19 Epilog: GISS in the Service of Humanity

The world is a very differentiated place: for example, 1% of the world's population owns 50% of the world's ownable assets. Although many people live in relative comfort, many millions of others live in great poverty, at risk of natural or human-made disasters, and succumb to avoidable diseases that kill or handicap; children often suffer the most. Warfare and strife are commonplace. The causes of this differentiation are many and varied. Moreover, we are increasingly interconnected: A disaster suffered by one community often extends to others directly or indirectly.

Most of us would wish the world functioned more equitably and with greater resilience. This chapter describes how we can use our geographic information science and systems (GISS) skills, tools, experience, and the knowledge set out in this book to make this happen. We start with a process for how we should operate then go on to suggest the Grand Challenges to whose solution GISS and GISS professionals can contribute.

LEARNING OBJECTIVES

After studying this chapter, you will understand:

- Just how differentiated is world geography, notably in the incidence of poverty and health.
- The biggest challenges facing humanity and how these are pervasive and dynamic.
- The interdependency between many factors causing these problems.
- Why geography is not merely the context for such challenges but also part of the problem and the solution.
- How GISS help us tackle these challenges.

19.1 GISS, the Active Citizen, and Citizen Scientists

In earlier chapters we have identified the science underlying the use of geographic information (GI) systems, the technologies that are transforming what we can do, and some of the constraints that need to be circumvented. We have given details of individual projects where the application of GI technology has made a real difference, and we have celebrated the work of people who have advanced the cause.

In this final chapter, however, we ask what we who work in GISS can, should, or will be able to do for humanity, which is faced with profound global challenges—a world that is divided, unequal, and troubled. To set the scene and ensure that everyone starts from a common base, we sketch out a process for maximizing beneficial use of GISS. Then we provide a thumbnail sketch of what we (and others) see as the Grand Challenges. Linked to this we draw on past experience of GI system deployment, the GI literature, foresight, and intuition to show how GISS practitioners can help improve matters.

19.1.1 Who Can Help?

We stress that contributions can be made by people in many walks of life: the GI systems designer or technician, their manager(s), presidents of firms and their Board members, and public servants and politicians. Commercial enterprises have a vital role to play. What is necessary is a commitment to using sound evidence to inform decisions and an understanding of how central is geography to the life experience of all of us. The biographical boxes in this book demonstrate that this is realistic, not utopian. Nor are we a tiny community: Because many GI technology functions are embedded in services, notably those in Web-based mapping and vehicle guidance systems, all users of these systems are therefore users of "our" functionality—even if they do not appreciate it (Section 10.1). In total, such users already may well number over a billion people worldwide. Beyond this ubiquity are the professional users of GI systems. Our guesstimate is that there are over a million of those around the world.

Some citizens are also amateur scientists. In the words of *Scientific American* "Research often involves teams of scientists collaborating across continents. Now, using the power of the Internet, nonspecialists are participating, too. Citizen Science falls into many categories. A pioneering project was SETI@Home (Section 10.1), which has harnessed the idle computing time of millions of participants in the search for extraterrestrial life. Citizen scientists also act as volunteer classifiers of heavenly objects [and] they make observations of the natural world."

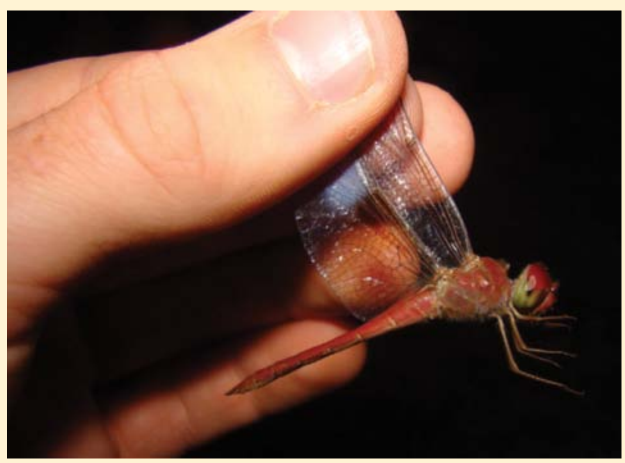
We have already identified (Section 18.6) the role of active citizens in building Open Street Map. A good example of the citizen scientist in the GI domain is given in Box 19.1.

Application Box 19.1

GI System–Enabled Field Science on a Budget

One example of what can be achieved with very modest means is the science work carried out in all its expeditions by British Exploring (BE). Formed in 1937, the society runs about five expeditions annually to very tough environments mainly for a total of around 200 people aged 17 to 21. Fund-raising is done by those on each expedition and by corporate means; the total staff of the Society is about 6 full-time equivalents but with contributions from many more volunteers. The overall aim is personal development and nurturing of leadership abilities of young people but carrying out good science (under expert guidance) and publicizing it afterward through scientific papers is a key measure of success. Figures 19.1A and 19.1B were

(A)



(B)

Figure 19.1 Work by citizen scientists. (A) An infrared photograph of the Arabian leopard, taken by the noninvasive means of a camera trap. *Panthera pardus nimr* is a critically endangered species—under 250 are believed to exist in the 3.2 m km^2 of Arabia (one-third of the area of the entire United States). (B) shows a male *Tholymis tillarga* dragonfly—never previously recorded in Arabia, found at a shallow pool in Wadi Sayq, Dhofar.

taken on a 2012 expedition to the Dhofar desert areas of Oman, with the active support of the Oman Office for Conservation of the Environment and use of GI systems to map and analyze research results. These show fauna in that area previously unknown to the "outside world."

Increasing Distance Inland from Wadi Mouth →

	A	B	C	D	E	F	G	H	I
Anax ephippiger		1.5%		2.6%		2.2%			
Anax imperator		0.8%			1.3%	1.1%			
Azuragrion nigridorsum						5.5%			
Ceriagrion glabrum	16.7%	21.5%	18.0%	20.5%	17.5%				7.2%
Crocothemis erythraea	16.7%	13.1%	2.0%	17.9%	1.3%	2.2%	6.3%	1.0%	9.3%
Diplacodes lefebvrii		7.7%		7.7%					
Ischnura evansi		0.8%							
Ischnura senegalensis		2.3%		2.6%	10.0%				
Nesciothemis farinosa		1.5%							
Orthetrum chrysostigma	16.7%	18.5%	64.0%	41.0%	7.5%		6.3%	17.6%	18.6%
Orthetrum ransonnetii							6.3%	17.6%	2.1%
Orthetrum sabina	8.3%	4.6%	8.0%	2.6%	8.8%	2.2%			
Pantala flavescens	16.7%	14.6%			3.8%	2.2%	12.5%	4.9%	
Rhyothemis semihyalina		0.8%							
Tholymis tillarga					2.5%				
Trithemis annulata		0.8%	8.0%		10.0%				
Trithemis arteriosa	25.0%	11.5%		5.1%	37.5%	84.6%	68.8%	58.8%	62.9%

0%
<2.5%
2.5-5%
5-10%
10-20%
20-50%
>50%

Survey Sites
A - brackish lagoon
B - vegetated freshwater lagoon
C - estuarine marshland
D - estuarine marshland
E - large temporary pool
F - small temporary pool
G - stagnant temporary pool
H - rocky pools
I - small pool at spring

(C)

Figure 19.1C shows the species composition of nine dragonfly communities in Wadi Sayq. All three figures are courtesy of the British Exploring Society and the Oman Office for Conservation of the Environment.

19.1.2 Areas Where GISS Contributes

Put simply, this approach is built on four big contributions that geographic information science and systems can make:

- Supporting our ability to help discover and share new understandings in the physical, environmental, and social sciences
- From these new understandings, providing the means to help us devise new products, processes, and services that improve the quality of life, especially for the disadvantaged of the world
- Using these to enhance the efficiency of public and private tasks to release resources for other valued things
- Achieving all this in as sustainable a way as possible

19.2 Context: Our Differentiated World

As suggested earlier, the world is highly differentiated and heterogeneous (Section 2.2). If this is true for the physical environment (Figures 1.9 and 19.2), it is at least as true for human societies that are very unequal in wealth, education, and much else. The best single guide to this is probably the World Bank's Development Indicators for the years published from 2008 to 2013. Given the difficulty of collecting reliable, consistent, and up-to-date statistics from 214 countries, some of these will be less good than is desirable. Nevertheless, the picture they paint is a bleak one, if improving in certain respects. And it is clear that, from topography through natural hazards to political systems, economic well-being, and adequacy of food,

Jonas Velin/Getty Images

(A)

Flickr RF/Getty Images

(B)

Figure 19.2 Examples of the world's differentiated physical landscapes—with very different spatial autocorrelation properties of their topography. (A) Wheatlands showing very little variation in elevation. (B) Mount Everest North Face.

our life experiences and opportunities are shaped—and in some cases determined—by geography. For example, our expectation of *how long* we will live differs greatly depending on *where* we live (Tables 19.1 and 19.2); life expectancy is often used as one indicator of life quality. Figure 19.3 shows the highly differentiated local geodemography of Glasgow.

Wealth and consumption are very unequally distributed globally (Figures 19.4 and 19.5). In 2011 Qatar had Gross National Income per capita of US$86,000 in Purchasing Power Parity (PPP) terms, 340 times that of the Democratic Republic of Congo. In 2010 there were 1.2 billion people living on less than $1.25 per day—the definition of extreme poverty. The rich consume massively more than the poor: for instance, electricity consumption per capita is over 13 times greater in high-income countries than in low-income ones. Figure 19.5 shows the consumption disparity by income level. Figure 19.6 illustrates the startling difference in power consumption between North Korea and its neighbors. The poorer you are and the poorer is the country in which you live, the lower tend to be the levels of education attained; this in turn affects much else, including statistics on mortality at birth.

Two important qualifications need to be made: The first is that some dire situations are becoming less so, notably through multinational efforts to reduce extreme poverty (Section 19.6.2) and the growth of some economies, notably the Chinese. The second point is that, despite these overall improvements in certain countries, variations within countries are often widening (notably in wealth and income). This is manifested geographically; for example, most rich people are geographically concentrated within their own countries.

The world is highly differentiated on almost every criterion and at many levels; if it were not, geography would not exist!

Table 19.1 Life expectancy at birth in 8 selected countries. (Source: www.cia.gov/library/publications/the-world-factbook/)

Country	Estimated life expectancy at birth in 2013
Japan	84.19
Singapore	84.07
Switzerland	82.28
Australia	81.98
Afghanistan	50.11
Guinea-Bissau	49.50
South Africa	49.48
Chad	49.07

Table 19.2 Life expectancy at birth in small administrative areas. (Source: World Health Organization, 2008. *Closing the gap in a generation.*)

Small area	Estimated life expectancy at birth
Calton, Glasgow, UK	54
Lenzie North, Glasgow, UK	82
Washington, DC, USA (black only)	63
Montgomery County, Washington Metropolitan Area (white only)	80

