 67 Sampling 67 A Census 68 2010 United States Census 68 Digitization of Historical Spatial Information 70 Digitizing Tables and Tablets 70 Heads-up On-screen Digitization Using Scanned Maps or Images 71 Raster-Scanning 71 Microdensitometer Digitization 71 Linear and Area Array Charge-Coupled Device (CCD) Digitization 74

#### Remote Sensing Data Collection 76

The Remote Sensing Process 77 **Resolution Considerations** 77 Spectral Resolution 78 Spatial Resolution 79 Temporal Information and Resolution 81 Radiometric Resolution 81 Trade-offs between Spatial and Temporal Resolution 82 Polarization Information 82 Angular Information 83 Remote Sensing Terminology 83 Aerial Photography 83 Analog Vertical Aerial Photography 83 Digital Vertical Aerial Photography 83 Digital Oblique Aerial Photography 85 Multispectral Remote Sensing 85 Landsat 87 SPOT Image, Inc. HRV 87 GeoEye, Inc. IKONOS-2 and GeoEye-1 88



DigitalGlobe, Inc. QuickBird and WorldView-2 88 NASA Terra and Aqua Multispectral Sensors 89 Hyperspectral Remote Sensing 89 Thermal-infrared Remote Sensing 91 Thermal-infrared Energy 91 Remote Sensing Thermal Characteristics 92 LiDAR Remote Sensing 94 Laser Remote Sensing 94 Extraction of Digital Surface Models (DSMs) 96 Extraction of a Bare-Earth DTM 98 RADAR Remote Sensing 99 RADAR Sensor Characteristics 99 RADAR Environmental Considerations 99 RADAR Interferometric Topographic Mapping 102

#### **Remote Sensing Data Analysis** 103

Analog (Visual) Image Processing 103 Digital Image Processing 103

Summary 103

**Review Questions** 103

Glossary 104

References 105

# CHAPTER 4 DATA QUALITY

#### **Overview 107**

#### Metadata 107

Elements of Metadata 107 Federal Geographic Data Committee (FGDC) Metadata Standards 108 Metadata and GIS Software 108 Other Metadata Issues 108

#### Accuracy and Precision 108

#### Types of Error in Geospatial Data 110

Attribute Error 110 Acceptable Level of Accuracy 110 Random Spot-checking 111 Spatial Sampling 111 Creation of an Error Matrix and the Computation of Overall Accuracy, Producer's Accuracy, User's Accuracy, and Kappa Coefficient of Agreement 111 Attribute Root-Mean-Square-Error (RMSE) 114 Attribute Logical Consistency 114 Attribute and Spatial Completeness 114 Positional Error 115 Map Accuracy Standards 115 United States National Map Accuracy Standards (NMAS) 115 ASPRS Map Accuracy Standards for Large-Scale Maps 115 FGDC National Standard for Spatial Data Accuracy (NSSDA) 116



Topological Error 117 Temporal Accuracy 117 Error Visualization 117 Error Propagation 118 Ecological Fallacy 118 Modifiable Areal Unit Problem 119

#### Summary 119

**Review Questions** 120

Glossary 121

References 122

# CHAPTER 5 SPATIAL DATA MODELS AND DATABASES



#### **Overview** 125

#### GIS Data Models 125

#### Vector Data 125

Points 125 Lines 126 Areas (Polygons) 126 Scale Considerations 127 Topology 128 Adjacency, Enclosure, and Connectivity 129 Georelational Vector Model 130 Arc Coverage 131 Shapefiles 131 Object-Based Vector Model 132 Classes 132 Geodatabases 133

#### Raster Data 134

Raster Cell Value 134 Cell Size 134 Raster Georeferencing 134 Raster File Formats 135

#### Vector and Raster Data Model Conversion 135

Vector-to-Raster Conversion 136 Raster-to-Vector Conversion 136

#### Databases 139

Flat Files 139 Relational Databases 139 Different Database Relationships 140 Relate and Join 141 Raster Databases 141 Types of Attribute Data 141 Adding and Deleting Attribute Fields 142 Date Entry 143 Integration with External Databases 143

