Understanding Earth

GIS Technology Drives a New Relationship Between Humans and the Environment

Jack Dangermond and Matt Artz

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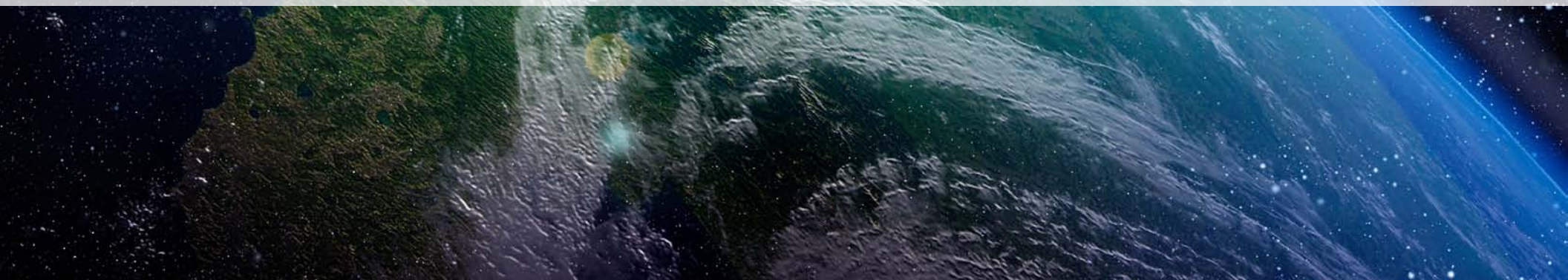

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Mapping Redefined

> *In a word, geography is a science—a thing not of mere names but of argument and reason, of cause and effect.*
>
> *—William Hughes, 1863*

From the dawn of humankind, man has sketched crude abstractions of geography on cave walls and rocks. These early maps documented and communicated important geographic knowledge our ancestors needed to survive:

- What is the best way to get from here to there?
- Where is the water at this time of year?
- Where is the best place to hunt animals?

Our ancestors faced critical choices that determined their survival or demise, and they used geographic information stored in map form to help them make better decisions.

Fast-forward to the 1960s. The world had become significantly more complex than it was for our early ancestors, and computers had arrived on the scene to help us solve increasingly complex problems. The 1960s were the dawn of environmental awareness, and it seemed a natural fit to apply powerful new computing technology to the serious environmental and geographic problems we were facing. And so the geographic information system (GIS) was born.

Early man used cave walls and rocks as a canvas to communicate and share geographic knowledge.

The era of computational geography was led by the groundbreaking work of Dr. Roger Tomlinson, who developed the Canada Geographic Information System in 1967. Similar efforts took place at Harvard's Laboratory of Computer Graphics and Spatial Analysis in the 1960s and beyond. Computational geography forever changed the way we view geography and place.

Dr. Roger Tomlinson pioneered the development of GIS, ushering in the era of computational geography.

Today, GIS has evolved into a crucial tool for science-based problem solving and decision making. GIS uses the power of information technology to examine geographic knowledge in ways that would be extremely time-consuming and expensive if done manually. The map metaphor remains the dominant medium for sharing our collective geographic intelligence, and widespread use of GIS technology is creating a revolution in how we understand our world and plan for the future.

GIS is the technology of our times and is uniquely suited to assist in solving the problems that we face.

—Roger Tomlinson

A Context for Understanding

Geographic knowledge is information describing the natural and human environment on the earth. For our ancestors, geographic knowledge was crucial for survival. For our own survival today, geographic knowledge plays an equally important role. The biggest differences between then and now are that our problems are much more complex, and the sheer volume of data at our disposal is daunting. And whereas communicating geographic knowledge in the past was limited to simple maps, GIS technology now enables a collective geographic intelligence that knows no spatial or temporal bounds.

Today we have more geographic data available than ever before. Satellite imagery is commonplace. Scientists are producing mountains of modeled data. And an ever-increasing stream of data from social media, crowdsourcing, and the sensor web is threatening to overwhelm us. Gathering all this information—this geographic knowledge—and synthesizing it so that we can more easily understand it and act on it is the domain of GIS. More data does not necessarily equate to more understanding, but GIS is already helping us to make sense of it all, turning this avalanche