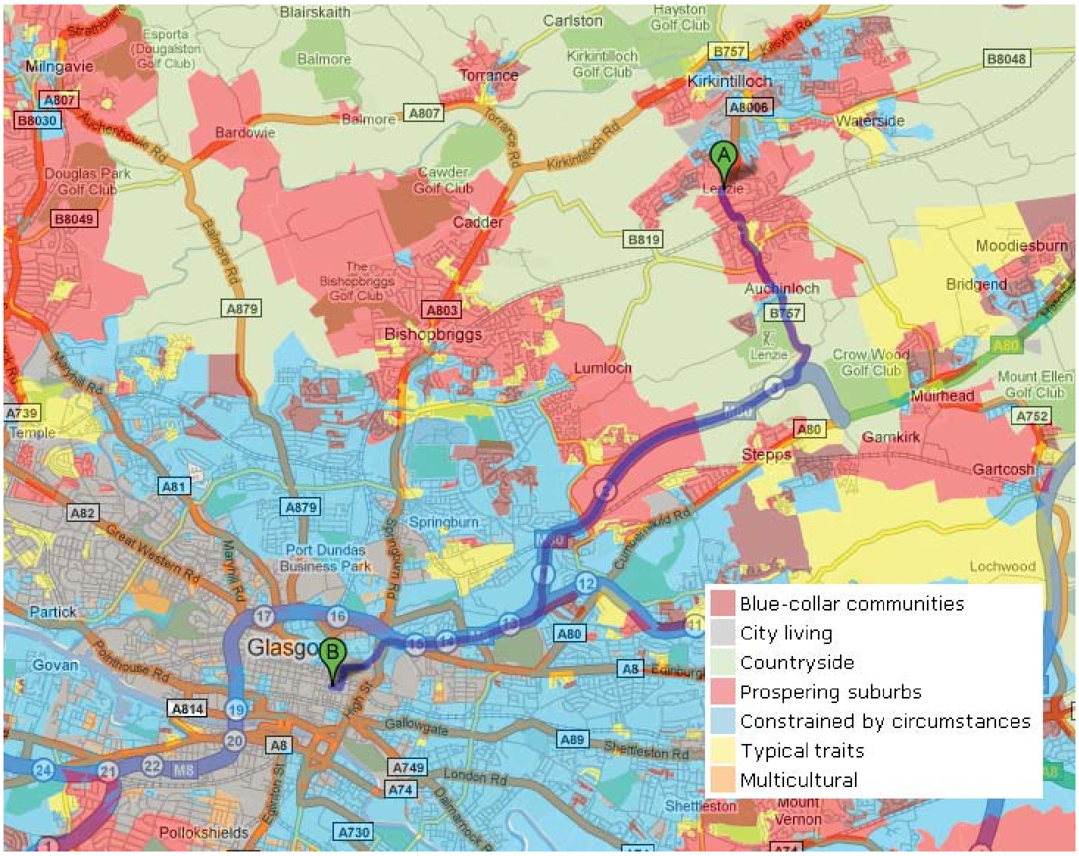
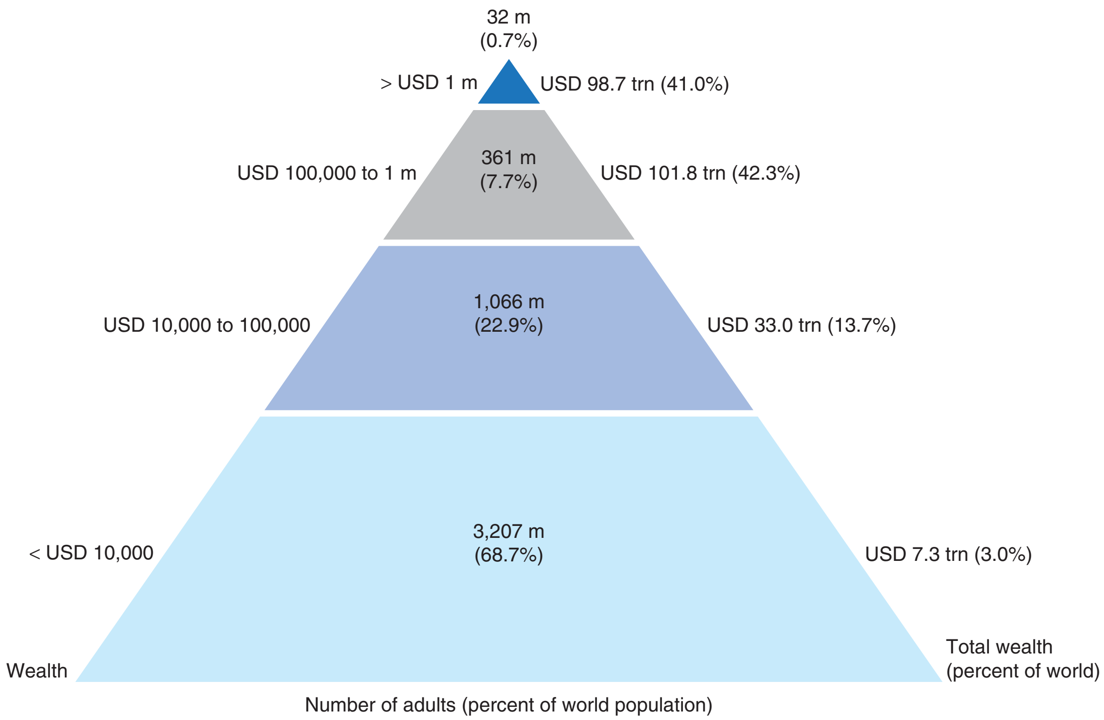


Figure 19.3 The local geodemography of Glasgow, showing the 7.8-mile (12.6-km) route that links communities (A: Lenzie and B: Calton) with life expectancies at birth that vary by 28 years (see Table 19.2). (Background data: Google Maps)

Figure 19.4 The global wealth pyramid: wealth held by adult individuals of different net worth in 2013. Individual net worth is defined as the marketable value of financial assets plus nonfinancial assets, mainly housing and land, less debt.



Source: Anthony Shorrocks, James Davies, Rodrigo Lluberas: Credit Suisse Global Wealth Databook 2013. Copyright 2013 Credit Suisse Group AG

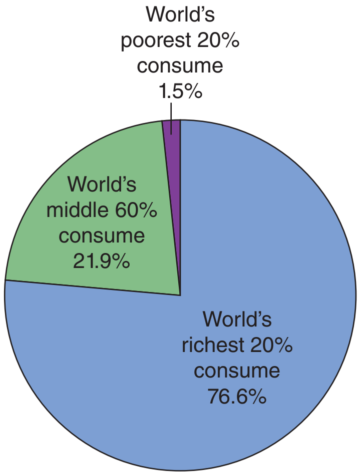


Figure 19.5 Shares of the world's private consumption in 2005 by wealth.

19.3 Context: Our Interdependent World

Interdependency operates at many different levels. For instance, there is clearly much interdependency at the local level between shortage of food, access to facilities like fresh water and sewage, and disease. It operates at all geographic levels: At the regional level the 2004 Indonesian tsunami killed around 225,000 inhabitants of several countries around the Indian Ocean.

Just as striking are the interdependencies that arise from human systems, notably financial and trade ones. The globalization of business has had major effects, some beneficial, and has led to big changes in the structure of employment and hence to human geography. Much employment in the developed world has moved out of manufacturing into service provision; low-margin manufacturing and many commoditized services have become the preserve of low-wage economies. Global firms or partnerships have been able to outsource or to move work offshore through the advent of the Web; the creation of workflow software has enabled collaborative working across the globe including integrated supply chains. The consequences of all this have included growing urbanization, international migration, and increasing global competition for talent and innovation.

Part of the taken-for-granted world that undergirds all this is the global trade and financial system. Over a 50-year period, trade between nations has multiplied hundreds of times. Seasonal availability was all but eradicated as we imported exotic flowers (and much else) by air from countries on the other side of the world. Measures of the world's wealth based on GDP grew dramatically between 1945 and 2006. Underlying all that was an increasingly globalized financial system in which stocks, commodities,

Figure 19.6 Differences in consumption of power in different countries: North Korea is a black area compared to its neighbors in this nighttime imagery collected by the Suomi National Polar-orbiting Partnership (Suomi NPP) satellite. The image has been processed to remove auroras, fires, and other stray light to emphasize the city lights.

foreign exchange, and much else were traded constantly, especially through the three major financial centers in New York, London, and Tokyo (their success owing much to their locations equally distributed around the world and permitting 24-hour trading). The entire system provided credit. Without credit, societies cannot change, business grow, or individuals acquire property. Technology played a major role: The ability to move funds near-instantaneously across the world in response to opportunities large and small enabled speculators to profit from minute differentials in pricing.

All of this, however, has led to bouts of massive instability. The financial boom, followed by a crisis from 2007 on, had dire consequences. In the United States, and especially Europe, economies were severely hurt and the lives of millions of individuals disrupted: in Spain and Greece for example, unemployment among those aged under 25 reached over 50% in 2013. If nothing else, all this demonstrates that global interdependency on most fronts—economic, environmental, and much else—is a fact of life, that virtually everyone on Earth is affected by it, and that consistent stability is an illusory concept. But the impacts are not the same everywhere: geography matters. To be successful we need a sound process that takes into account our knowledge, analytical skills, tools, and information.

Today's world is tightly interlinked: A disaster in one geographic area can trigger global impacts.

19.4 The Process

The problems on which we have focused (Section 19.5) are bewildering in the range and linkage of their causal factors and their interdependencies. The feedback loops involved are only partly understood. Some of the factors are not even easily quantifiable. And the situation is often dynamic. All this indicates we need some sort of process that enables us to prioritize our actions and a recognition of the uncertainty involved.

What follows is aimed at active GISS professionals. The essence of working in GISS is that we are committed to the use of evidence to underpin decisions. Evidence must be assembled from the best available sources; tested to ascertain its veracity; used in defined ways with tools whose internal mechanics are well understood; and shared so that our findings can be tested and replicated by others. In short, we must operate as scientists. The nature of the Grand Challenges outlined later enables those working with GISS to make particular contributions because:

- Many problems are manifested initially through geographical variations.
- Studying the geographical manifestation can help us to propose and test causal factors and hence identify possible solutions to the problems. Even if causal factors cannot be isolated, we can compute correlations between GI variables as a second-best outcome (see Box 17.2 on Big Data).
- The human systems through which we have to tackle problems are normally geographically structured (e.g., administrations that control access or provide resources or that need persuading).
- There has been a significant change, at least in Western democracies, toward the requirement for quantifiable and published evidence to support and justify policy making. Audit trails of analyses are a crucial part of such a way of working, and integrated GI systems can provide such audit trails.

As shown in earlier chapters, GISS has developed greatly in the last 30 years and provides demonstrable benefits:

- The integrative capacity of GI technology, enabling us to link multiple datasets and generate added value, analyze the results spatially, then redo the whole operation at short notice whenever the situation changes or we wish to vary our assumptions.
- Use of the same GI system tools at local, regional, national, and global levels simplifies linking models operating at different levels of abstraction.
- GI systems' growing modeling capability now forms part of common tools for data mining, mathematical modeling, and simulation. These tools are central to work in sectors from retailing through financial services to health care, environmental modeling, and transport planning and design.
- Superb visualization and user interaction capabilities, especially in regard to a widely appreciated communication medium—mapping.
- Our ability and willingness to share data, ideas, and concepts, increasingly on a global basis via a combination of workflow software, common standards, interoperability, and a GI community where mutual support is commonplace.
- A growing awareness and acceptance of the value of GI systems among policy makers/government leaders, public servants, and the business and education communities.

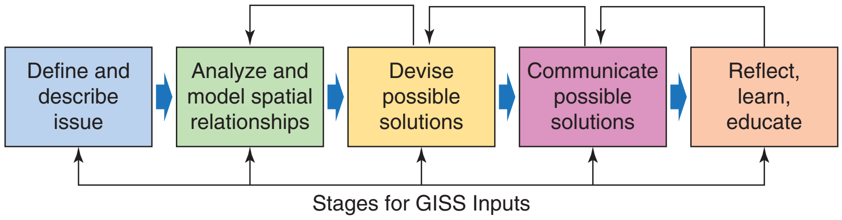


Figure 19.7 Simplistic illustration of the process by which inputs by GISS professionals can contribute to tackling the Grand Challenges. Note that this ignores many feedback loops and other complications; GI systems have a more limited area of contributions.

We can best structure our potential contributions to the Grand Challenges under the simple model of different stages shown in Figure 19.7. Rarely, of course, is such a process so linear in practice: this ignores many feedback loops and the "soft factors" involved in innovative resolution of problems. But it will serve for present purposes.

19.4.1 Stage 1: Defining and Describing the Issue

This seems basic, even prosaic, but defining the objective and describing a problem are fundamental to success. In some cases we simply seek to know what (e.g., the type of geology or what is the most common disease) at a particular place or where specified incidences exist (e.g., rocks of type *X* or a high prevalence of certain diseases are to be found). In other cases we will wish to compute the trafficability of terrain or the distribution of wealth by combining multiple datasets, some of them proxies for what we would really use if only they were available. In a Big Data approach we may however simply let the computer find high correlations among many datasets and then seek to isolate ones of interest for further analysis.

To do this involves assembling and reusing any possibly relevant data from whatever sources are available—internal to an organization, from national or international statistical bodies, from commercial sources, or from the Web. To maximize the reliability of our answers this necessitates assembling and integrating the data in as consistent, documented, and professional a way as is possible in the circumstances. In addition, making them as widely available as possible to others with an interest is potentially invaluable because it provides for independent scrutiny and critique: Where data are widely used they become of higher quality as shortcomings become identified and better investigations ensue. We recognize that the confidentiality of work in the commercial sector and the need to be first to market sometimes precludes such widespread sharing. Yet in today's service-driven economy, the speed of innovation is such that it is often churlish, time consuming, and ultimately pointless to become totally consumed by issues of intellectual property rights. This is acknowledged, for example, in commercially funded work of the Willis Research Network. Willis is a global commercial insurance organization that has successfully embraced an open publication approach involving more than 50 universities worldwide.

19.4.2 Stage 2: Analyzing and Modeling Spatial Interrelationships

Many examples of spatial analysis have been presented in this book. Beyond the simple queries such as "where is . . ." we normally wish to find the root causes of problems. But the reality is that detailed analysis of correlations and apparent relationships, of leads and lags between changes in different variables, and of changes in these relationships through time and over space are required if we are to go beyond superficial judgments.