#### Data Query 143

Selection by Attribute 143 Selection by Location 144 Combinations of Data Queries 144 New Data Layers 145

#### Summary 146

**Review Questions** 146

Glossary 146

References 147

# CHAPTER 6 SPATIAL ANALYSIS OF VECTOR AND RASTER DATA



#### Overview 149

#### Vector Data Analysis 149

Buffering Using Vector Data 149 Buffering Point Features 149 Buffering Linear Features 150 Buffering Area Features 151 **Buffer Dimensions** 153 Types of Buffering 153 Arbitrary Buffering 154 Causative Buffering 154 Mandated Buffering 154 Overlay Using Vector Data 155 Types of Topological Overlay 155 Point-in-Polygon Overlay 155 Line-in-Polygon Overlay 155 Polygon-on-Polygon Overlay 157 Overlav Analysis Example 157 Overlay Analysis Using an Interactive Model-building Program 162

#### Raster Data Analysis 165

Raster Distance Measurement Operations 165 Buffering Using Raster Data 166 Local Raster Operations 168 Local Operations Applied to a Single Raster Dataset 168 Reclassification (Recoding) Using a Single Raster Dataset 169 Raster Reduction and Magnification 171 Local Operations Applied to Multiple Registered Raster Datasets 172 Map Algebra 173 Examples of Map Overlay Using Local Operations Applied to Multiple Registered Raster Datasets 174 Universal Soil Loss Prediction Using Map Overlay Local Operations Applied to Multiple Raster Datasets 174 Sea-level-Rise Prediction Using Map Overlay Local Operations Applied to Multiple Raster Datasets 175 Neighborhood Raster Operations 180 Qualitative Raster Neighborhood Modeling 181 Quantitative Raster Neighborhood Modeling 182 Simple Univariate Statistics 182

Spatial Convolution Filtering of Map and Image Data 182 Low-frequency Filtering in the Spatial Domain 183 High-frequency Filtering in the Spatial Domain 186 Edge Enhancement in the Spatial Domain 186 Linear Edge Enhancement 186 Nonlinear Edge Enhancement 188 Zonal Operations 189 Zonal Statistics 189 Zonal Statistics from a Single Raster 190 Zonal Statistics from Two Raster Datasets 190

## Summary 191

**Review Questions** 191

Glossary 192

**References** 193

# CHAPTER 7 NETWORK ANALYSIS

#### **Overview** 195

## Geocoding 196

Geocoding Components 197 Preprocessing 198 Address Matching 198 Geocoding Quality 200

#### Types of Networks 200

Transportation (Undirected) Networks 200 Geometric Utility (Directed) Networks 200

#### Transportation (Undirected) Network Analysis 200





Network Analysis Problem: Location-Allocation Modeling for Facility Location 213 Maximize Attendance Problem 214 The Network 214 Candidate Facilities That Provide Goods or Services 214 Demand Points for the Goods and Services 216 Model Assumptions and Results 216 Incorporating Existing Facilities in the Modeling Process 218 Network Analysis Problem: Maximize Market Share 218 Network Analysis Problem: Target Market Share 222

## Geometric Utility (Directed) Network Analysis 222

Building a Topologically Correct Geometric Utility (Directed) Database 222
Collect Source Network Information 222
Build Topologically Correct Utility (Directed) Network Elements and Attributes 223
Specify the Network Analysis to Be Performed and Solve the Problem 225
Network Analysis Problem: Flow Direction in a Utility Network 226
Network Analysis Problem: Tracing Edges and Junctions Upstream or Downstream in a Utility Network 226
Network Analysis Problem: Using Barriers in a Utility Network 228
Network Analysis Problem: Network Schematic Diagrams 229