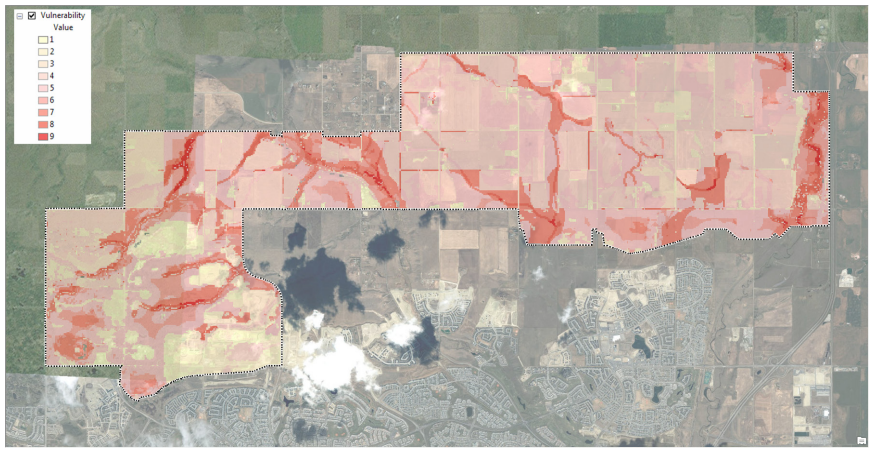
of raw data into actionable information—a new context for understanding our world and planning for the future.

Only when people know will they care.
Only when they care will they act.
Only when they act can the world change.

—Dr. Jane Goodall

A Framework for Action

Our traditional understanding of ecosystems as natural landscapes is changing. Anthropogenic factors are now the dominant contributor to changing ecosystems. Human beings have not only reshaped the physical aspects of the planet, in some cases literally moving mountains, but also profoundly reshaped its ecology.



GIS helps us understand the vulnerability of the environment to our actions.

And it's not just landscape-scale geographies that can be considered human-made ecosystems. In modern society, cities and towns are where we spend the vast majority of our waking and sleeping hours. Even our homes and office buildings are themselves man-made ecosystems—vast assemblages of interdependent living and nonliving components. Entirely man-made ecosystems have become the primary habitat for the human species, and this is changing the way we think about, collect, store, and use information describing our environment.

A key aspect of our social evolution is recognizing the effects we have already had on ecosystems, as well as learning to predict what future impacts will result from our actions. Once we achieve this level of understanding, we can direct our actions in a more responsible manner. This type of long-term thinking and planning is one of the things that make us human.

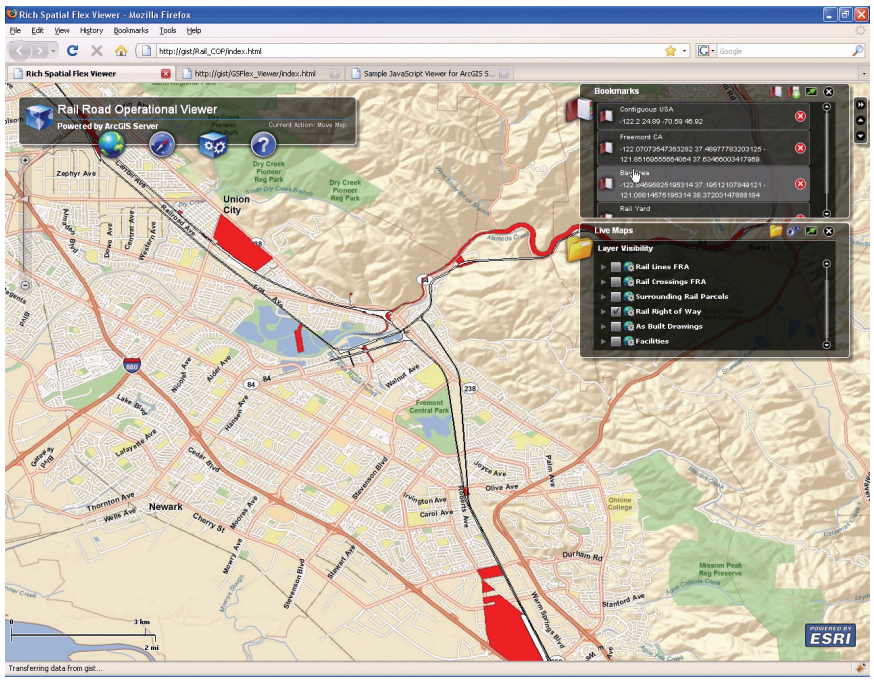
Recognition of the overwhelming dominance of man-made ecosystems also makes us cognizant of the tremendous responsibility we have—the responsibility to understand, manage, and steward these ecosystems with decisions based on sound science.

Understanding precedes action.

—Richard Saul Wurman

Our Geospatial Infrastructure

People intuitively understand maps, and maps have historically been our best method for communicating geographic knowledge. But over the last 10 years, we have seen a fundamental change in the way geographic knowledge is delivered and used. Thanks in large part to the Internet, our definition of what constitutes a "map" is evolving quickly, along with geospatial information management technologies, including GIS.

