Super Typhoon Haiyan made landfall in the central Philippines on the morning of November 7, 2013, with sustained winds over 306 km·h⁻¹, the strongest ever recorded for a tropical cyclone at landfall using satellite measurements. In *Geosystems*, we discuss tropical cyclones and other severe weather events on Earth in Chapter 8. [NOAA Forecast Systems Laboratory.]
AN INTRODUCTION TO PHYSICAL GEOGRAPHY

Geosystems

Fourth Canadian Edition

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PEARSON
Toronto
dedication
To the students and teachers of Earth, and
to all the children and grandchildren, for it
is their future and home planet.

The land still provides our genesis,
however we might like to forget that our
food comes from dank, muddy Earth, that
the oxygen in our lungs was recently
inside a leaf, and that every newspaper
or book we may pick up is made from the
hearts of trees that died for the sake of
our imagined lives. What you hold in your
hands right now, beneath these words, is
consecrated air and time and sunlight.

—Barbara Kingsolver

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Welcome to the Fourth Canadian Edition of *Geosystems*. This edition marks the addition of Dr. Ginger Birkeland as a coauthor to Robert Christopherson, Mary-Louise Byrne, and Philip Giles. The Fourth Canadian Edition features significant revision, with a new chapter on climate change, new features, updated content, and many new photos, maps, and illustrations. We continue to build on the success of the previous editions, as well as the companion texts, *Geosystems*, now in its Ninth Edition, and *Elemental Geosystems*, Eighth Edition. Canadian students and instructors appreciate the systems organization, scientific accuracy, integration of figures and examples specific to Canada while maintaining an international flavour throughout. The clarity of the summary and review sections, and overall relevancy to what is happening to Earth systems in real time are valued by all who use the *Geosystems*, Fourth Canadian Edition text. *Geosystems* continues to tell Earth’s story in student-friendly language.

The goal of physical geography is to explain the spatial dimension of Earth’s dynamic systems—its energy, air, water, weather, climate, tectonics, landforms, rocks, soils, plants, ecosystems, and biomes. Understanding human–Earth relations is part of physical geography as it seeks to understand and link the planet and its inhabitants. Welcome to physical geography!

**New to the Fourth Canadian Edition**

Nearly every page of *Geosystems*, Fourth Canadian Edition, presents updated material, new Canadian and international content in text and figures, or new features. A sampling of new features includes:

- **A new chapter on climate change.** Although climate change science affects all systems and is discussed to some extent in every chapter of *Geosystems*, we now present a stand-alone chapter covering this topic—Chapter 11, Climate Change. This chapter covers palaeoclimatology and mechanisms for past climatic change (expanding on topics covered in Chapter 17 in the previous edition), climate feedbacks and the global carbon budget, the evidence and causes of present climate change, climate models and projections, and actions that we can take to moderate Earth’s changing climate. This new Chapter 11 expands on the climate change discussion that was formerly part of Chapter 10, Climate Systems and Climate Change, in the previous edition. Canadian content has been added, including Canada’s decision to withdraw from the Kyoto Protocol in 2012.

- **A new *Geosystems in Action* feature focusing on key topics, processes, systems, or human–Earth connections.** In every chapter, *Geosystems in Action* is a one- to two-page highly visual presentation of a topic central to the chapter, with active learning questions and links to media in *MasteringGeography*, as well as a GeoQuiz to aid student learning. Throughout each part of the *Geosystems in Action* figure, students are asked to analyze, explain, infer, or predict based on the information presented. Topics include Earth–Sun Relations (Chapter 2), Air Pollution (Chapter 3), Earth–Atmosphere Energy Balance (Chapter 4), The Global Carbon Budget (Chapter 11), Glaciers As Dynamic Systems (Chapter 17), and Biological Activity in Soils (Chapter 18).

- **A new feature, *The Human Denominator*, that links chapter topics to human examples and applications.** At the end of Chapters 2 through 20, this new feature includes maps, photos, graphs, and other diagrams to provide visual examples of many human–Earth interactions. This feature replaces and expands on the former Chapter 21 in previous *Geosystems* editions, called *Earth and the Human Denominator*.

- **New and revised illustrations and maps to improve student learning.** More than 250 new photos and images bring real-world scenes into the classroom. Our photo and remote sensing program, updated for this edition, exceeds 500 items, integrated throughout the text.