Summary 229

**Review Questions** 229

Glossary 230

References 231

# CHAPTER 8 STATISTICS AND SPATIAL DATA MEASUREMENTS



# Overview 233

# Length (Distance) Measurement 233

Linear Distance Measurement Based on the Pythagorean Theorem 233 Manhattan Distance Measurement 235 Other Considerations 236

# Polygon Perimeter and Area Measurements 236

Perimeter Measurement 237 Polygon Area Measurement 238 Raster Polygon Measurement 240

# **Descriptive Statistics** 240

# **Descriptive Spatial Statistics** 243

Mean Center 243 Standard Distance 244

# Spatial Autocorrelation 244

Moran's I 245

# Point Pattern Analysis 247

Quadrat Analysis 247 Nearest-Neighbor Point Analysis 249 Dispersed Distribution Index 250 Nearest-Neighbor Ratio 250 Nearest-Neighbor Test Statistic 251

Summary 252

**Review Questions** 252

Glossary 253

**References 254** 

# CHAPTER 9 SPATIAL ANALYSIS OF 3-DIMENSIONAL DATA



#### **Overview 257**

#### Vector Representation and Processing of 3-Dimensional Data 258

Triangular Irregular Network (TIN) Data Structure 258 TIN Surface Processing 259 Displaying TIN Data 260 Isoline (e.g., Contour) Mapping Using TIN Data 261 Slope Mapping Using TIN Data 261 Aspect Mapping Using TIN Data 261

#### Raster Representation and Processing of 3-Dimensional Data 261

Spatial Interpolation 261 Nearest-neighbor Spatial Interpolation 262 Inverse-Distance-Weighting (IDW) Interpolation 263 Geostatistical Analysis, Autocorrelation, and Kriging Interpolation 265 Calculating Average Semivariance 267 Empirical Semivariogram 268 Spline Interpolation 270 Surface Processing of Raster 3-Dimensional Data 272 Black-and-White and Color Display 272 Slope Mapping Using Raster Data 274 Aspect Mapping Using Raster Data 276

Summary 276

**Review Questions** 276

Glossary 277

**References 278** 



# CHAPTER 10 CARTOGRAPHY USING A GIS

#### Overview 279

#### Are You a Geographer/Cartographer at Heart? 279

#### Historical Cartography 280

The Oldest Maps 280 Medieval T-in-O Maps 280 Ptolemy's *Geographica* 150 AD 282 Age of Exploration, Printing, and Atlases 282 Modern Map-making 284

#### The Cartographic Process 285

#### Feature Type and Measurement Level 287

Feature Type 287 Geographic Measurement Level 288

#### Map Design Fundamentals 290

Map Composition (Layout) 290 Title 290 Typography 290 Font 292 Type Size 292 Type Color 292 Thematic Content and the Figure-Ground Relationship 292 North Arrows and Compass Roses 293 Scale Bar 294 Legend 295 Graticule or Reference Grid 295 Geospatial Metadata 295

#### Mapping Point Data 296

Point Mapping Using Simple Symbols 296 Point Mapping Using Graduated Colors 296 Point Mapping Using Proportional or Graduated Symbols 296 Standardized Point Symbols 298

#### Mapping Linear Data 299

Line Mapping Using Simple Line Symbolization and Color 300 Flow Mapping Using Graduated (Proportional) Line Symbolization 300 Isarithmic Mapping 301 Topographic and Bathymetric Contours 302

#### Mapping Area Data 306

Thematic Mapping of Spatial Data Unconstrained by Administrative Unit Boundaries 306 Thematic Mapping of Spatial Data Constrained by Administrative Units: Choropleth Mapping 306 Choropleth Mapping 306 Standardization 308 Number of Class Intervals 309 Choropleth Map Class Intervals 309 Choropleth Map Symbolization 310

## Photomaps, Orthophotomaps, Imagemaps, and Orthoimagemaps 313

Uncontrolled Photomaps (Photomosaics) and Imagemaps 313 Controlled Photomaps and Imagemaps 313 Orthophotos, Orthophotomaps, Orthoimages, and Orthoimagemaps 315 National Digital Orthophoto Programs 316 USGS Digital Orthophotos 316 USDA National Agriculture Imagery Program (NAIP) 317