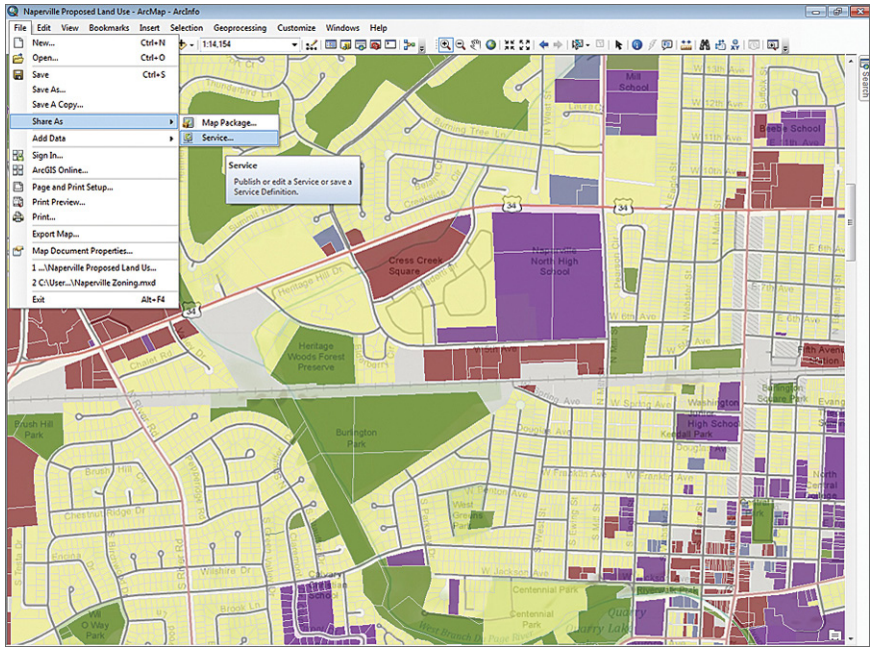


Our geospatial infrastructure includes details about physical infrastructure and other aspects of our natural and human-made geography.

The next 10 years will see an explosion of faster, more powerful mobile devices, and the line dividing cell phones and personal computers will fade. Mobile devices will continue to grow to support more geospatial functionality, and they will easily connect to GIS-enabled systems around the world, empowering people to use and also create geographic knowledge. Democratization of data—both its widespread use and its universal creation—will result in a new kind of infrastructure: a geospatial infrastructure. Over time, society will become increasingly dependent on this geospatial infrastructure, much as it has become dependent on other, more traditional forms of infrastructure such as electrical grids or highway networks.

A New Approach

A transformation is taking place. Businesses and governments, schools and hospitals, nonprofit organizations, and private citizens are taking advantage of it. All around the world, people are working more efficiently because of it. Information that was limited to spreadsheets and databases is being unleashed in a new, exciting way—through the use of geography.



GIS helps us see where things are and decide where they should be.

A geographic information system lets us visualize, question, analyze, interpret, and understand data in new ways. Its analytic power can reveal relationships, patterns, and trends.

With GIS we are not simply replacing paper-and-ink maps with maps on computer screens; we are evolving and extending the definition of what maps are and redefining how we use and interact with them.

The Geographic Approach

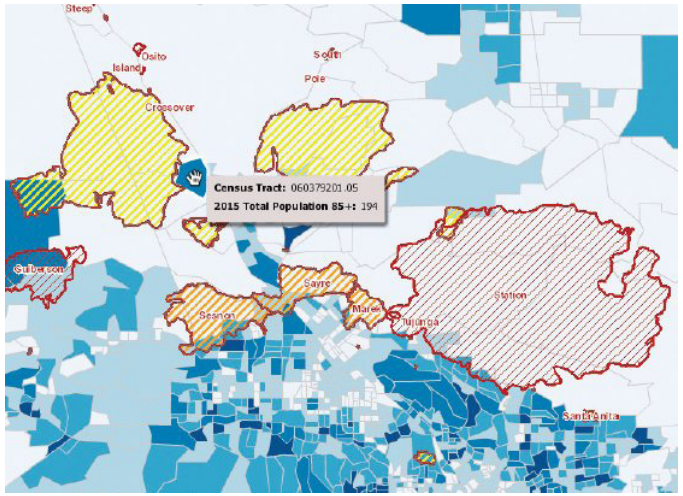
Maps are a proven method of communicating geographic knowledge. When a decision needs to be made, GIS helps us gather place-based information and organize it on a digital map. We then use GIS to evaluate the decision. Once we fully understand the geographic consequences of our decision, we can act in an informed, responsible manner.

Map → **Evaluate** → **Act**

This geographic approach to problem solving helps us answer a wide variety of important questions related to geography, such as these:

- Where are my customers and potential customers?
- Which areas of my town are most vulnerable to natural disasters?
- Where should we locate a new elementary school?