- **New images and photos for the 20 chapter openers, and redesigned schematics and photos for the 4 part openers.**

- **Learning Catalytics**, a “bring your own device” student engagement, assessment, and classroom intelligence system, integrated with *MasteringGeography*.

**Continuing in the Fourth Canadian Edition**

- **Twenty-two Focus Studies**, with either updated or new content, explore relevant applied topics in greater depth and are a popular feature of the *Geosystems* texts. In this edition, these features are grouped by topic into five categories: Pollution, Climate Change, Natural Hazards, Sustainable Resources, and Environmental Restoration.

Ten new Focus Study topics include:

- Heat Waves (Chapter 5)
- Hurricanes Katrina and Sandy: Storm Development and Links to Climate Change (Chapter 8)
- Thawing Methane Hydrates—Another Arctic Methane Concern (Chapter 11)
- Earthquakes in Haiti, Chile, and Japan: A Comparative Analysis (Chapter 13)
- Stream Restoration: Merging Science and Practice (Chapter 15)
Flooding in Southern Alberta in 2013 (Chapter 15)
The 2011 Japan Tsunami (Chapter 16)
Snow Avalanches (Chapter 17)
Wildfire and Fire Ecology (Chapter 19)
Global Conservation Strategies (Chapter 20)

- The chapter-opening Geosystems Now case study feature presents current issues in geography and Earth systems science. These original, unique essays, updated for the Fourth Canadian Edition, immediately engage readers into the chapter with relevant, real-world examples of physical geography. New Geosystems Now topics in this edition include: Canada’s December 2013 claim to extend its boundary in the Arctic to the edge of the continental shelf (Chapter 1), getting water from the air in arid climates (Chapter 7), a large-scale look at Vancouver Island’s climate (Chapter 10), and the effects of proposed dams on rivers in China (Chapter 15). Many of these features emphasize linkages across chapters and Earth systems, exemplifying the Geosystems approach.

- GeoReports continue to describe timely and relevant events or facts related to the discussion in the chapter, provide student action items, and offer new sources of information. The 84 GeoReports in the Fourth Canadian Edition, placed along the bottom of pages, are updated, with many new to this edition. Example topics include:
  - Did light refraction sink the Titanic? (Chapter 4)
  - Yukon and Saskatchewan hold records for extreme temperatures (Chapter 5)
  - Stormy seas and maritime tragedy (Chapter 8)
  - Water use in Canada (Chapter 9)
  - Satellite GRACE enables groundwater measurements (Chapter 9)
  - Tropical climate zones advance to higher latitudes (Chapter 10)
  - Sinkhole collapse in Ottawa caused by human activities (Chapter 14)
  - Surprise waves flood a cruise ship (Chapter 16)
  - Greenland ice sheet melting (Chapter 17)
  - Overgrazing effects on Argentina’s grasslands (Chapter 18)

- Critical Thinking exercises are integrated throughout the chapters. These carefully crafted action items bridge students to the next level of learning, placing students in charge of further inquiry. Example topics include:
  - Applying Energy-Balance Principles to a Solar Cooker
  - What Causes the North Australian Monsoon?
  - Identify Two Kinds of Fog
  - Analyzing a Weather Map
  - Allocating Responsibility and Cost for Coastal Hazards
  - Tropical Forests: A Global or Local Resource?

- The Geosystems Connection feature at the end of each chapter provides a preview “bridge” between chapters, reinforcing connections between chapter topics.

- At the end of each chapter is A Quantitative Solution. This feature leads students through a solution to a problem, using a quantitative approach. Formerly called Applied Physical Geography, several of these were expanded or updated for this edition, and a new one was added (Map Scales, in Chapter 1).

- Key Learning Concepts appear at the outset of each chapter, many rewritten for clarity. Each chapter concludes with Key Learning Concepts Review, which summarizes the chapter using the opening objectives.

- Geosystems continues to embed Internet URLs within the text. More than 200 appear in this edition. These allow students to pursue topics of interest to greater depth, or to obtain the latest information about weather and climate, tectonic events, floods, and the myriad other subjects covered in the book.