As a result, some of the team members at least must be mathematically and statistically literate and expert in managing and exploiting data. Modeling drought frequency on a global basis or even demonstrating the relationship between the incidence of diarrhea and the availability of piped water in Africa is not a trivial endeavor. It is all too easy to create false positives and false negatives in circumstances where data at different spatial and temporal resolutions and different accuracies are involved.

19.4.3 Stage 3: Devising Possible Solutions

To devise possible solutions requires not only technical GI skills but also much domain knowledge. It is rare that one individual has both, unless someone has been trained in a relevant substantive discipline and then been immersed in GI systems. So normally this stage requires effective teamwork and continuing challenge. The criteria for deciding what is a possible solution involve not only sound analysis steered by the set objectives but also whether the solution is deliverable, the risks (e.g., the possible unintended consequences of adopting it), and its cost and ease of implementation.

19.4.4 Communicating Results and Possible Solutions to Decision Makers

The communication of the results of analyses and of possible solutions (including options) is critical to success as Section 18.1 illustrates. The skills of the decision makers may be very different to those of the GISS specialist. It is essential that those communicating results to decision makers are skilled in verbal and presentational skills as well as technical ones. The communication must be made in terms that the decision maker clearly understands and also made available in written form. The need to ensure that the decision maker knows enough safely to brief the media (where required) is essential.

Although this is generic to dealing with the challenges we have described earlier and will develop in Section 19.6, this counsel of perfection is difficult when dealing with emergencies. The role of small, technologically accomplished, and savvy organizations (such as MapAction; Section 19.6.5) in natural disasters has proven hugely important. Fast in action and less encumbered by bureaucracy than many state organizations, they typically exploit whatever information is available. They succeed only insofar as they do not alienate the local authorities who determine access to the area (compare this with the Bowman expedition: Section 1.5.5). This means that they too have to be able to communicate the nature of the problem to those authorities in a way that minimizes misunderstandings, facilitates discussion, and enables effective decision making—but in a truncated timetable.

19.4.5 Stage 5: Reflect, Learn, and Educate

After any project we must review what happened, the things that went well, and those that did not. This is an essential part of learning and continuous improvement. But there is a much wider issue about education for, in our view, the world of education needs to evolve substantially because of the rapid changes in technology, the diverse challenges we face, and globalization of enterprises. Ideally, we want technologically alert individuals who have specialist skills and also broad understanding of many other facets which determine success—the so-called T-shaped people.

For the past several decades, however, it has been standard practice to think of GI systems education as a process of training professionals to acquire substantial skills in manipulating the user interfaces of GI systems and (sometimes) in understanding the science that lies behind them. But today many of these GI system capabilities are familiar even to young children, who have become accustomed to the user interfaces of Google Maps and similar services. So we need to shape our education systems to a very different world full of digital natives. What skills, if any, are needed by a general public that is now increasingly able both to produce and to consume geographic information? Is there any point in teaching navigation when our handheld GPS receivers do it all for us (Section 10.3)? Do we need to carry out fieldwork if or when augmented reality can deliver an adequate understanding of parts of the real world with minimum cost and reduced risk? Our conclusion—on which this book is based—is that much greater levels of understanding of science principles and also wider societal issues are required than in the past. In particular, one of the fundamental forms of human reasoning—spatial thinking—is given little attention in the school or college curriculum. Yet there is abundant research to show that early attention to these concepts can lead to improved performance in a range of subjects. The delivery mechanism for all this may involve a different educational paradigm to that in place until now. We note the dramatic innovations in how education can be delivered and the form it takes through such developments as the Khan Academy and MOOCs (massive open online courses).

Traditional GI system education needs to be replaced by more science-based curricula.

In the longer term such education can only be achieved through schools and through inspiring teachers. But official recognition helps: in England, for instance, a revision of the national curriculum for Geography in 2014 made clear that all pupils must be ". . . competent in the geographical skills needed to . . . interpret a range of sources of geographical information, including maps, diagrams, globes, aerial photographs and Geographical Information Systems (GIS)." This was mandated for all 11- to 16-year-old pupils in all state-funded schools.

Finally, we need all those who are involved in GISS to become ambassadors for what we can contribute. This is easiest where we converse with those commissioning work. Beyond those, however, we have a need to reach the general public. To do so requires recognizing that our technical lexicon is a foreign language to others and requires us to use their own language to inform or persuade them.

19.5 The Grand Challenges

There are many different views on the most important challenges facing humanity: some might point to the growth of urbanization and its consequences. Whereas only 13% of the world's population lived in cities in 1900, over 50% now do so, creating particular hazards (and opportunities). Indeed almost all the Grand Challenges we describe are encountered in the world's major cities.

There is no shortage of problems that GISS experts can help to ameliorate! An obvious set was formed at the global level through the adoption of the Millennium Development Goals (MDGs) following the Millennium Declaration in 2000 by all United Nations Member States. Progress in meeting the Goals is tracked annually by the UN against 21 targets and 60 indicators addressing extreme poverty and hunger, education, women's empowerment and gender equality, health, environmental sustainability, and global partnership (see, for example, mdgs.un.org/unsd/mdg/Resources/Static/Products/Progress2014/English2014.pdf). A new set of goals—the Sustainable Development Goals—is likely to succeed the MDGs when the latter expire in 2015. The 2013 World Bank Development Indicators Report (see Further Reading) summarizes progress since 1990. This has been good on certain indicators—for example, reducing numbers in extreme poverty by 100 million since 2008—but 1.2 billion are still in such poverty.

Another assessment of global risks—and hence Grand Challenges—is given by the World Economic Forum, which seeks to look up to 10 years ahead. Quantifying most risks more than 5 years ahead is extraordinarily difficult in any meaningful way. Given the periodicity of many natural hazards, this often makes anticipation beyond that period informed speculation at best, but is still vital because lead times for remedial action often take many years.

Some Grand Challenges are quintessentially national or subnational in scope. An example of a (rarely public) National Risk Register is set out in Table 19.3. Even where such risks of national and international importance—such as climate change—are identified, anticipation of the detailed threat, adaptation, and immediate action needed to remedy a disaster are often local. In the United States, for instance, land use, zoning, much construction, and transport are typically under state or very local control. This provides many opportunities for GISS professionals to achieve benefits in planning, communicating threats, and carrying out operations efficiently.

Even where challenges, for example, from climate change, are national or international, anticipation, adaptation to, and remedy of disasters are often largely local—and GISS expertise can help.

Table 19.3 UK high-level National Civilian Risk Register as of March 2013. (Source: Beddington, J. B., *Threats and Opportunities—the scientific challenges of the 21st Century*. www.foundation.org.uk/events/pdf/20130206_Beddington.pdf)

		Relative likelihood of occurring in the next 5 years				
		Low Between 1 in 20,000 and 1 in 2,000	*Low-Medium Between 1 in 2,000 and 1 in 200*	*Medium Between 1 in 200 and 1 in 20*	*Medium-High Between 1 in 20 and 1 in 2*	*High Greater than 1 in 2*
Relative impact	*5 Catastrophic*		Catastrophic terrorist attacks		Pandemic influenza	
	4 Significant			Coastal flooding Effusive volcanic eruption		
	3 Moderate	Major industrial accidents	Major transport accidents	Other infectious diseases Inland flooding Smaller scale CBR attacks	Severe space weather Low temperatures and heavy snow. Heatwaves	
	2 Minor			Zoonotic animal diseases Drought	Explosive volcanic eruption Storms and gales Public disorder	
	1 Limited			Non-zoonotic animal diseases	Disruptive industrial action	

Our own selection of challenges, described in the following section, overlaps with but is not identical to governmental views. Our aim is to describe the challenges in such a way as to highlight interdependencies and to identify where, with our skills, knowledge, and technologies and determination, we GISS practitioners might make a contribution to ameliorating them.

19.6 Grand Challenges Whose Effects We Can Help to Ameliorate

19.6.1 Population Growth

Reaching the first billion population took almost all human history; the second billion took just over a century up until 1930; whereas the third and fourth billions took 30 years and 15 years, respectively. The global population as of 8 October 2014 was estimated by the U.S. Bureau of Census to be 7.197 billion.

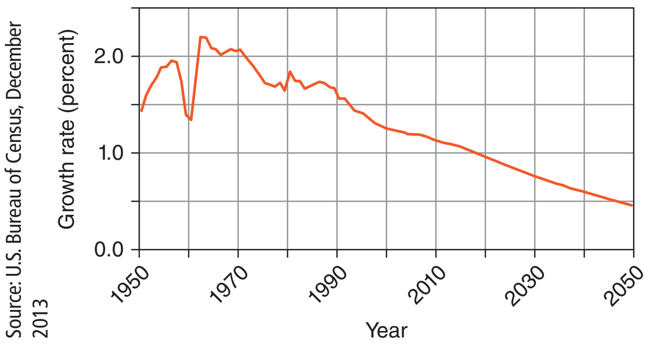
Eighteenth-Century views that population growth would outrun food supply have been averted or delayed by crop breeding, technological improvements, and other factors. But the problem of feeding the world's population remains. The size of global, national, and local populations, and economic or political migrations between them, manifestly drives consumption of food and many natural resources, some of which are finite though in practice may be substitutable. Furthermore, positive feedbacks occur: If any of the inequalities described in this section can be rectified, consumption will increase still further, placing even greater stresses on the environment and its sustainability.

The good news is that the *rate of increase* of global population has been falling (Figure 19.8). Until the publication of a new UN report in September 2014 many demographers expected the total to level off to somewhere under 10 billion after the middle of the Twenty-First Century, that is, with about 35% more people on the planet than now. Much of the net increase will occur in the poorest areas of Africa and Asia (Figure 19.9). The new report, however, uses a Bayesian probabilistic methodology and suggests world population is unlikely to stop growing this century. There is claimed to be an 80% probability that world population, now 7.2 billion, will increase to between 9.6 and 12.3 billion in 2100. Notwithstanding this new development, the factors seemingly influencing a deceleration of growth as compared to previous decades are highly relevant for this epilog: they include the consequences of better sanitation and health care, increased education and employment opportunities for women, and the availability of family planning and contraception.

The geography of population change, as well as population density, is far from uniform. In many developed countries such as Germany and Russia, population growth is zero or negative. This has serious implications for sustaining the tax base to provide public services, providing enough labor for commerce, or supporting the increasing numbers of aged people.

In a narrow sense, international migration provides a simple solution, and it more than doubled between 1970 and 2000, with the largest proportion of migrants moving to countries in the developed world. In Europe, for example, almost all population growth is due to in-migration and the fecundity of the new arrivals. However, political tensions frequently arise from such migrations and from the changes they make in local culture and values. It is also the case that migrants are often disproportionately the most able and skilled in their country of origin, particularly given that developed countries place entry restrictions on in-migration of low-skilled workers. This means that migration ensures that the origin countries themselves usually become less well equipped to

Figure 19.8 World population annual growth rates 1950–present and projected to 2050.



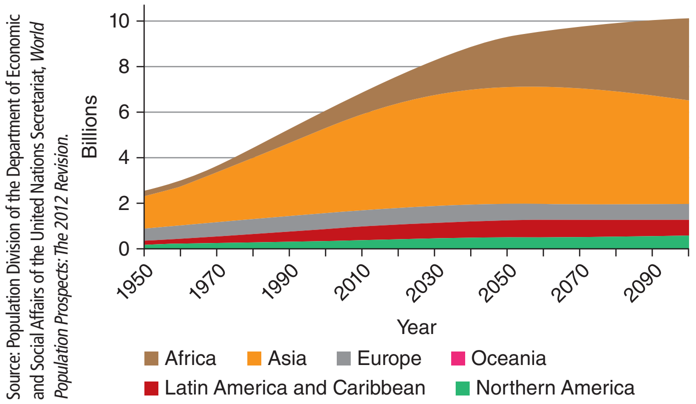


Figure 19.9 Past and projected total global population broken down by major regions.

develop, thereby further accelerating the differentiation between rich and poor countries.

Population migration is a major contributor to the size and average age of many national populations, with both benefits and problems.