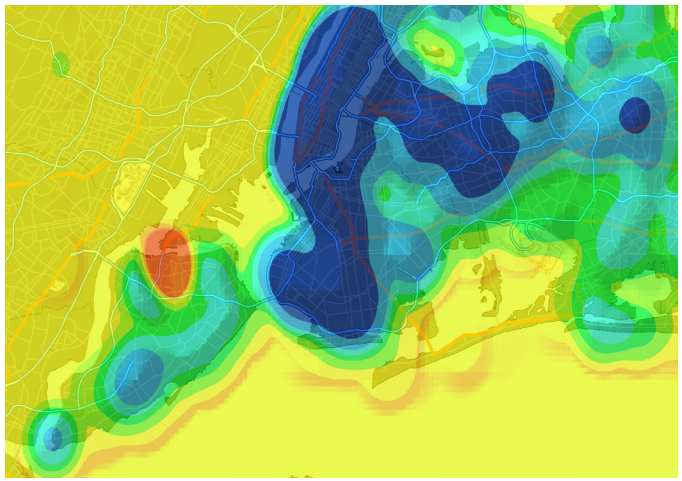
GIS helps answer such questions by combining data from governments and other sources in a personalized map.



By comparing historical disaster data with vulnerable populations, GIS reveals patterns useful for disaster planning.

GIS benefits organizations of all sizes and in almost every industry, and there is a growing interest in and awareness of its economic and strategic value. The benefits of GIS generally fall into five basic categories:

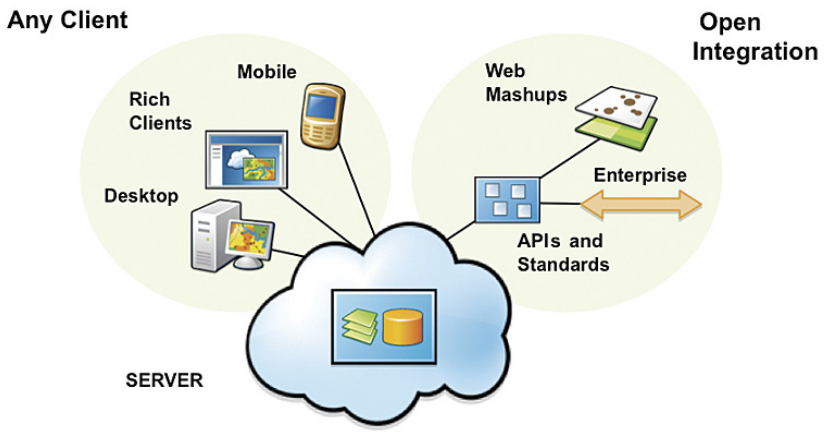
- Cost savings resulting from greater efficiency
- Better decision making
- Improved communication
- Better geographic information record keeping
- Managing geographically



GIS can produce "heat maps" to visually represent information using colors.

Remote-sensing satellites and earthbound sensors are providing us with vast amounts of data about our planet. With the availability of new, easy-to-use GIS tools for displaying and analyzing this data, now everyone can be an explorer. The benefits to both society and the environment are far reaching and usher in a new era of understanding for our world.

From desktop computers to smartphones to the cloud, it is becoming easier for anyone to use and benefit from GIS.



"The cloud" supports both enterprise and web deployments, transforming GIS access, usability, and collaboration.

Evolving Technology

The geospatial industry, the IT environment, and the world around us are all changing rapidly. We often talk about how GIS is changing the world, but at the same time, it's important to understand how the world is changing GIS.

GIS has a long history of successfully adapting to new technologies, applications, customer types, and business models. From mainframes to minicomputers, UNIX workstations to PCs, desktop to enterprise deployment, each round of technological innovation has led to improvements for GIS. Today, GIS continues to evolve in response to changes in information technology. The distributed computing environment enabled by the web introduces a whole new set of challenges and opportunities. Merging with and adapting to the latest advances is making GIS easier to use, more collaborative, more powerful, and ultimately more useful for the work you do every day.

The Cloud

Cloud computing delivers technological capabilities on demand as a service via the Internet. Unlike the classic computing model of operating system plus software applications with files and database storage, the cloud model consists of services, clients, hosted content, and virtual machines. In other words, you do not load and run software and store data on your computer; you log in and use the system in the cloud. In addition to allowing computing on the public Internet, the cloud can be implemented within a smaller, more secure community (creating a so-called private cloud) using the same concepts.

Cloud computing is emerging as an important technology trend in almost every industry, including the GIS community, and it is rapidly moving into the mainstream. For many people, this is a more efficient solution for maintaining an information technology infrastructure. It also provides a solution for many government agencies, because it allows them to serve their data without the cost of administering hardware.

Crowdsourcing engages citizens in spatial data collection and civic participation, empowering everyone to participate.

Crowdsourcing

Sometimes referred to as volunteered geographic information (VGI) or user-generated content (UGC), crowdsourced data is data contributed by nonauthoritative sources (e.g., everyday citizens). Long the keepers of purely authoritative data, GIS practitioners are beginning to take crowdsourced data seriously.

Crowdsourcing gives ordinary citizens the opportunity to provide feedback directly to the government. It can significantly augment authoritative datasets. It provides extraordinary opportunities for citizen science, and it can put a virtual army of volunteers on a large project in short order.