- The MasteringGeography™ online homework and tutoring system delivers self-paced tutorials that provide individualized coaching, focus on course objectives, and are responsive to each student’s progress. Instructors can assign activities built around Geoscience Animations, Encounter “Google Earth™ Explorations”, MapMaster interactive maps, Thinking Spatially and Data Analysis activities, new GeoTutors on the most challenging topics in physical geography, end-of-chapter questions, and more. Students also have access to a text-specific Study Area with study resources, including an optional Pearson eText version of Geosystems, Geoscience Animations, MapMaster™ interactive maps, new videos, Satellite Loops, Author Notebooks, additional content to support materials for the text, photo galleries, In the News RSS feeds, web links, career links, physical geography case studies, flashcard glossary, quizzes, and more—all at www.masteringgeography.com.

Author Acknowledgments

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I give special gratitude to all the students during the success of Geosystems. A beautiful photograph made by my wife, photographer, and expedition partner, Bobbé Christopherson. Her contribution to the success of Geosystems is obvious.

From Robert: I give special gratitude to all the students during my 30 years teaching at American River College, for it is in the classroom crucible that the Geosystems books were forged. I appreciate our Canadian staff at Pearson and the skilled Canadian educators that coauthored this edition, Mary-Lou Byrne and Philip Giles, who I am honored to call my colleagues. The Canadian environment is under accelerating climate-change stress that exceeds that occurring in the lower latitudes. For this reason, Geosystems, Fourth Canadian Edition, takes on an important role to educate and, hopefully, provoke actions toward a slower rate of climate change and a more sustainable future.

Thanks and admiration go to the many authors and scientists who published research that enriches this work. Thanks for all the dialogue received from students and teachers shared with me through e-mails from across the globe.

I offer a special thanks to Ginger Birkeland, Ph.D., our new coauthor on this edition and previous collaborator and developmental editor, for her essential work, attention to detail, and geographic sense. The challenge of such a text project is truly met by her strengths and talents. As you read this book, you will learn from many beautiful photographs made by my wife, photographer, and expedition partner, Bobbé Christopherson. Her contribution to the success of Geosystems is obvious.

From Ginger: Many thanks to my husband, Karl Birkeland, for his ongoing patience, support, and inspiration throughout the many hours of work on this book. I also thank my daughters, Érika and Kelsey, who endured my absence throughout a ski season and a rafting season as I sat at my desk. My gratitude also goes to William Graf, my academic advisor from so many years ago, for always exemplifying the highest standard of research and writing, and for helping transform my love of rivers into a love of science and all things geography. Special thanks to Robert Christopherson, who took a leap of faith to bring me on this Geosystems journey. It is a privilege to work with him.

From Mary-Louise: The incredible journey continues and once again I need to thank so many for their help. I owe my greatest thanks to my immediate family—my husband, Alain Pinard, and our children, Madeleine and Julianne, who continue to be curious about the world around them. To my extended family I am indebted to your honest comments and criticisms.

Geosystems is an amazing textbook, and I am so pleased to participate in its development. I thank all my colleagues in the geographic community in Canada who, by comment, communication, or review, helped to shape the contents of this text. I am forever indebted to Brian McCann for teaching me to look at physical processes from many perspectives and to integrate these perspectives in order to form an explanation. He is sadly missed.

To all the students with whom I had contact in 24 years of teaching at Wilfrid Laurier University, your enthusiasm and curiosity keep me focused on the goal of explaining planet Earth. I have had the pleasure of communicating with several current students from across the country that have had positive and constructive criticism about the book. I took your comments seriously and have addressed them where appropriate. It is amazing to hear from you and I encourage you to continue to communicate. To future students, our planet is in your hands: Care for it.

From Philip: I am very pleased and grateful to continue as part of the author team on Geosystems, Fourth Canadian Edition. For many years I admired the choice of content and writing style, as well as the presentation quality, in Geosystems. When selected to join the team for the Third Canadian Edition, it was an honor to know that I would be contributing to the preparation of this textbook which will play an important role for so many students in learning about physical geography. I knew quite early that I wanted to make physical geography my career, so to reach this stage and be playing this role as an author on a successful and influential textbook is extremely satisfying.

As an undergraduate and graduate student, one is influenced by many people. All of my course instructors and advisors helped me to learn and develop academically, and collectively they deserve recognition. In particular, like Mary-Lou, I also had the pleasure and
good fortune to have been taught and advised by Brian McCann during my time at McMaster University. Mary-Lou completed her Ph.D. while I was in the B.Sc. and M.Sc. programs at McMaster; we were both supervised by Brian for our thesis research on coastal sand dunes.

To Yvonne, my parents, and my colleagues in the Department of Geography and Environmental Studies at Saint Mary’s University, thank you all for your support over the years.