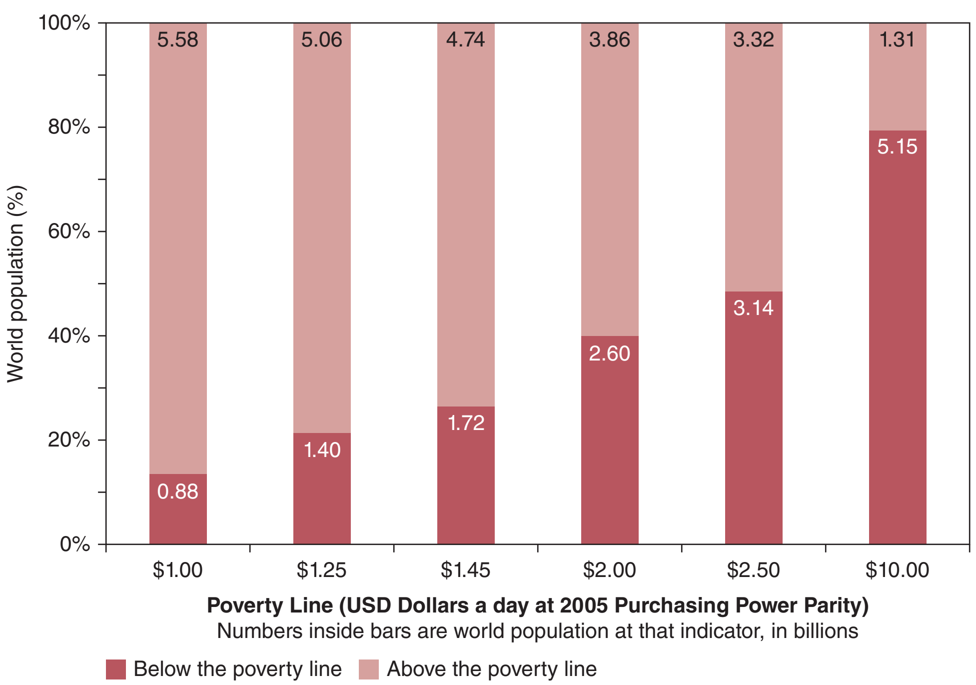
In principle, GI systems provide an excellent instrument for measuring the movement flows and the stock of population. However, measuring people numbers is becoming more difficult as response rates to censuses and surveys decline in most countries (Section 17.3.1.1) and proxy methods (e.g., remote sensing) remain less reliable (see Section 17.3.1.4). What works in some societies (e.g., the population registers of Scandinavian countries) will not be acceptable or effective in others. Thus there is a major challenge for scientists and GISS and other computer specialists to produce better methodologies—almost certainly based on linkage of many different kinds of data together—for measuring populations and changes to them over time (see Box 1.2).

Once again, however, the use of GI systems to measure and represent what is need not be the end of the story. Understanding *why* people move, *what* entices and constrains them, and *how* land-use patterns and social structures change as a consequence of population change is a major challenge for social scientists and GI experts. Together, GISS leverages the benefits of better data and modeling tools that are necessary to predict the impacts of changed laws, barriers, or incentives. Without this, deep understanding of migration in particular and population change in general is impossible, and policies to cope with them are likely to be ill-founded.

19.6.2 Poverty and Hunger

Poverty is a difficult concept to measure in a meaningful way, but the UN and other bodies have devised widely used thresholds based on measures of average personal income adjusted for purchasing power parity. Figure 19.10 shows how the numbers in poverty in 2005 varied depending on the income threshold used. Thanks to much effort, extreme poverty—experienced by those living on $1.25 per day or less—has more than halved to 22% compared with the situation in 1990. Yet almost half the world—nearly 3 billion people—still live on less than $2.50 a day, whereas about 5.2 billion people live on incomes of less than $10 per day. In addition, over 80% of the world's population lives in countries where income differentials are widening. Numerical comparisons are valuable: Box 19.2 presents some further, selected, grim figures concerning the state of global poverty and inequality. Mapping using GI systems adds greater richness and diversity to statistics such as these. GI science can further enrich the representation of geographic variation. For example, Figure 19.11 compares

Figure 19.10 The global proportion and numbers of people in poverty in 2005 when that is defined at different income thresholds.



Applications Box 19.2

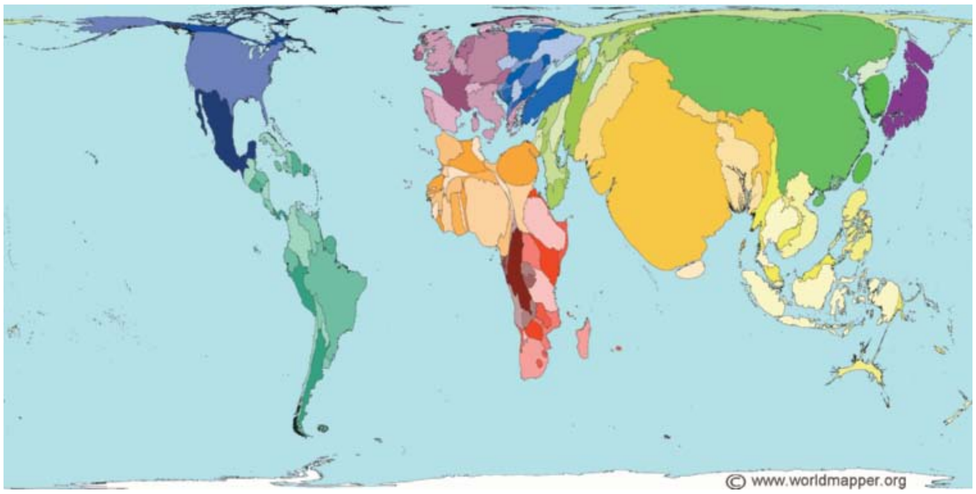
Poverty and Inequality

- Almost 3 billion people live on less than $2.50 a day.
- The poorest half of the world's adults, 3.5 billion people, own a total of about $1.7tn worth of assets (about $400 per adult). That is similar to the wealth owned by the world's richest 85 people. Income disparities between rich and poor in most countries are widening.
- Nearly a billion people entered the Twenty-First Century unable to read a book or sign their names.
- Less than 1% of what the world spent every year on weapons was needed to put every child into school.
- One billion children live in poverty (1 in 2 children in the world), 640 million live without adequate shelter, 400 million have no access to safe water, 270 million have no access to health services, and 10.6 million died in 2003 before they reached the age of 5 (or roughly 29,000 children per day).
- According to UNICEF, 22,000 children die each day due to poverty.

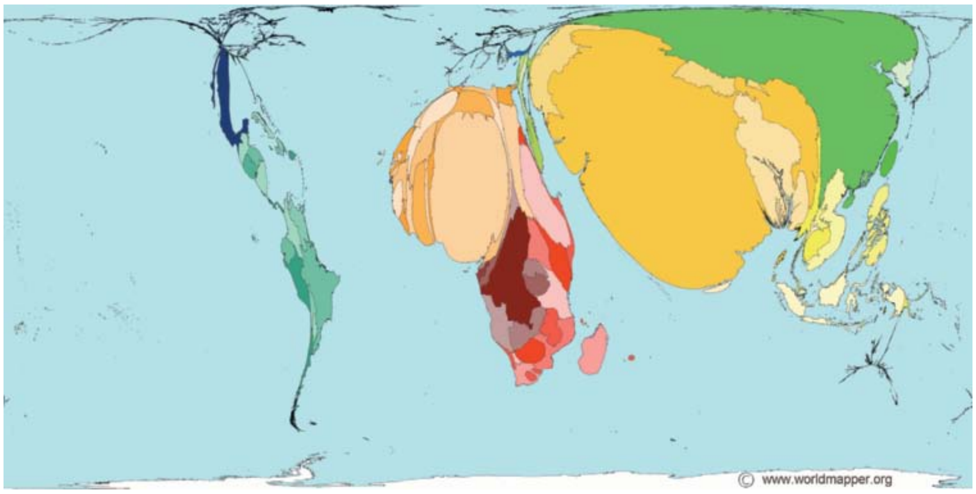
Source: www.globalissues.org/article/26/poverty-facts-and-stats and policy-practice.oxfam.org.uk/blog/2014/01/working-for-the-few.

Figure 19.11 The geography of human poverty. (A) The size of each territory shows the relative proportion of the world's population living there. (B) Territory size shows the proportion of all people living on less than or equal to US$1 in purchasing power parity a day in 2000. (Reproduced under a Creative Commons License. © Copyright Sasi Group (University of Sheffield) and Mark Newman (University of Michigan).)

(A)



(B)



a cartogram (Box 11.5) showing each country's proportion of the world's population (A) by the area allocated to it with another (B) where the country's area is scaled in proportion to its fraction of the global population living there which is in extreme poverty (i.e., living on $1 or less a day).

The combined wealth of the world's seven richest people exceeds the gross domestic product of 567 million people in 41 indebted countries.

Poverty also generally means poor levels of nutrition or, in rural areas at least, dependence on one crop. Failure of that crop can mean starvation and death or enforced migration. Food security is therefore a key risk faced by many people worldwide. Research published in mid-2013 by the Institute on the Environment at the University of Minnesota highlighted the threat of growing global hunger. It is widely accepted that to feed the projected global population growth by 2050, global food production will need to increase between 60 and 100%. The researchers' results suggest that, based on current trends, production of maize, rice, wheat, and soybeans will increase only by 38 to 67%. This does not take into account possible consequences of climate change.

GISS professionals can contribute to our understanding of poverty and inequality and the scale of these (see Figure 19.3). We do this through our ability to integrate, analyze, and portray multiple datasets and to support logistics and communications through the use of our tools. Thus the Minnesota researchers argued that the approaches most likely to cope with a looming agricultural crisis are more efficient use of current arable lands and spreading best management practices—areas where precision farming utilizing GPS and GI technology can be hugely effective. Our abilities to do this in practice remain constrained by data that are of highly variable quality and inadequate modeling tools. Nevertheless new civilian developments like the use of low-cost unmanned aerial vehicles (UAVs) to collect timely local data (Section 17.5.3) and experience of the use of GI systems in developed countries suggest that we can develop better evidence-based approaches. Implementing them on a widespread scale would inevitably require us to engage closely with political and bureaucratic processes.

19.6.3 Human Health

The spread of disease, access to care, and the prevention and treatment of illness are all unevenly distributed across the globe, partly related to poverty. The substantial progress in overall global health improvement over recent decades has, however, been deeply unequal, with convergence toward improved health in a large part of the world but with a considerable number of other countries falling further behind. Every year there are 350–500 million cases of malaria in the world, with 1 million fatalities: Africa accounts for 90% of malarial deaths, and African children account for over 80% of malaria victims worldwide. Furthermore, there is now ample documentation, which was not available 30 years ago, of considerable and often growing health inequalities within countries. Even within a relatively prosperous country such as the United States, for example, cancers of various types are much more prevalent in some places than in others.

There are three areas in which GISS interacts closely with human health. These are

- Public health policies and campaign activity to prevent illnesses becoming rampant and to encourage action by individuals to stay healthy.
- Analysis, modeling, and understanding of patterns of disease.
- Operating the health system. Because health systems worldwide cost between 2 and 19% of total GDP (Table 19.4), it is crucial that they are operated effectively and efficiently.

19.6.3.1 Supporting Public Health Planning

Improving the level of public health has benefits for the individual (better personal health) and for the nation (reducing the need for and cost of acute treatment in hospitals). Examples of highly effective campaigns of this sort include the reduction in smoking and associated cancers, the reduction in incidence of malaria through use of insecticide-treated mosquito nets, and reductions in mortality at birth through enhanced education—especially for women. By and large such campaigns work through increasing the awareness of risks, changing attitudes, beliefs, motivations, and social norms. But to make them effective, such campaigns must be based on an understanding of current morbidity patterns and be targeted based on a detailed socioeconomic understanding of the geography of different populations.

Public health planning saves lives and money. It works by increasing awareness of risks, and changing attitudes, beliefs, motivations, and social norms.

A simple example is given by the great variations in the impact of certain cancers (see, for example, Figure 13.6)—largely because some groups present themselves for treatment much earlier than others. This occurs even where treatment is free. Another example relates to the growth of obesity in many countries. GI systems have been used to analyze how different environments present people with different opportunities to be healthy and hence can lead to different health behaviors and health outcomes. The "obesogenic environment" has been defined as one involving proximity to fast food. Increasingly studies are seeking to measure the impact of a wide range of environment factors. These include alcohol provision, food, green space, and places to do physical activity, right through to ways of characterizing urban form as complicit in population health. Bringing all this together in GI systems is an obvious benefit.

19.6.3.2 Analysis and Modeling of Disease Patterns
Many studies of the geographical variations in morbidity and the treatment they receive have been made. Perhaps the best-known work is that by the Dartmouth Institute of Health Policy and Clinical Practice and published in the Dartmouth Atlas of Health Care. The geographical variations apparent in Figure 19.12 strongly suggest the need for more detailed analysis of multiple datasets to understand the factors causing the variations.