The challenge for GIS practitioners is to ensure the usability of this data in a GIS workflow or to turn this crowdsourced data into useful geographic knowledge. This can mean checking the data to make sure it is authoritative; it can also mean getting involved in data collection, structuring the process to ensure that the collected data has meaning and is appropriate and authoritative.

GIS tools supporting crowdsourcing are changing the way organizations collect and manage spatial data. New tools support the ability to modify geographic content within any web mapping application and allow online communities to become active contributors to geographic databases. Web editing makes it easy to capture ideas and observations for distributed problem solving and extends GIS editing capabilities to more people within an organization. These capabilities allow everyone—from authoritative data editors to citizens on the street—to contribute content to the geodatabase. This will enrich geospatial infrastructure, giving GIS practitioners new types of data to use, manage, interpret, and incorporate into their work.

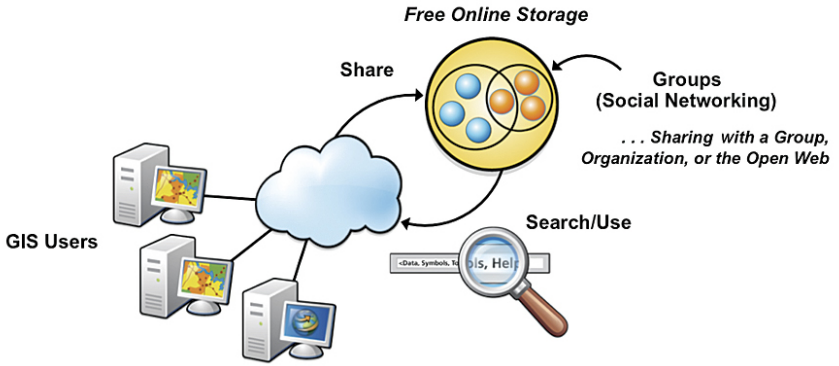
Neogeography

The neogeography movement—emphasizing ease of use, visualization, mashups, and so on—has been very successful at changing the way society uses and interacts with computer-based maps and geographic knowledge. Purveyors such as Google and Microsoft have made great advances in basic mapping, visualization, and mashups, and in the process have shown us new user interface patterns. GIS technology is learning from these new patterns and incorporating them in the next generation of software. As a result, the distinction between the world of neogeography and the GIS world is gradually disappearing, and GIS technology is becoming much more straightforward. This simplification comes from a new focus on how everyday people use the information and capabilities of GIS, resulting in a simple yet powerful system for working with maps and geographic knowledge. These changes are greatly increasing usability of the technology by GIS practitioners as well as society in general.

Collaboration

New collaboration technologies are redefining how we work together and share geographic information at every scale. This collaboration crosses traditional lines such as organizational boundaries, professional domains, and geographic borders. Sharing gives people access to vast stores of geographic knowledge that was previously difficult or impossible to obtain and leads to more informed decision making.

With new GIS collaboration tools, people can share and discover maps and apps and mash them up through virtually any device. The map is still the focus, but this map is different: behind this map sits the data model; the symbology of the map; and, in some cases, analytics. So when you share a map, you're not simply sharing a picture; you're sharing a collection of geographic knowledge. GIS professionals are already using this capability to



With GIS in the cloud, anyone can share maps, data, and applications.

create knowledge, maps, and models and easily publish them on the web for anybody to access

No one organization can create the GeoWeb or own the entire global spatial data infrastructure. These are being constructed by thousands of individuals and organizations all over the world

using new collaboration tools to create geoservices and build applications on top of this infrastructure.

GIS Is Changing

GIS has proved to be a flexible, adaptive technology, evolving as the information technology ecosystem around it changes. At each step in this evolution, GIS has not just adapted to these changes but embraced them, becoming more powerful and more valuable. Recent technological advances are helping us reenvision what a GIS is in a new context. As a web-hosted or cloud-based system with ready-to-use maps and apps, GIS is rapidly moving toward the vision of use anywhere, anytime, by anyone.

How we use GIS, the way we interact with it, and the way it interacts with the world are all changing. While some of this change has been and will be driven by new tools and technology, the biggest driver of change is you, the GIS user. Esri is not redefining GIS; you are. You're identifying the technologies that need to be embraced and the new functionality that needs to be added; and perhaps most significant, you are showing how GIS can be applied in new and exciting ways for the betterment of humankind and the environment.