Whether you are taking this course as a requirement for your major or as an elective, I hope this textbook will help you find pleasure as you develop a better understanding of the physical environment. Robert, Ginger, Mary-Lou, and I each have a deep passion for this subject and one of the goals of this book is to inspire the same passion in you, our readers.

From all of us: Physical geography teaches us a holistic view of the intricate supporting web that is Earth’s environment and our place in it. Dramatic global change is underway in human–Earth relations as we alter physical, chemical, and biological systems. Our attention to climate change science and applied topics is in response to the impacts we are experiencing and the future we are shaping. All things considered, this is a critical time for you to be enrolled in a physical geography course! The best to you in your studies—and carpe diem!

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digital and print resources

For Students and Teachers

MasteringGeography for Geosystems is the most effective and widely used tutorial, homework, and assessment system for the sciences. The Mastering system empowers students to take charge of their learning through activities aimed at different learning styles, and engages them in learning science through practice and step-by-step guidance—at their convenience, 24/7. MasteringGeography™ offers:

- **Assignable activities** that include Geoscience Animations, Encounter Google Earth™ Explorations, MapMaster™ interactive maps, Thinking Spatially and Data Analysis activities, GeoTutors on the most challenging topics in Physical Geography, end-of-chapter questions, reading questions, and more.
- **Student study area** with Geoscience Animations, MapMaster™ interactive maps, new videos, Satellite Loops, Author Notebooks, additional content to support materials for the text, photo galleries, In the News RSS feeds, web links, career links, physical geography case studies, a glossary, self-quizzing, an optional Pearson eText and more. http://www.masteringgeography.com
- **Pearson eText** gives students access to the text wherever they have access to the Internet. Users can create notes, highlight text, and click hyperlinked words to view definitions. The Pearson eText also allows for quick navigation and provides full-text search.

We also offer prebuilt assignments for instructors to make it easy to assign this powerful tutorial and homework system. The Mastering platform is the only online tutorial/homework system with research showing that it improves student learning. A wide variety of published papers based on NSF-sponsored research and tests illustrate the benefits of the Mastering program. Results documented in scientifically valid efficacy papers are available at www.masteringgeography.com/site/results.

CourseSmart CourseSmart goes beyond traditional expectations—providing instant, online access to the textbooks and course materials you need at a lower cost for students. And even as students save money, you can save time and hassle with a digital eTextbook that allows you to search for the most relevant content at the very moment you need it. Whether it's reading textbooks or creating lecture notes to help students with difficult concepts, CourseSmart can make life a little easier. See how when you visit www.coursesmart.com/instructors.

Television for the Environment Earth Report Geography Videos on DVD (0321662989). This three-DVD set helps students visualize how human decisions and behavior have affected the environment and how individuals are taking steps toward recovery. With topics ranging from the poor land management promoting the devastation of river systems in Central America to the struggles for electricity in China and Africa, these 13 videos from Television for the Environment’s global Earth Report series recognize the efforts of individuals around the world to unite and protect the planet.

Geoscience Animation Library 5th edition DVD-ROM (0321716841). Created through a unique collaboration among Pearson’s leading geoscience authors, this resource offers over 100 animations covering the most difficult-to-visualize topics in physical geology, physical geography, oceanography, meteorology, and earth science. The animations are provided as Flash files and preloaded into PowerPoint(R) slides for both Windows and Mac.

Practicing Geography: Careers for Enhancing Society and the Environment by Association of American Geographers (0321811151). This book examines career opportunities for geographers and geospatial professionals in the business, government, nonprofit, and education sectors. A diverse group of academic and industry professionals shares insights on career planning, networking, transitioning between employment sectors, and balancing work and home life. The book illustrates the value of geographic expertise and technologies through engaging profiles and case studies of geographers at work.

Teaching College Geography: A Practical Guide for Graduate Students and Early Career Faculty by Association of American Geographers (0136054471). This two-part resource provides a starting point for becoming an effective geography teacher from the very first day of class. Part One addresses “nuts-and-bolts” teaching issues. Part Two explores being an effective teacher in the field, supporting critical thinking with GIS and mapping technologies, engaging learners in large geography classes, and promoting awareness of international perspectives and geographic issues.