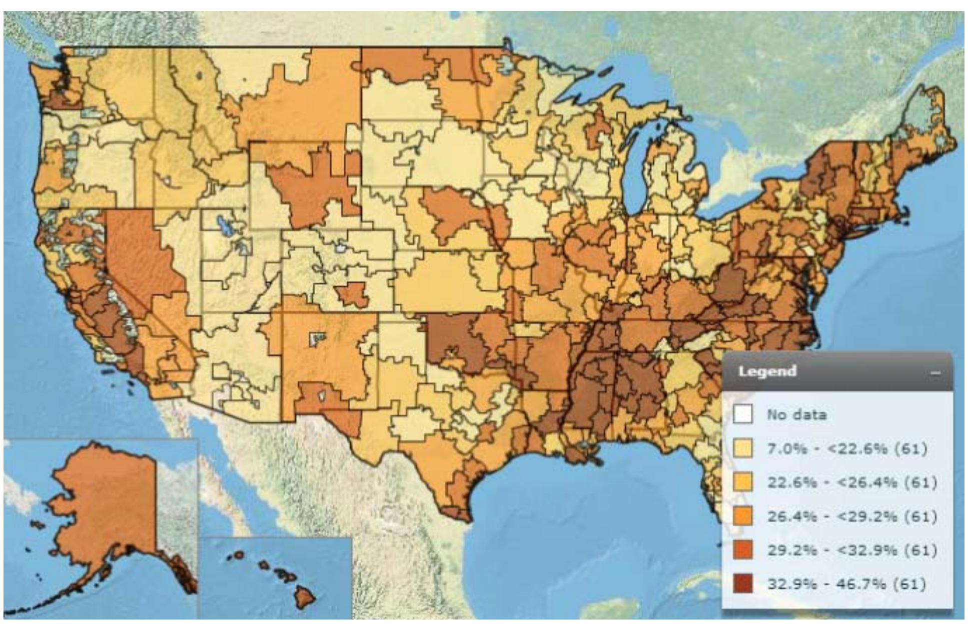
Big Data approaches and GI technology have been argued to be effective in mapping the spread of certain diseases even before they can be detected by official mechanisms (Section 17.3.1.4). Typically, however, research to identify causes—and hence identify effective treatments—requires access to individual data (Section 17.3.1) and, ideally, geocoded data from large longitudinal studies.

Central to understanding of disease patterns is also the need to examine trends through time as well as geographic patterns. As a coarse spatial resolution example, studies have shown that populations in Spain, France, and Italy all suffered increased rates of prostate cancer from the 1980s; Spain showed the lowest increases. Incidence started to rise around 1985 in France and after 1990 in Italy and Spain. Age-adjusted mortality increased until the late 1980s in all these countries, then declined in France and Italy, but not in Spain. Younger people showed a much higher rise in incidence than the elderly. Why such temporal differences occurred in adjacent countries is a serious research question.

Modeling the likely course of future pandemics is an exercise in applied geography.

The most pressing clinical health challenge of our times is perhaps the study of past pandemics and preparation for forthcoming ones. The world has suffered six pandemics in the last 120 years. For three years from 1918, between 20 and 100 million individuals worldwide were killed by the so-called Spanish Flu—many of them healthy young adults. More died in this pandemic than in World War I. It has been estimated that there is a 65% chance of a pandemic within the next 20 years. Because of the much greater extent of international travel and expansion of high-density urban environments, the spread of a new virus strain for which there is as yet no protection could be devastating—hence its appearance in the

Figure 19.12 The percentage of cancer patients who died in hospitals in the period 2003 to 2007 by Hospital Referral Region. All rates are adjusted with the following patient level characteristics: age, race (black/nonblack), sex, cancer type, and noncancer chronic conditions.



Applications Box 19.3

Eyam's Self-Sacrifice and the Black Death

Eyam is a small village in Derbyshire in England. Bubonic plague was discovered there in August 1665. The source of the infection was fleas in a bundle of cloth delivered from London to the tailor. On the advice of the local rector, villagers chose to isolate themselves, staying within the confines of the village in order to minimize the spread of the disease to nearby areas. About three-quarters of the village population perished, but deaths in the surrounding area were less frequent.

UK national civilian risk register in Table 19.3. Unsurprisingly, therefore, great effort is being put into rapid identification of the location of outbreaks of infectious diseases—crucial to containment or remedial action. This response requires good information networks and the ability to aggregate information geographically and report different aggregations routinely and speedily, to different audiences. Much of this is essentially an exercise in applied geography in which GI systems play an important part. It also, however, requires suspension of belief in economists' "rational expectations" about human behavior. These are not always a sound basis for modeling: Not all individuals or groups behave selfishly (see Box 19.3).

19.6.3.3 Operating a Health System

As we said earlier, health systems are expensive and becoming more so. The World Bank estimated that the median cost of such national health systems in 2011 was 6.4% of national GDP. Table 19.4 shows some of the extremes. Such costs have major impacts on national taxation and influence the level of poverty when the services have to be paid for by poor people. Effective and efficient treatment of patients is therefore a management task as well as a clinical one.

In some countries, health costs are greater than total education and defense costs. GISS professionals can support more effective health management.

Recent studies have begun to show that huge geographical variations exist in costs of treatment even within a single country. They suggest means by which these can be reduced, while ensuring quality of treatment is maintained. This applies everywhere, not least in the United States, which spends some $2.1 trillion annually on health care. According to the McKinsey consultants, this is $650bn more than would be expected in taking into account the whole U.S. economy. In *Health Services Research* in 2009 Mays and Smith argued that "On balance, very little empirical evidence exists about the extent and nature of geographic variation in public health spending [in the USA]." They analyzed community level variation and change in per capita public health agency spending between 1993 and 2005 in the 2900 health agencies in the United States. Using multiple regression models with panel data, they estimated associations between spending, institutional characteristics, health resources, and population characteristics. They showed that the top 20% of communities had public health agency spending levels over 13 times higher than communities in the bottom quintile. Most of this variation persisted even after adjusting for differences in demographics and service mix.

Various other studies, notably by the Dartmouth Institute for Health Policy and Clinical Practice, have also shown that costs of hospital health care vary greatly by area in the United States. Figure 19.13 shows how the average costs of surgery in the last two years of life have varied by a factor of four. Moreover, researchers found that high costs are not always associated with higher quality of treatment. The Dartmouth approach was to ask how much might be saved if all regions could safely reduce care to the level observed in low spending regions with equal quality. They made estimates ranging from 20–30%,

Table 19.4 The costs of national health systems as a percentage of national GDP—some selected examples from a World Bank analysis (Source: data.worldbank.org/indicator/SH.XPD.TOTL.ZS?order=wbapi_data_value_2011+wbapi_data_value+wbapi_data_value-last&sort=desc)

Country	% of GDP
USA	17.9
Netherlands	12.0
France	11.6
Cuba	10.0
UK	9.3
South Africa	8.5
China	5.2
India	3.9
Myanmar	2.0

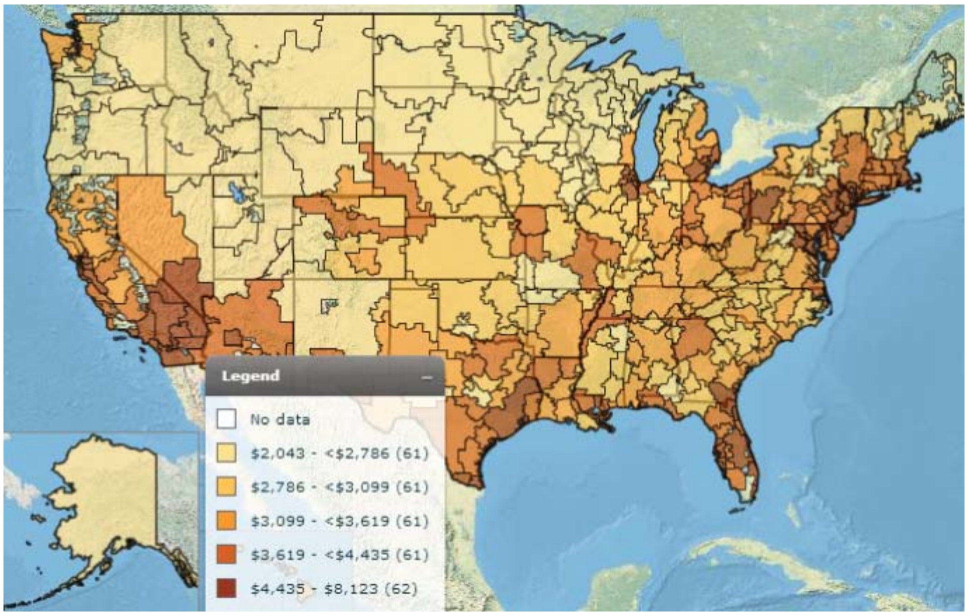


Figure 19.13 Total payments for physician visits per decedent during the last two years of life for the period 2003–2007; by Hospital Referral Region.

but viewed these as an underestimate given the potential savings even in low-cost regions. Such colossal geographical variations are certainly not restricted to the United States.

Where competition is permitted in national health systems, the use of GI systems to map referrals from physicians to different hospitals, often broken down by groups of types of illness and the flows of patients (and hence money), is now commonplace. These support marketing functions and strategic decisions on the hospital's business model.

Central to all health service activity is the need to maintain confidentiality of patient details. The publication of mapping of individual-level data can disclose such confidential data (e.g., a patient suffering from sexually transmitted disease). Figure 18.2 shows how a percent volume contour associated with a kernel function (Section 13.3.5) can be used to represent the density of features within a neighborhood, avoiding disclosure of the locations of any individual with a specific morbidity—hence preserving privacy.

A common feature in the developed world is the rapid increase in use being made of emergency facilities in hospitals. This overloads them and is very expensive, especially if the patient is being admitted on a "just in case" basis. Sophisticated geographically based "spatial hurdles" modeling of factors contributing to the overcrowding is becoming more common. This models the different effects of proximity, ethnic differences, private health insurance, and other factors on access to emergency departments and suggests solutions based on 24-hour community health facilities.

The World Health Organization (WHO) has argued that there are several main causes of ineffective health treatment: Poor people have the least access to health care and leave treatment to the last moment because they cannot easily pay for it. Many health services for the poor are highly fragmented and thus provide poor service, often where hospital-acquired infections flourish. The WHO is calling for the redirection of available resources toward the poor and toward primary rather than expensive tertiary services, that is, toward the local everywhere. This presupposes that we can identify the highest-priority areas for such support and create systems that are efficient and effective. Use of GI systems to describe the geographies of need and identify good access points could be a good contribution to a more equitable health system.

Many of the Grand Challenges—poverty, disease, hunger—are closely connected.

Given their impact on the experienced quality of life and the costs of treatment, health issues form one of the most urgent and compelling areas in which GISS can contribute to society. Whether the focus is malaria, HIV-AIDS, cholera, avian influenza, children's obesity, access to health care, cancer, or the impact of climate change on health, developing a more thorough understanding of and response to critical health issues cannot be achieved without the approaches and concepts of different branches of science. GISS provides the organizing and analytical framework that accommodates and focuses our different approaches to science in ways amenable to practical problem solving. Examples of past successes include work to identify disease clusters; computation of correlations between disease outcomes and their possible causes; the formulation and testing of spatially explicit models of disease spread that incorporate concepts such as distance and connectivity directly into the model (often in the form of cellular automata or as agent-based models: see Sections 15.2.2 and 15.2.3); and research on the significance of proximity in determining successful treatments (e.g., the distance between the home of a stroke victim and the nearest emergency center). GISS has played a significant role in almost all contemporary work of this kind.

19.6.4 Access to Food, Potable Water, and Boundary Disputes

Water problems affect half of humanity: Some 1.1 billion people in developing countries have inadequate access to water, and 2.6 billion lack basic sanitation. About 1.8 million child deaths occur each year as a result of diarrhea. Close to half of all people in developing countries are suffering at any given time from a health problem caused by water or poor sanitation. GISS professionals can help identify problem areas and possible causes of ill health just as Snow did in 1854 (Box 13.1).

Water shortages are already increasing in many parts of the world as a result of competing uses, growing populations, and international disputes over riverine water flowing across national boundaries. Moreover, if the Intergovernmental Panel on Climate Change (the IPCC) is correct, the situation can only get worse. The Panel's 2013 and earlier reports projected that most dry regions will get drier, most wet regions will get wetter, drought-affected areas will become larger, heavy precipitation events are likely to become more common and will increase flood risk, and water supplies stored in glaciers and snow cover (Figure 19.14) will be further reduced.

Wars have often been caused by competition for water or because of other boundary disputes.