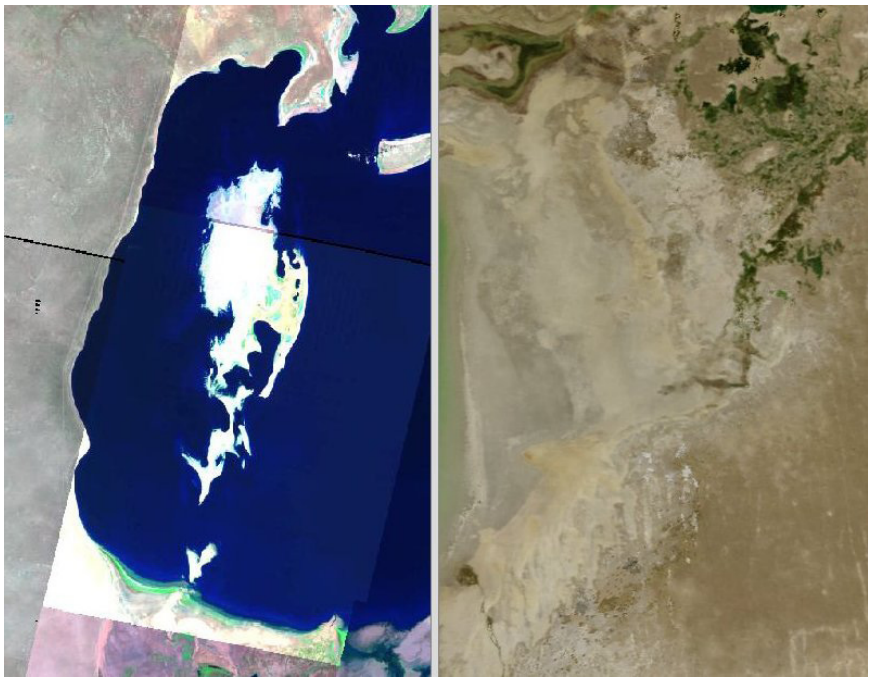
A New Understanding

Stories play an important role in society, and storytelling is one of the things that make us uniquely human. Stories convey important knowledge about the world around us, often in a simplified yet dramatic fashion designed for maximum impact. We have much to learn, remember, and understand in life, but wrap a great story around something, and it will make an impression on us that lasts a lifetime.

Maps are wonderful organizers of information, and they are an ideal stage on which to tell stories. But the stories that maps tell are not designed strictly for entertainment. Stories told with maps are designed to educate, inform, and inspire people. They are a platform for understanding and action.

What Is Understanding?

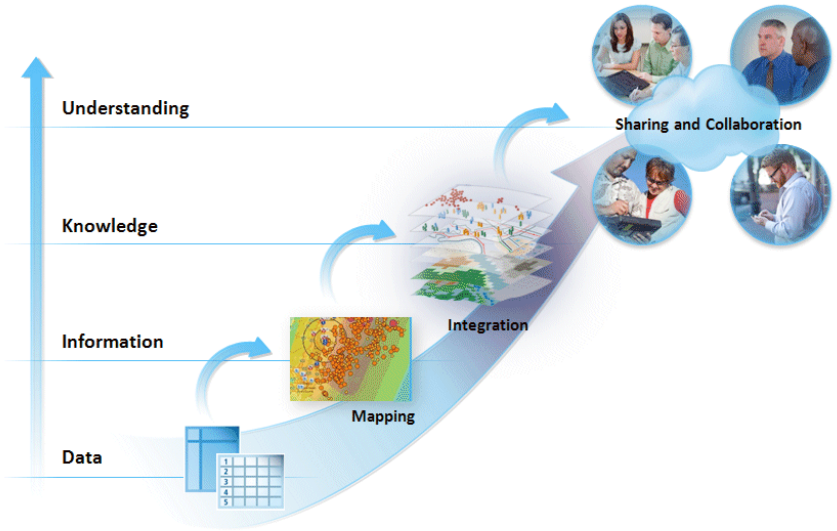
Our world is changing rapidly, and we're increasingly aware of the role humans are playing in that change. Climate change, urbanization, security, poverty, inequality—these are difficult problems that we must deal with, and they're affecting us as individuals as well as impacting our organizations and governments. For us to really address these things, we can't just keep doing the same things that got us here. We need a different approach. We need collective intelligence, and our actions need to be based on this intelligence. An informed, science-based approach is our best hope for confronting these unprecedented challenges. And the people who use GIS technology are playing



GIS is an important tool for telling stories that help us understand how human activity is reshaping the surface of the earth.

an increasingly important role in helping to create this new understanding of our world.

Understanding is about knowing. It's quite human and is built on real experiences, reasoning, and deep thinking. Knowing enables us to understand, think, predict, explain, add meaning, and gain insight. Our minds are the framework within which all this happens. They organize and synthesize information for us, then integrate it into our lives. This is understanding.