Aspiring Academics: A Resource Book for Graduate Students and Early Career Faculty by Association of American Geographers (0136048919). Drawing on several years of research, this set of essays is designed to help graduate students and early career faculty start their careers in geography and related social and environmental sciences. Aspiring Academics stresses the interdependence of teaching, research, and service—and the importance of achieving a healthy balance of professional and personal life—while doing faculty work. Each chapter provides accessible, forward-looking advice on topics that often cause the most stress in the first years of a college or university appointment.

For Students

Applied Physical Geography—Geosystems in the Laboratory, Ninth Edition (0321987284) by Charlie Thomsen and
Robert Christopherson. A variety of exercises provides flexibility in lab assignments. Each exercise includes key terms and learning concepts linked to Geosystems. The ninth edition includes new exercises on climate change, a fully updated exercise on basic GIS using ArcGIS online, and more integrated media, including Google Earth and Quick Response (QR) codes. Supported by a website with media resources needed for exercises, as well as a downloadable Solutions Manual for teachers.

**Companion website for Applied Physical Geography: Geosystems in the Laboratory.** The website for lab manual provides online worksheets as well as KMZ files for all of the Google Earth® exercises found in the lab manual. [www.mygeoscienceplace.com](http://www.mygeoscienceplace.com)

**Goode’s World Atlas, 22nd Edition** (0321652002). *Goode’s World Atlas* has been the world’s premier educational atlas since 1923—and for good reason. It features over 250 pages of maps, from definitive physical and political maps to important thematic maps that illustrate the spatial aspects of many important topics. The 22nd Edition includes 160 pages of digitally produced reference maps, as well as thematic maps on global climate change, sea-level rise, CO₂ emissions, polar ice fluctuations, deforestation, extreme weather events, infectious diseases, water resources, and energy production.

**Pearson’s Encounter Series** provides rich, interactive explorations of geoscience concepts through Google Earth activities, covering a range of topics in regional, human, and physical geography. For those who do not use *MasteringGeography*, all chapter explorations are available in print workbooks, as well as in online quizzes at [www.mygeoscienceplace.com](http://www.mygeoscienceplace.com), accommodating different classroom needs. Each exploration consists of a worksheet, online quizzes whose results can be emailed to teachers, and a corresponding Google Earth KMZ file.

- *Encounter Physical Geography* by Jess C. Porter and Stephen O’Connell (0321672526)
- *Encounter Geosystems* by Charlie Thomsen (0321636996)
- *Encounter World Regional Geography* by Jess C. Porter (0321681754)
- *Encounter Human Geography* by Jess C. Porter (0321682203)
- *Encounter Earth* by Steve Kluge (0321581296)

**Dire Predictions: Understanding Global Warming** by Michael Mann, Lee R. Kump (0133909778). Appropriate for any science or social science course in need of a basic understanding of the reports from the Intergovernmental Panel on Climate Change (IPCC). These periodic reports evaluate the risk of climate change brought on by humans. But the sheer volume of scientific data remains inscrutable to the general public, particularly to those who still question the validity of climate change. In just over 200 pages, this practical text presents and expands upon the essential findings in a visually stunning and undeniably powerful way to the lay reader. Scientific findings that provide validity to the implications of climate change are presented in clear-cut graphic elements, striking images, and understandable analogies.

### For Teachers

**Learning Catalytics** is a “bring your own device” student engagement, assessment, and classroom intelligence system. With Learning Catalytics, you can:

- Assess students in real time, using open-ended tasks to probe student understanding.
- Understand immediately where students are and adjust your lecture accordingly.
- Improve your students’ critical-thinking skills.
- Access rich analytics to understand student performance.
- Add your own questions to make Learning Catalytics fit your course exactly.
- Manage student interactions with intelligent grouping and timing.

Learning Catalytics is a technology that has grown out of twenty years of cutting-edge research, innovation, and implementation of interactive teaching and peer instruction. Available integrated with *MasteringGeography*.

**Instructor Resource Manual** by Mary-Louise Byrne, Wilfrid Laurier University. Includes lecture outlines and key terms, additional source materials, teaching tips, and a complete annotation of chapter review questions.

**Computerized Test Bank** by Mary-Louise Byrne, Wilfrid Laurier University. Pearson’s computerized test banks allow instructors to filter and select questions to create quizzes, tests, or homework. Instructors can revise questions or add their own, and may be able to choose print or online options. These questions are also available in Microsoft Word format.

**Lecture Outline PowerPoint™ Presentations** by Khaled Hamdan, Kwnten Polytechnic University. Outlines the concepts of each chapter with embedded art and can be customized to fit teachers’ lecture requirements.