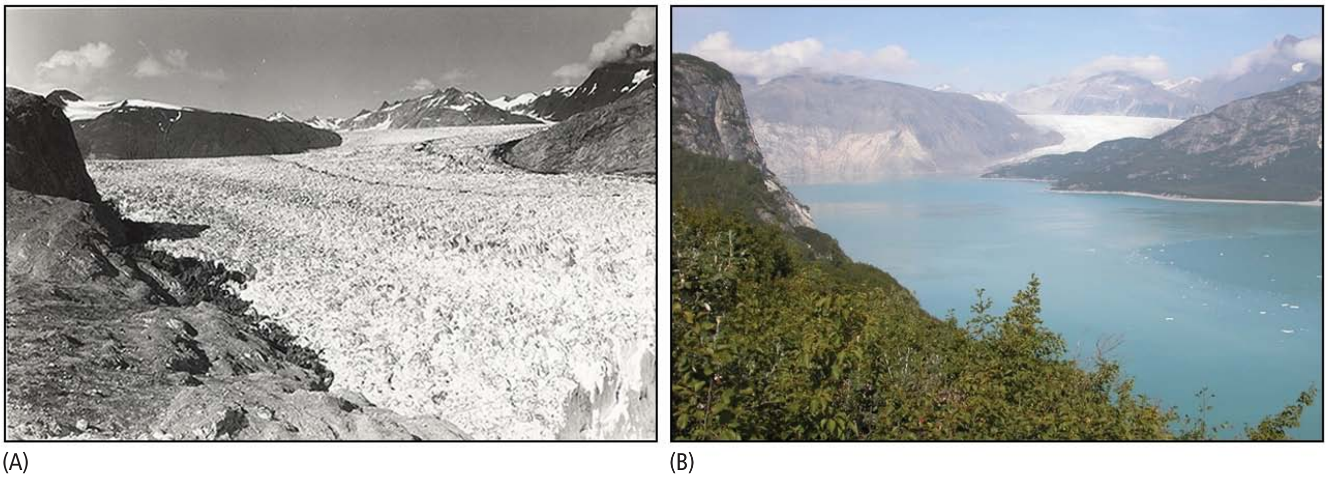
Rivers have long been a popular choice for boundary makers because of their defensive nature, their clarity on the ground, and some belief in their permanence. However, as dynamic natural features, the movement of rivers has generated frequent disputes over the position of boundaries that are often understood to require rigidity. In these circumstances, disputes over who has the rights to water resources can only grow still further.

One example of attempts to minimize such water-related disputes is the agreement between China and India announced in August 2009 to monitor jointly the state of glaciers in the Himalayas. Seven of the world's greatest rivers, including the Ganges and the Yangtse, are fed by glaciers. They supply water to about 40% of the world's population. In 1962 the two countries went to war over disputed territory in this sensitive area.

In 2013 Egypt and Ethiopia agreed to hold further talks to quell tensions over the building by Ethiopia of a new hydroelectric dam on the Blue Nile, following threats of military action. The Nile waters have been crucial to the survival of Egyptian agriculture for several millennia (see Figure 19.15). The strife began when Ethiopia's parliament ratified a controversial treaty to replace colonial-era agreements that gave

Figure 19.14 (A) A photograph of Muir Glacier taken on August 13, 1941, by glaciologist William O. Field; (B) is a photograph taken from the same vantage point on August 31, 2004, by geologist Bruce F. Molnia of the U.S. Geological Survey (USGS). According to Molnia, between 1941 and 2004 the glacier front retreated more than 7 miles (12 km) and thinned by more than 800 m. Ocean water has filled the valley, replacing the ice of Muir Glacier; the end of the glacier has retreated out of the field of view.

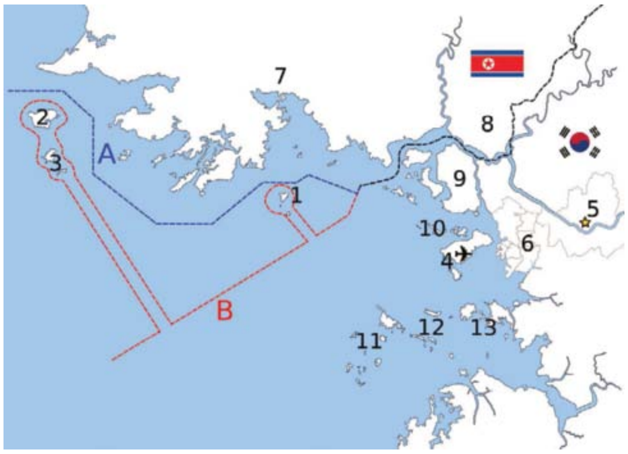
Source: U.S. National Snow and Ice Data Center



(A) (B)

Source: NASA

Figure 19.15 The Nile seen from space. The green area is vegetated or urban areas (including Cairo and the delta). Eighty six million people live there. The remaining areas are desert and very sparsely populated.



Source: Wikipedia Commons, under a Creative Commons License, Attribution: Moo Bong Ryoo

Figure 19.16 Unresolved maritime boundaries of North and South Korea. The area was the site of a North Korea torpedo attack in 2010 that killed 46 South Korean sailors and an artillery attack on South Korea territory eight months later. Line A (blue) is the Northern Limit Line, created by the United Nations in 1953. Line B (red) is the "Inter-Korean MDL in the Yellow Sea," declared by North Korea in 1999. The locations of specific islands are reflected in the configuration of each maritime boundary, including 1–Yeonpyeong Island, 2–Baengnyeong Island, and 3–Daecheong Island.

Egypt and Sudan the biggest share of the Nile's water. The original 1929 treaty written by Britain awarded Egypt veto power over any project involving the Nile by upstream countries. The new treaty had earlier been signed by five other Nile-basin countries—Rwanda, Tanzania, Uganda, Kenya, and Burundi. This is a classic example where the skills and tools of GISS practitioners could be invaluable.

Another example of a potentially catastrophic boundary dispute—but not involving potable water—is that between North and South Korea. The differences between the UN's and North Korea's versions of the boundary between the two Koreas is shown in Figure 19.16. In this highly politicized case, however, it is not clear how GISS professionals can contribute much beyond recording the different versions of the boundary.

GI system practitioners have already made many significant contributions to the definition of many boundaries. For instance, the International Boundaries Research Unit (IBRU) at Durham University has built up internationally recognized expertise over several decades in supporting boundary demarcations (many defined in relation to river courses), training those involved in such demarcations anywhere in the world, and maintaining in GI system form a geographical record of (often disputed) boundaries such as of Israel–Palestine and Cyprus–Northern Cyprus.

19.6.5 Coping with Natural Disasters

Television brings us frequent updates on natural disasters from many parts of the world, though reporting is usually massively biased toward reporting low-frequency but high-impact events. The most extreme natural disaster in recent years was probably the December 2004 tsunami originating from a submarine earthquake, whose epicenter was off Banda Ache in Indonesia; approximately 225,000 people were killed. Subsequently a real-time tsunami monitoring system was built spanning the Indian Ocean (Section 18.3.2.3).

In some cases the impact of natural hazards is exacerbated by human factors. An example was the aftermath of a 9.0 magnitude earthquake that struck the Fukushima prefecture north of Tokyo on March 11, 2011 (Box 1.1). Mismanagement exacerbated the problem. A second—and different—example followed an earthquake that devastated the city of Port-au-Prince, Haiti, on 12 January 2010, causing the death of up to 300,000 people. This is a city with a booming population, cramped and informal housing, poor sanitation, and extremes of wealth and poverty. The earthquake was followed by a severe outbreak of cholera with over a quarter of a million cases and more than 7,000 reported deaths. Many Haitians blamed the outbreak on a sewage spill from a UN peacekeeping base; a group of human rights lawyers sued the UN on behalf of those Haitians who contracted cholera. Based in part on geographical detective work by the U.S. Centers for Disease Control, the suit alleges that the cholera pathogen was introduced to Haiti inadvertently by a group of UN peacekeepers who traveled to the island from Nepal to provide aid after the earthquake.

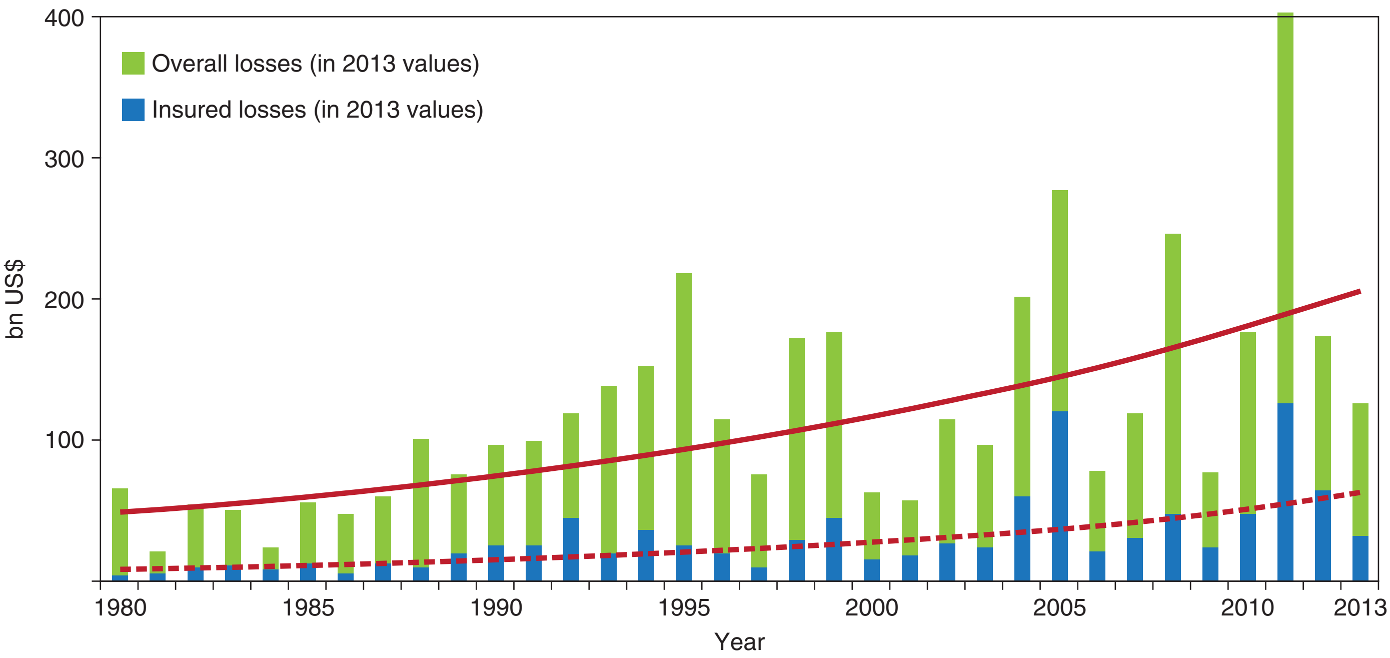
If earthquakes and resulting tsunamis are the most destructive natural hazards, most natural disasters are caused by hydrological and/or meteorological factors. These usually result in flooding on a massive scale, such as caused by Hurricane Katrina and Hurricane Sandy in the United States. As Figure 19.17 shows, natural disasters have had huge economic, as well as human, impact; on average about three-quarters of these losses were due to weather-related events. The global reinsurer Munich Re summarized insurance losses in 2011 as around $125bn. The potential losses from flooding in global cities like New York are particularly massive: The Rockefeller Foundation has funded a large study on how to protect that city (see Further Reading). But even such dire figures disguise the real extent of natural disasters because many of the losses are uninsured or otherwise unquantifiable in areas with poor populations. Munich Re estimated that the worldwide uninsured losses in 2011 were over twice as large as the insured ones and amounted to over $300bn.

Natural disasters have had huge economic, as well as human, impact.

Given the human misery and economic costs of such disasters, it is no surprise that GI systems are becoming widely used in attempts to predict areas where disasters may occur—taking into account natural circumstances plus deforestation, construction, and other human activities likely to contribute. The vastly experienced Belgian coordinating center for details of natural disasters recognized as long ago as 2008 that "GIS technology has imposed itself as an essential tool for all actors involved in the different sectors of the disaster and conflict management cycle." Unfortunately while real-time monitoring of hurricane tracks has proved relatively valuable—both for enhancing evacuations and predicting insurance losses—forecasting the occurrence of natural disasters remains mostly unreliable. Even where probabilistic statements of the likelihood of a disaster have been made, these have often been inadequately persuasive for governments to take action. The prime example of this is the warnings by geologists of the high risk of an earthquake off the shoreline of Banda Ache years before the catastrophe. Thus there is much for GISS experts, in partnership with other earth and social scientists, to do, though the lessons of the L'Aquila affair must be heeded (Section 18.1).

A relatively new development is the use of crowdsourcing (Section 1.5.6). Online disaster response communities have grown in support of the traditional aspects of disaster preparedness, response, recovery,

Figure 19.17: Natural catastrophes worldwide 1980–2012: Overall and insured losses and their trend lines. Losses adjusted to inflation based on country CPI.