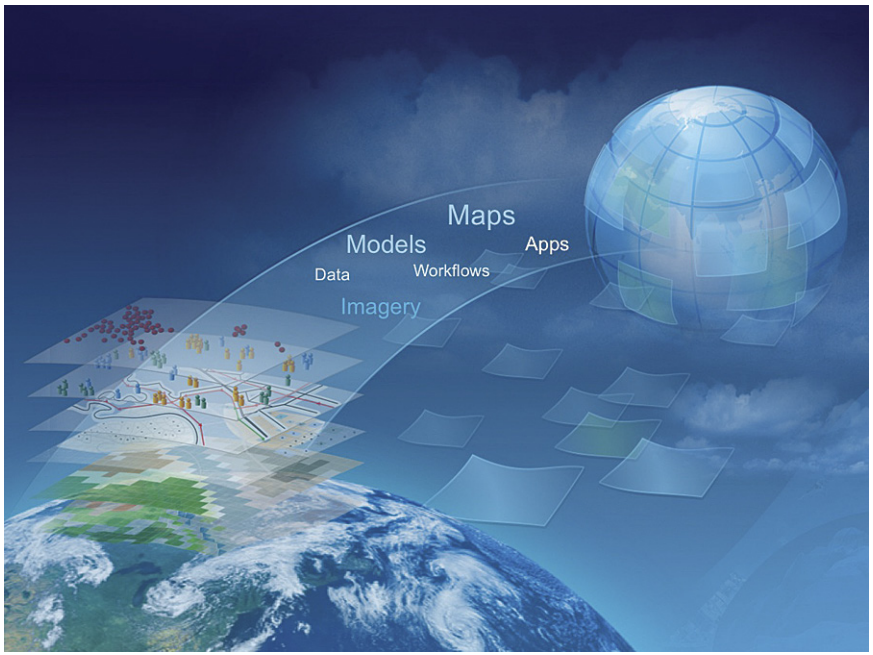
GIS helps us to understand and to make better decisions.

GIS as a Language

Geography has always been a critical type of information that humans—in fact, all animals—collect, organize, and use. Place-based information is vital to survival on our planet. As our world has become more complex, and our ability to understand has also grown, GIS technology has evolved to help us process information about place and put it in a context that allows us to act. GIS is actually extending our minds by abstracting our world into pieces of knowledge that we create and maintain—data, imagery, models, maps, and apps. GIS is facilitating a systematic framework for knowing, and our shared work is leading to collective understanding.

This is not just theoretical. From the beginning, GIS has been a very practical technology. When Tomlinson and his colleagues first began to implement these ideas in the 1960s, the problem was to harness the power of information technology to gain an understanding of geography that the human mind could not deduce without the assistance of computers.

Today, GIS integrates and synthesizes information from many sources and does it in volumes we could not have imagined 30 years ago. The availability of new technologies and the growing concern for our planet mean that we are producing an ever-increasing store of data describing our earth. We're being bombarded with data from a combination of old and new sources—satellites, sensors, crowdsourcing ("human sensors"),



GIS extends our minds, abstracting our world and providing a systematic framework for understanding.

models, digitized historic records, and much more. Only when these billions of bits of information are combined and organized can we achieve a higher meaning—a true understanding of our world. And arriving at this understanding will require the right technology and culture for sharing our data and building a common geospatial infrastructure.

As a kind of language, GIS also facilitates communication and collaboration, breaking down barriers between individuals, organizations, institutions, and the world. This is part of its power.

With the number and severity of the problems facing our modern world, many of them having to do with place, GIS is becoming an essential new language for understanding.

> *Our species needs, and deserves, a citizenry with minds wide awake and a basic understanding of how the world works.*
>
> *—Carl Sagan*

GIS for Everyone

A new pattern for GIS has emerged, making GIS available to everyone. A long progression of efforts is bringing our work—substantial, authoritative source information—to the web and blending it with social network and crowdsourced information. This new pattern is making all of this work available through lightweight viewers and mobile devices, providing a broad context of understanding to individuals, organizations, and governments—to everyone.

But will this new pattern be broadly adopted? Is it just of interest to GIS professionals, or will it be adopted by a wider audience?

In fact, because the benefits are so great, this new pattern of GIS for everyone is already being broadly adopted. It is connecting GIS professionals with knowledge workers, managers, policy makers, and citizens, extending the reach of geographic knowledge to everyone. It is empowering citizens

to participate in the same network environment, using the same infrastructure and sharing common services, to create a collective understanding.

GIS professionals continually amaze us with the creativity they display in applying the technology in solving complex problems and supporting critical decisions. From sea-level rise to deforestation; from disaster recovery to disease monitoring; from vehicle routing to demographic analysis, it's clear that GIS is already being widely used as a tool to help us understand and act.

Seeing the Big Picture

Geography has at least one thing in common with other disciplines: it has become fragmented. As our world has become more complex, science has responded by becoming narrowly focused. Thousands of very smart people are making remarkable discoveries in their own disciplines. But who is looking at the "big picture"?

It's only logical. When life gets complicated, we often tend to focus on the little things. It's a coping mechanism. It helps us deal with being overwhelmed; it helps us feel as if we are accomplishing something.

At some point we need to take a step back and realize that we can't understand an entire forest if we're addressing issues one tree at a time.