**Image Library** contains all textbook images as JPEGs for instructors to use when personalizing their PowerPoint™ Presentations.

These instructor resources are also available online via the Instructor Resources section of *MasteringGeography* and [http://catalogue.pearsoned.ca/](http://catalogue.pearsoned.ca/).

**Pearson Custom Library** For enrollments of at least 25 students, you can create your own textbook by choosing the chapters that best suit your own course needs. To begin building your custom text, visit [www.pearsoncustomlibrary.com](http://www.pearsoncustomlibrary.com). You may also work with a dedicated Pearson custom editor to create your ideal text—publishing your own original content or mixing and matching Pearson content. Contact your local Pearson representative to get started.

**Learning Solutions Managers** Pearson’s Learning Solutions Managers work with faculty and campus course designers to ensure that Pearson technology products, assessment tools, and online course materials are tailored to meet your specific needs. This highly qualified team is dedicated to helping schools take full advantage of a wide range of educational resources, by assisting in the integration of a variety of instructional materials and media formats. Your local Pearson Education sales representative can provide you with more details on this service program.
In March 2013, scientists began the fifth year and modern science, Geosystems combines a structured learning path, student-friendly writing, current applications, outstanding visuals, and a strong multimedia program for a truly unique physical geography experience.

**NEW! Chapter 11: Climate Change.** Incorporating the latest climate change science and data, this new chapter covers paleoclimatology and mechanisms for past climatic change, climate feedbacks and the global carbon budget, the evidence and causes of present climate change, climate forecasts and models, and actions that we can take to moderate Earth’s changing climate.
Visualizing Processes and Landscapes

NEW! Geosystems in Action present highly-visual presentations of core physical processes and critical chapter concepts. These features include links to mobile-ready media and MasteringGeography, as well as GeoQuizzes and integrated active learning tasks that ask students to analyze, explain, infer, or predict based on the information presented.

An unparalleled visual program includes a variety of illustrations, maps, photographs, and composites, providing authoritative examples and applications of physical geography and Earth systems science.
Humans Explore the Atmosphere

Astronaut Neil Armstrong, on a spacecraft from the Soviet Union's Soyuz program, descended to the surface of the Moon in 1969. In 2002, 30 years after leaving the Moon, Armstrong returned to a university in New Mexico for a series of classes. The purpose of the trip was to educate students about space exploration and to inspire them to pursue careers in the field. The trip was part of a broader effort to bring Zukunft, the future, to the students and the public.

Eustace's Record-Setting Jump

Eustace's record-setting jump was described as a "giant leap for mankind." It was a test of the ability of National Aeronautics and Space Administration (NASA) scientists to ensure that a space suit could protect astronauts from the rigors of space travel.

Protection in a Spacesuit

Recent jumps by Baumgartner and Eustace have captured the attention of the world. Both jumps have set free-fall height and speed records.

Record-Breaking Jumps


Figure GN 3.3         Felix Baumgartner's jump set free-fall height and speed record in 2014.

Figure 13.1.1  Plate tectonic setting of the Pacific coast of Canada.

Figure 13.1.2  Felix Baumgartner's jump set free-fall height and speed record. (a) Eustace on a training jump.

Plate tectonic setting of the Pacific coast of Canada.

The Pacific coast is the most seismically active region of Canada. The region is one of the few areas in the world where subduction, convergent, and transform plate boundaries occur in proximity to one another (Figure 13.1). In July 2012, 11 earthquakes of magnitude 7 or greater occurred in the Pacific Northwest.

Farther north, in a region extending from the northern tip of Vancouver Island to northern Canada, there are small, unpressurized compartments floaters. This protected his ability to duplicate the Earth's atmosphere.

At 31.3 km altitude, floating from a high-speed polyester cloth. His speed was remarkable, quickly surpassing the equator of a human being using this cloth. Crossing the vacuum of space all around him. Where the Sun is 17 seconds.

When his free fall reached the stratosphere, Eustace survived using a specially designed suit to maintain an internal air pressure of 1342 kPa, which is roughly 90% helium.

Eustace's speed was 1342 km/h, reaching a top velocity of 1342 kPa, which roughly 90% helium.

Figure 13.1.3 Assembly of a pressure suit with a pressure sensor section.

Figure 13.1.4  Felix Baumgartner's jump set free-fall height and speed record. (b) Baumgartner on a training jump.