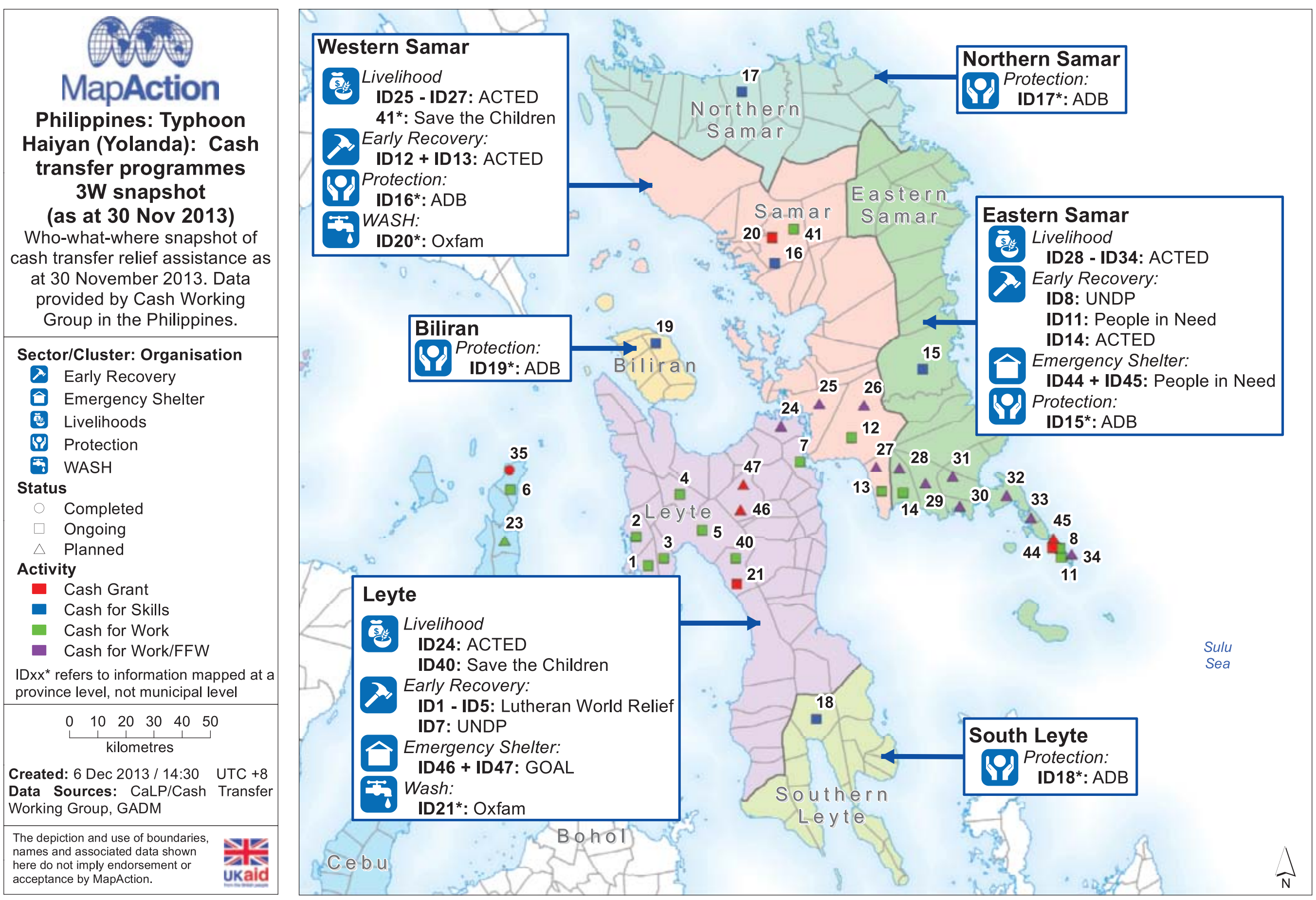
mitigation, and policy as facilitated by governmental agencies and relief response organizations. But these communities now use the Internet to donate money quickly and efficiently, create blogs, upload pictures, and disseminate information—often much faster than government agencies—and use message boards to seek family members and identify shelters. In essence they create a living and easily accessible geography.

GISS experts have made major contributions to improving the effectiveness of post-disaster recovery work.

Where GI system experts have made the greatest contributions in recent years is through improving the effectiveness of postdisaster recovery work. The charity MapAction is a prime example of good practice, now being copied by many others. A standing organization founded in 2002, MapAction has made much use of highly trained volunteers for disaster relief. It argues that aid that ends up in the wrong place is of no use in relieving human suffering and that, in a humanitarian crisis, relief agencies need rapid answers to questions such as "Where are the greatest needs?" and "Where are the gaps that need to be filled?" To provide such information, the volunteer teams are skilled in use of GI systems and GPS, produce frequently updated situation maps for all other agencies active in the area, and publish them on the Web (Figure 19.18); disaster relief agencies can also access free-of-charge maps from all current and previous deployments. The MapAction teams have operated in countries such as Angola, Bolivia, the Central African Republic, Cote d'Ivoire, Guatemala, Indonesia, Jamaica, Kenya, Libya, Madagascar, Myanmar, Japan, Pakistan, Paraguay, Philippines, Sri Lanka, Suriname, Syria, and Tajikistan. That this has major benefits is shown by an independent report produced after a deployment in Haiti following the passage of a hurricane. The review concluded that such GI system products made decision making by aid agencies much quicker, simpler, and more effective.

All the preceding relates to contemporary disasters. GI systems, however, can be used to model and depict long-term scenarios. The National

Figure 19.18 Example of one type of map produced by MapAction to facilitate and report on rescue work after typhoon Haiyan (Yolanda) in the Philippines: Who-what-where snapshot of cash transfer relief assistance payments as of 30 November 2013.



Source: MapAction, data provided by the Cash Learning Partnership

Geographic Society has published an interactive map (ngm.nationalgeographic.com/2013/09/rising-seas/if-ice-melted-map) that shows the impact in Asia of the extreme event of the melting of all land ice. The Society's calculations suggest about a billion people would be displaced in Asia alone. Similarly disastrous consequences would occur elsewhere, as New York, London, and many other major cities would be submerged.

19.6.6 Coping with Terrorism, Crime, and Warfare

Coping with terrorism, crime, and warfare all ideally require combinations of intelligence on the likely threats, frequently updated risk registers and plans to mitigate risk, operational plans for deployment of forces to control the threats, excellent communications, and descriptions of the affected geography occupied by the terrorists and the populace alike. As described in more detail earlier (Section 17.5), the result of growing security threats has been increasing use of surveillance technologies and linkage of all the sensors used together through GI systems to portray the movements of suspects or monitor suspicious activities around sensitive sites. The sensor arrays range from those on satellites and unmanned airborne vehicles to closed-circuit TVs, telephone interceptions, and much else. Even at the less serious level of crime against individuals or their properties, monitoring of activity in high-risk areas is important, as is post hoc analysis of the characteristics of the crime scene.

Increasingly, all security-related activities need socioeconomic and other social science information as well as that describing the physical landscape. Geodemographic profiling of the characteristics of local populations to quantify risk is commonplace, and matching of DNA samples from suspects or databases with that found at crime scenes is permitted in some jurisdictions. The integration and analysis of such admixtures of data with different characteristics, often to very short time scales, can be very demanding. Chicago's police pioneered such predictive policing in 2008, based on historical crime data and street intelligence then targeting resources where crime was predicted; there was a rapid reduction in homicide rates—for a time at least. While encouraging, we should, however, note unintended consequences: There is contention, for instance, that crime mapping and prediction has simply displaced crimes such as burglary from one location to another rather than stopping them.

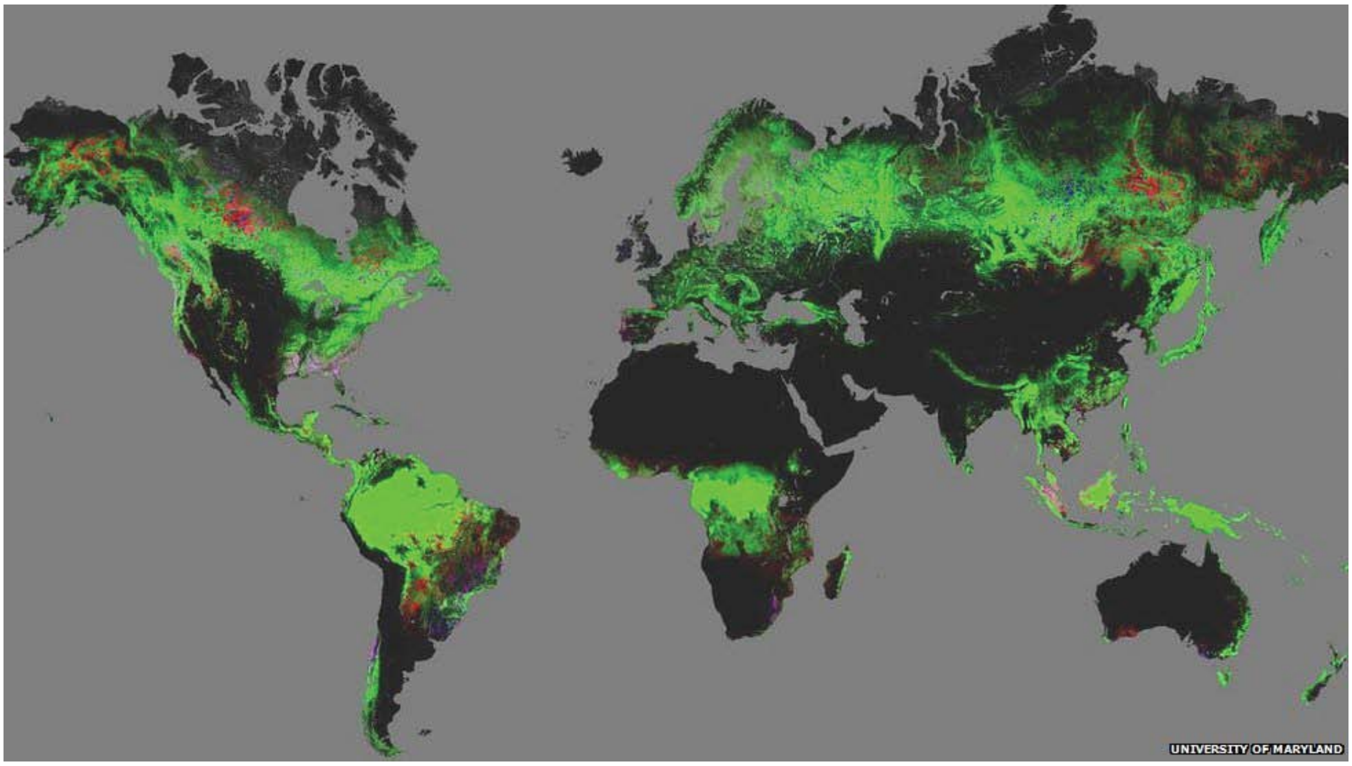
Surveillance of individuals can reduce risk of harm but endangers privacy.

The descriptions of military GI infrastructure in Section 17.5 demonstrate that such information and contemporary GI system tools play a key role in efforts to safeguard life and well-being. All this, however, raises difficult trade-offs between potentially enhanced security and loss of privacy (see Section 18.4.1).

19.6.7 Environmental Sustainability

The book *Silent Spring*, published by Rachel Carson in 1962, is widely credited with helping launch the environmental movement. Within a few years of the publication, satellite remote sensing and GI technology began to play a significant role in monitoring the state of the environment globally and more locally. But the perceived seriousness of environmental sustainability and, in particular, the threats caused by climatic change—which seem to have been at least exacerbated by human action—are now widely perceived as major challenges. A further complicating factor is that some of the worst-affected areas are likely to be those in which some of the poorest people on Earth live. The most vulnerable regions are Africa, the Asian mega-deltas, small islands, and the Arctic. The biggest challenges are held to be the availability of water (especially in the dry tropics); agriculture (especially in low latitudes); human health in countries with low adaptive capacity; and some ecosystems, notably coral, sea-ice biomes, coastal mangrove and salt marshes, and those in tundra/boreal/mountain areas. The debate and controversies are now wide-ranging and encompass coping strategies as well as avoidance ones. As GI scientists, however, we have no doubt that climate change is underway, that some ameliorative and adaptive action is essential, if difficult, and that we in GISS have a role to play.