Summary 317

**Review Questions** 317

Glossary 318

**References 319** 

# CHAPTER 11 GIS HARDWARE/SOFTWARE AND PROGRAMMING



## Overview 321

## GIS Hardware Considerations 321

Type of Computer 321 Personal Computers 322 Computer Workstations 322 Mainframe Computers 322 Central Processing Unit (CPU) 322 Memory (Read-Only and Random Access) 322 Operating System 323 Display 323 Input Devices 324 Digitizing Using a Digitizing Table 324 On-screen Digitizing 324 Output Devices 324 GIS Laboratories 324 GIS Data Storage and Archiving Considerations 324 Rapid Access Mass Storage and Backup 324 Long-term Data Storage and Archiving 325

# GIS Software Considerations 325

GIS Software 326 ArcGIS<sup>®</sup> for Desktop 326 GRASS 326

**IDRISI 326** Cost 328 Open-source GIS 328 Operating System 328 Data Capture and Data Formats 328 Incorporation of Vector, Raster, and GPS Data 329 Database Management 329 Cartographic Output 329 GIS Software Support 329 Online Manuals and Help 329 Customer Support 329 GIS Software User Groups 329 Software Maintenance Contracts 329 Online Training and/or Software Workshops 330 Integration of External Code and Software Modification 331 Hand-held GIS 331

# Programming and GIS 331

When Should You Program? 331 Computer Programming Basics 332 How Can You Learn to Program? 332 Object-Oriented Programming 332 ArcObjects 333 Python—A Commonly Used Programming Language 333 GIS Programming Integration 334 Stand-alone GIS Programming Applications 335

Summary 335

**Review Questions** 335

Glossary 337

**References 337** 

# CHAPTER 12 FUTURE CONSIDERATIONS



# Overview 339

# GIS Career and Education Considerations 339

GIS Careers in the Public and Private Sectors 339 GIS Careers in the Public Sector 340 GIS Careers in the Private Sector 341 Association with Professional Organizations 341 Knowledge about Other Mapping Sciences (Geotechnologies) 343 GIS Certificates, Certification, and Licensure 344 GIS Certificates 344 GIS Certification 344 The GIS Certification Institute 344 ASPRS Certification 344 Esri Technical Certification 345 Potential GIS Licensure 345 Continuing Education 345

# GIS Technical Considerations 345

Cloud Computing and GIS 346 Web-based GIS 347 Desktop versus Web-based GIS 348 Mobile GIS 348 Volunteered Geographic Information 349 Volunteered Geographic Information Quality 350 Improvements in Data Formats and Standards 350 Three-Dimensional Visualization 350 Terrain Visualization 350

#### Geospatial Public Access and Legal Considerations 353

Public Data Access 353 Freedom of Information Act 353 GIS Data Liability 353 Fourth Amendment Privacy Considerations 354

# Integration of Remote Sensing and GIS 356

Advances in Data Collection Platforms 356 Advances in Remote Sensing Systems 357 Advances in Digital Image Processing 357

Summary 358

**Review Questions** 358

Glossary 358

**References 359** 

# APPENDIX: SOURCES OF GEOSPATIAL INFORMATION 361

# Table of Contents 361

## Federal Geospatial Data Repositories 362

USGS EarthExplorer 362 USGS The National Map 363 Geo.Data.gov 363 U.S. Census Bureau 364

Open-source Volunteered Geographic Information (VGI) Repositories 365

OpenStreetMap 365

# Commercial Geospatial Data Repositories 366

Esri ArcGIS® Online 366

Digital Elevation Data 367

Hydrography Data 368

Land Use/Land Cover and Biodiversity/Habitat Data 368



Network (Road) and Population Demographic Data 368 Remote Sensor Data—Public 368 State GIS Data Clearinghouses 368 References 368

GLOSSARY 379

**INDEX 389**