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Tools for Structured Learning

Geosystems provides a structured learning path that helps students achieve a deeper understanding of physical geography through active learning.

KEY LEARNING CONCEPTS

After reading the chapter, you should be able to:

• Sketch a basic drainage basin model, and identify different types of drainage patterns by visual examination.
• Explain the concepts of stream gradient and base level, and describe the relationship between stream velocity, depth, width, and discharge.
• Explain the processes involved in fluvial erosion and sediment transport.
• Describe common stream channel patterns, and explain the concept of a graded stream.
• Describe the depositional landforms associated with floodplains and alluvial fan environments.
• List and describe several types of river deltas, and explain flood probability estimates.

A Quantitative Solution at the end of each chapter leads students through an exercise by using a quantitative approach to solve a problem.

A Quantitative Solution

Flood Frequency Analysis

The degree to which any phenomenon is a hazard depends on its magnitude and frequency of occurrence. The frequency with which a flood of a certain magnitude or higher can be expected to occur is called its recurrence interval. Recurrence intervals can be determined either long-term mean or by using records of stream discharge for a region or the drainage basin of interest, during a period of record. A recent method for estimating a recurrence interval is the method of maximum likelihood, which fits statistical distributions to a set of data. A statistical distribution is a function of the recurrence interval, which is the number of floods of the given magnitude or higher to occur on a regular cycle of once every 7 to 8 years. Sometimes the recurrence interval is rounded to the next lower power of 10. Thus, for a flood of magnitude 425 m³·s⁻¹ to be expected on average once every 7 years, we express the recurrence interval as 10 years.

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Statistically, we then expect a flood of magnitude 425 m³·s⁻¹ to happen exactly once every 7 years. A flood of magnitude 198 m³·s⁻¹ has a recurrence interval of 10 years. The expected value of the flood discharge is the sum of the expected values of the individual floods in the series. The expected value of the flood discharge for a recurrence interval of 10 years is the mean of the flood discharge for a period of record, or the mean of the flood discharge for a period of record plus a certain magnitude. The expected value of the flood discharge for a period of record plus a certain magnitude is the sum of the expected values of the individual floods in the series. The expected value of the flood discharge for a period of record plus a certain magnitude is the sum of the expected values of the individual floods in the series. The expected value of the flood discharge for a period of record plus a certain magnitude is the sum of the expected values of the individual floods in the series.

Key Learning Concepts

A Key Learning Concepts review at the end of each chapter concludes the learning path and features summaries, narrative definitions, a list of key terms with page numbers, and review questions.

Critical Thinking Activities

Critical Thinking Activities integrated throughout chapter sections give students an opportunity to stop, check, and apply their understanding.

Geosystems Connection

Geosystems Connection at the end of chapters help students bridge concepts between chapters, reminding them where they have been and where they are going.

Geosystems Connection

While following the flow of water through streams, we examined fluvial processes and landforms and the river-system outputs of discharge and sediment. We saw that a scientific understanding of river dynamics, fluvial landscape, and related flood hazards is integral to society’s ability to perceive hazards in the familiar environments we inhabit. In the next chapter, we examine the erosional activities of waves, tides, currents, and wind as they sculpt Earth’s coastlines and desert regions. A significant portion of the human population lives in coastal areas, making the difficulties of hazard perception and the need to plan for the future, given a rising sea level, important aspects of Chapter 16.
Mastering Geography™

Mastering Geography delivers engaging, dynamic learning opportunities—focusing on course objectives and responsive to each student’s progress—that are proven to help students absorb geography course material and understand difficult physical processes and geographic concepts.

Visualize the Processes and Landscapes That Form Earth’s Physical Environment

- **Encounter Activities** provide rich, interactive explorations of geography concepts using the dynamic features of Google Earth™ to visualize and explore Earth’s physical landscape. Available with multiple-choice and short answer questions. All Explorations include corresponding Google Earth KMZ media files, and questions include hints and specific wrong-answer feedback to help coach students toward mastery of the concepts.

- **Geoscience Animations** illuminate the most difficult-to-visualize topics from across the physical geosciences, such as solar system formation, hydrologic cycle, plate tectonics, glacial advance and retreat, global warming, etc. Animations include audio narration, a text transcript, and assignable multiple-choice quizzes with specific wrong-answer feedback to help guide students toward mastery of these core physical process concepts. Icons integrated throughout the text indicate to students when they can login to the Study Area of Mastering Geography to access the animations.
Engage in Map Reading, Data Analysis, and Critical Thinking

**MapMaster** is a powerful tool that presents assignable layered thematic and place name interactive maps at world and regional scales for students to test their geographic literacy, map reading, data analysis, and spatial reasoning skills.