Even aside from climate change, human-induced environmental stress is now much more widespread and severe, whether it is manifested in the deforestation of the Amazon Basin or the progressive disappearance of wild areas and the extinction of species. Since 1970, over 600,000 square kilometers of Amazon rainforest have been destroyed. More recently, between May 2000 and August 2006 Brazil is said to have lost nearly 150,000 km^2 of forest—an area larger than Greece. Most definitively, in 2013 a multiorganizational team skilled in GI systems and led from the University of Maryland used 650 thousand satellite images to map (Figure 19.19) and publish a globally consistent portrayal of forest loss (2.3 million km^2) and gain (0.8 million km^2) from 2000 to 2012 at a spatial resolution of 30 meters. The tropics were the only climate domain to exhibit a trend, with forest loss increasing by some 2100 km^2 per year. Brazil's well-documented reduction in the rate of deforestation from around 2004 was offset by increasing forest loss in Indonesia, Malaysia, Paraguay, Bolivia, Zambia, Angola, and elsewhere. Intensive forestry practiced within subtropical forests resulted in the highest rates of forest



Source: Published by Hansen et al., 2013, University of Maryland

Figure 19.19 Forest cover of the world and changes to it between 2000 and 2012. Red: reduction in forested area; green: forested areas; blue: gain in forest area; pink: areas of both loss and gain.

change globally. Boreal forest loss due largely to fire and forestry was second to that in the tropics in absolute and proportional terms. Clearly, then, we only know the true scale of the problem through use of GI systems. It seems self-evident to us that ways of reducing this stress and at least adapting to climate change (if amelioration proves impossible to enact) are essential and, again, that GISS practitioners will play a role at every scale from the local to the global.

Although mapping and measurement of environmental change is valuable, still greater value can be added through explanatory and predictive modeling. One area where GISS has made and will continue to make a contribution is in regard to preserving biological diversity and protecting endangered ecosystems. Nearly 850 known species have become extinct or disappeared in the wild over the past 500 years, apparently because of human activity. About two-thirds of endangered mammal and bird species owe their threatened status to habitat destruction and fragmentation. This matters because ecosystem functioning and the services provided by ecosystems are critical to human welfare. These functions include sequestration of carbon, production of oxygen, primary production of chemical energy from sunlight, soil formation, nutrient cycling, food production, wood and fiber production, fuel production, and regulation of water flow and transfer to the atmosphere.

Scientists from many backgrounds working in GISS are playing a significant role in documenting and explaining the current state of biodiversity and the rate and magnitude of ecosystem loss and in developing possible coping strategies. Astonishingly, we still know surprisingly little about such matters. Successful preservation of biodiversity and ecosystem functioning also requires anticipation of how and where land use and climate change will produce increased extinction rates. Built on that, it also requires the development of models that can estimate potential biodiversity and the selection of conservation areas and conservation management strategies to mitigate extinctions and declining ecosystem functioning. Typically, the models have to be at different scales and levels of generalization—global, national, and local—and linked. The same geographical scientists have already contributed significantly in recent years to advances in methods and applications linking land cover changes not only with biophysical processes and consequences, but also with human circumstances.

The U.S. National Research Council (see Further Reading) has argued that we need reliable and relatively fine-resolution global atlases of the world's threatened species and habitats/ecosystems in order to develop a series of geographically explicit, biophysically sound conservation strategies for the most endangered areas. Even that is not enough. We also need socially acceptable strategies that take into account locally differing cultural approaches to nature valuation, conservation practices, and compliance. In short, GI systems provide a framework for integration of knowledge and information about the Earth or parts of it and have a crucial role to play in so doing. We again stress that in this area, as in all others, the GISS specialist cannot resolve all the problems on his or her own. Typically, close partnerships (Section 18.6) are needed with physical, biological, and social scientists to describe and understand what is going on and to seek solutions. Expert leadership of the institutions charged with fostering environmental sustainability is also essential (Box 19.4).

To succeed, GISS specialists must work with other natural, environmental, and social scientists, and with decision-makers.

19.6.7.1 Geoengineering

Elsewhere in this book we have tended to regard at least the physical environment as a given, though it can be modified (and often degraded) locally by humans. In preceding pages we have described how GI systems have been used to monitor changes through a range of applications. But in principle we now have the capacity to change certain aspects of the physical environment far beyond such local activities as quarrying.

One area where this *may* be desirable is in relation to climate change. Such change is happening, and part of it at least has been influenced by human action. On the basis of much scientific work—though disputed by some—the impacts and costs of climate change will be large, serious, and unevenly spread. We may already be seeing consequences on human health from extreme weather events of the past decade,

Biographical Box 19.4

Jacqueline McGlade, Earth Scientist

After serving two terms as Executive Director of the European Environment Agency (EEA), Jacqueline (Figure 19.20) retired in May 2013. The EEA is an agency of the European Commission serving the interests of 32 EU member countries and others. Her tenure of that post was widely judged to have been a considerable success.

In her 10 years there, she presided over a fundamental shift in the thinking behind environmental reporting and indicator development. Manifestations of this were a shared European spatial environmental information system and the production of integrated environmental assessments, analyzing the state of Europe's environment as a whole and providing soundly based projections.

Professor McGlade oversaw a significant increase in the coverage and extent of data and information processed and analyzed by the EEA and a doubling of the resources for the agency to support this work. She has been a strong advocate of using new technologies to improve information gathering and make it accessible to an increasing number of users.

As Executive Director, she worked to strengthen the link between science and policy. She urged policy makers to start developing and applying adaptation measures to climate change. To complement this, Professor McGlade encouraged dialogue with citizens, including indigenous peoples in remote regions such as the Arctic. In 2008, the EEA launched Eye on Earth, which brought together environmental data in the form of dynamic maps of air and water quality. Eye on Earth was recognized in the 2012 Rio+20 summit declaration as a key public information platform on the environment.

Prior to her leadership role in the EEA, Jacqueline McGlade was educated in the UK and Canada in marine biology and aquatic zoology. Her PhD research was on the importance of spatial dynamics in determining evolutionary divergence and ecological sustainability in freshwater and marine fish populations. Later her work helped establish research in spatial modeling and artificial intelligence and applying space-based observations to biological oceanography at the Bedford Institute of Oceanography.

Source: European Environment Agency

Figure 19.20 Jacqueline McGlade, earth scientist.

including droughts, floods, and superstorms. The impacts may be reduced by adaptation and moderated by mitigation, especially by reducing emissions of greenhouse gases. However, global efforts to reduce emissions have not yet been sufficiently successful to provide confidence that the reductions needed to avoid dangerous climate change will be achieved. This has led to growing interest in geoengineering—the deliberate large-scale manipulation of the planetary environment to counteract anthropogenic climate change.

Geoengineering methods fall into two basic categories:

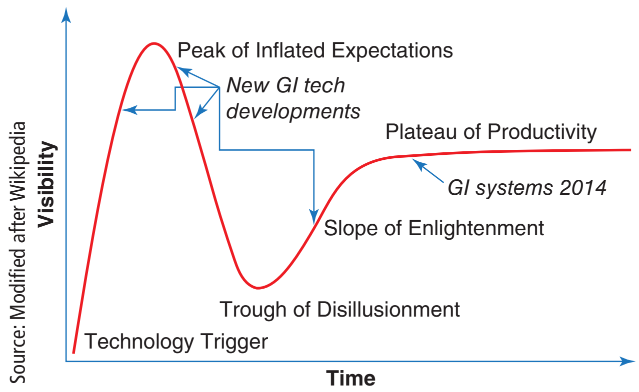
- Carbon dioxide removal (CDR) techniques, which remove CO_2 from the atmosphere. As they address a root cause of climate change—rising CO_2 concentrations—they have relatively low uncertainties and risks. However, these techniques work slowly to reduce global temperatures.
- Solar radiation management (SRM) techniques, which reflect a small percentage of the sun's light and heat back into space. These methods act quickly and so may represent the only way to lower global temperatures quickly in the event of a climate crisis. However, they only reduce some, but not all, effects of climate change, while possibly creating other problems. They also do not affect CO_2 levels and therefore fail to address the wider effects of rising CO_2, including ocean acidification.

Given that attempts to reduce atmospheric CO_2 by international treaty have proved disappointing, geoengineering is seemingly attractive. We should recognize, however, that under present knowledge it remains unproven and potentially dangerous. That said, any such trials or larger scale application of such techniques will inevitably necessitate use of GI technology and GISS expertise to model and project consequential changes at all geographic levels from the global to the local.

19.7 Conclusions

This epilog could simply have set out to anticipate the future developments of science and technology in our field and their implications. These will impact on us all. In particular, the very way we do much science is mutating from largely a hypothesis-verification model to a data "dredging" Big Data one (Box 17.2). In the latter, relationships are computed between a mass of variables and interesting relationships isolated and studied further. As it happens, this is how much of GI science has always operated, so we are mainstream in new science. This is not new: We are traditionally ahead of the mainstream in data science, having developed methods of data sharing, with interoperability and metadata, decades ago.

Figure 19.21 The Gartner Hype Cycle and GI technology. In general GI systems are where shown but some new developments are at various earlier stages.



We have chosen in this final chapter to focus on Grand Challenges to humanity. After 50 years of evolution, GI systems in general and GI technology are now well established: We seem to be at a plateau of productivity in Gartner's Hype Cycle (Figure 19.21). Yet we know that further technological change is coming, but we do not know what that is or what its effects will be other than that employment will change. Over the last 30 years bank tellers, typists, and many other jobs have disappeared—but new ones and new capabilities have replaced them. We are equally confident that the evolution already underway from Terascale to Yottascale computing and beyond will certainly have major impacts on our ability to model complex realities like energy flows in the atmosphere and in ocean currents at finer spatial resolutions—and hence contribute to understanding and remedial actions.

The most casual reading of this chapter should tell us several things. The first is that, whatever their local manifestations, certain problems face us all: We cannot isolate ourselves from the impact of global pandemics, climate change, some natural hazards, or the consequences of financial collapses. Moreover these propagate increasingly rapidly. The second conclusion is that, although the realization of some Grand Challenges seems improbable, sudden changes of a catastrophic nature will occur. In an ideal world, therefore, precautions should be planned beforehand. Although accepting that it is difficult to anticipate the next crisis, business continuity planning is important for every organization. GI systems can often help with "what-if" scenario planning.

The third conclusion is that many of the challenges—and solutions—are interconnected, notably poverty, food and water supply, disease, and population numbers.

These challenges are truly formidable and complicated. Analyzing and anticipating threats involves use of both quantitative and qualitative information, which varies widely in reliability. No one set of skills—of geographers, earth or computer scientists, economists, or others—can resolve these problems on their own. Indeed, the collaborations involved must be multinational, multidisciplinary, and geographically extensive in scale. There is already a vast and partly connected set of organizational silos charged with responsibility for tackling these problems. That responsibility is discharged mainly through national and local governments, multinational bodies like the United Nations and its agencies, commercial enterprises, and nongovernmental organizations (NGOs). We need to be adept at working with organizations as well as being technically competent.

All physical and human systems on the Earth are interconnected. Geography is the study of the interactions, and GISS helps us to understand and manage them.

A fourth conclusion follows from everything that has been said earlier: Good communications of all sorts are a necessary (but not sufficient) condition for success, especially in emergencies. The impact of the Internet and Web have already been astonishing in providing new tools to describe, communicate, and tackle problems, some of it via volunteered GI or that collected without consent.

Another conclusion is that, although there has been a huge global increase in use of GI system functionality, this has not been paralleled by widespread development of a fundamental form of human reasoning—spatial thinking. We argue the need for encapsulating this in school and college courses in many disciplines but also advocate a rethinking of many courses in GI systems and a move to incorporate more GI science.

Finally, based on the earlier part of this chapter and indeed on the biographical examples throughout the rest of the book, we contend that as GISS practitioners we can manifestly each make a (mostly) small but important contribution to meeting these challenges big and small. Not all of us can be major players in regulating financial institutions or leading the World Health Organization or global environmental bodies to play key roles in the diminution of risk to humanity. But our skills, technology, knowledge of what works, plus our commitment and working with others enable us individually and collectively (Box 19.1) to make a real difference. We are convinced that such an activist, science-based approach is the right one. We wish you well in that noble endeavor.

Multinational problems require multinational collaborations between scientists and governments.

QUESTIONS FOR FURTHER STUDY

1. Why is the world so differentiated?
2. What do *you* think are the biggest challenges to humanity where GISS can make a contribution?
3. You are invited to a local radio or TV station to talk about what GI systems can do to solve local problems. What would you say, and how would you say it?
4. How can GISS practitioners help to enhance the health of the general populace?

FURTHER READING

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United Nations. 2013. *Millennium Development Goals*. www.un.org/millenniumgoals/bkgd.shtml

View Hans Rosling video on how to communicate complex technical material to lay audiences: www.youtube.com/watch?v5YpKbO6O3O3M