**MapMaster Layered Thematic Interactive Map Activities** allow students to layer various thematic maps to analyze spatial patterns and data at regional and global scales. Available with assignable and customizable multiple-choice and short-answer questions organized around the textbook topics and concepts. This GIS-like tool includes zoom and annotation functionality, with hundreds of map layers leveraging recent data from sources such as NOAA, NASA, USGS, U.S. Census Bureau, United Nations, CIA, World Bank, and the Population Reference Bureau.

**Thinking Spatially & Data Analysis and NEW GeoTutor Activities** help students master the toughest geographic concepts and develop both spatial reasoning and critical thinking skills. Students identify and label features from maps, illustrations, graphs, and charts, examine related data sets, and answer higher-order conceptual questions, which include hints and specific wrong-answer feedback.

**Videos** provide students with a sense of place and allow them to explore a range of locations and topics. Covering physical processes and critical issues such as climate and climate change, renewable energy resources, economy and development, culture, and globalization, these video activities include assignable questions, with many including hints and specific wrong-answer feedback.

Student Study Area Resources in MasteringGeography:
- Geoscience Animations
- MapMaster™ interactive maps
- Videos
- Practice quizzes
- “In the News” RSS feeds
- Optional Pearson eText and more
With the Mastering gradebook and diagnostics, you’ll be better informed about your students’ progress than ever before. Mastering captures the step-by-step work of every student—including wrong answers submitted, hints requested, and time taken at every step of every problem—all providing unique insight into the most common misconceptions of your class.

- The Gradebook records all scores for automatically graded assignments. Shades of red highlight struggling students and challenging assignments.

- Diagnostics provide unique insight into class and student performance. With a single click, charts summarize the most difficult questions, vulnerable students, grade distribution, and score improvement over the duration of the course.

- With a single click, Individual Student Performance Data provide at-a-glance statistics into each individual student’s performance, including time spent on the question, number of hints opened, and number of wrong and correct answers submitted.
Learning Outcomes

MasteringGeography provides quick and easy access to information on student performance against your learning outcomes and makes it easy to share those results.

- Quickly add your own learning outcomes, or use publisher provided ones, to track student performance and report it to your administration.
- View class and individual student performance against specific learning outcomes.
- Effortlessly export results to a spreadsheet that you can further customize and/or share with your chair, dean, administrator, and/or accreditation board.

Easy to customize

Customize publisher-provided items or quickly add your own. MasteringGeography makes it easy to edit any questions or answers, import your own questions, and quickly add images, links, and files to further enhance the student experience.

Upload your own video and audio files from your hard drive to share with students, as well as record video from your computer’s webcam directly into MasteringGeography—no plugins required. Students can download video and audio files to their local computer or launch them in Mastering to view the content.

Learning Catalytics

Learning Catalytics is a “bring your own device” student engagement, assessment, and classroom intelligence system. With Learning Catalytics you can:

- Assess students in real time, using open-ended tasks to probe student understanding.
- Understand immediately where students are and adjust your lecture accordingly.
- Improve your students’ critical-thinking skills.
- Access rich analytics to understand student performance.
- Add your own questions to make Learning Catalytics fit your course exactly.
- Manage student interactions with intelligent grouping and timing.

Learning Catalytics is a technology that has grown out of twenty years of cutting edge research, innovation, and implementation of interactive teaching and peer instruction. Available integrated with MasteringGeography or standalone.

Pearson eText gives students access to Geosystems Fourth Canadian Edition whenever and wherever they can access the Internet. The eText pages look exactly like the printed text, and include powerful interactive and customization functions. Users can create notes, highlight text in different colors, create bookmarks, zoom, click hyperlinked words and phrases to view definitions, and view as a single page or as two pages.

Pearson eText also links students to associated media files, enabling them to view an animation as they read the text, and offers a full-text search and the ability to save and export notes. The Pearson eText also includes embedded URLs in the chapter text with active links to the Internet.

The Pearson eText app is a great companion to Pearson’s eText browser-based book reader. It allows existing subscribers who view their Pearson eText titles on a Mac or PC to additionally access their titles in a bookshelf on the iPad and Android devices either online or via download.
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