We've done an admirable job of examining and understanding a multitude of component pieces that make our planet work. Now our grand challenge is to integrate all this knowledge so we can understand the big picture.

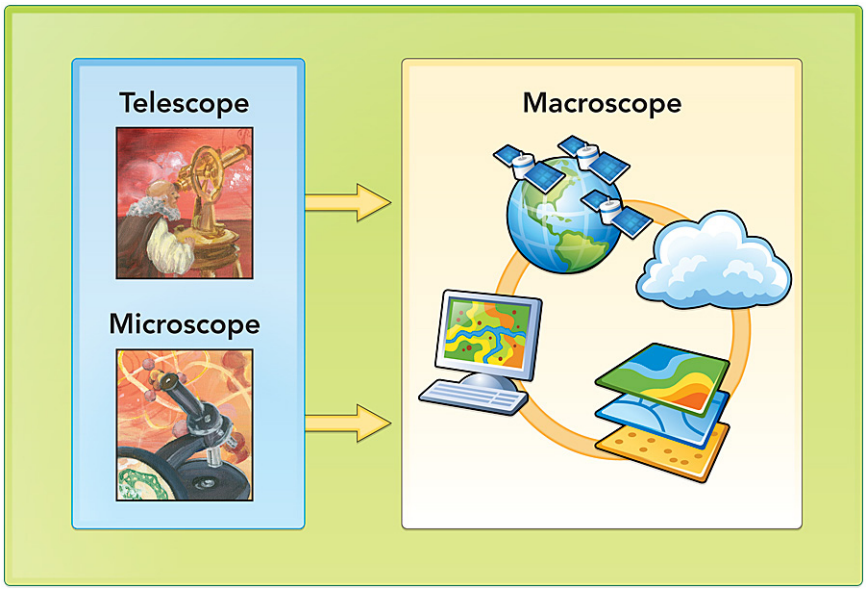
But how do we put all the pieces back together again so that we can understand the whole? How do we defragment our geographic knowledge?

Jerry Dobson, professor of geography at the University of Kansas, suggests that we already have the ideal tool for the job: the macroscope.

Citing the work of Joël de Rosnay, an early proponent of systems thinking, Dobson argues that the future of geography is "the macroscope"—a framework for assembling large amounts of environmental and human knowledge so that we can get a truly geographic understanding of our world.

> *We have in our hands a new scientific instrument as powerful as any that have come before it, including the microscope and the telescope. Collectively, GIS, GPS, satellite remote sensing, and popular geographics constitute a macroscope that allows scientists, practitioners, and the public alike to view the earth as never before.*

GIS technology is the unifying force that can bring together fragmented data and disciplines into a common framework. Collating and combining all the little discoveries is the next scientific frontier. It's where the next big discoveries will be made—by enticing people to view old questions in new ways—and dramatic new insights are likely to result from this.



"This geographically enabled macroscope . . . allows humans to visualize earth processes extending over vast regions or even the whole globe while still maintaining the finest measurable detail," says Dobson.

> *Clearly, there is much left to discover, and our community is in an ideal position to advance the macroscope and support or lead the coming revolution in science theory,* continues Dobson.

> *The macroscope is here today, and science is already changing in response to it. We are entering a new scientific era that may be every bit as exciting and enlightening as the revolutions prompted earlier by the microscope and telescope. Surely our professional lives will be richer, and science itself will gain, if we, who know the marvelous instrument best, insist on using it ourselves to tackle the greatest mysteries of our time.*

The Geoscape

The world around us is a complex place, and one way we manage that complexity is through a process of abstraction. In its purest sense, abstraction is about the reduction of detail down to the bare essentials we still need in order to understand.

Maps are a fascinating example of abstraction. Maps are abstractions of landscapes and geography, and they have proved to be a particularly useful aspect of human technology throughout our history. Until relatively recently, maps were predominantly two-dimensional: paper maps with complex geography abstracted onto a flat surface. New methods of presentation were created in an attempt to relay complex terrain and other information that moved beyond the two dimensions, but these methods, while useful, often fell short of conveying the true nature of complex geographic space.

Enter computers. The move from paper-based abstractions toward computer-based abstractions of geographic space has given us a powerful new context for understanding—and not just for two-dimensional landscapes, but for geography spanning the

third and fourth dimensions as well. Bill Miller likes to call this new canvas "the geoscape."

Beyond Landscape

Miller, head of the GeoDesign Services group at Esri, has a vision for the integration of geospatial technologies with the design process—a vision long shared by a group of people that includes University of California, Santa Barbara's Michael Goodchild, Harvard University's Carl Steinitz, and a handful of others. Miller took the first step toward making this vision a reality when he assembled a small team to develop a tool that allowed users to quickly sketch features in a GIS environment—the first small step toward what is now commonly referred to as "geodesign."

While identifying the technology hurdles the GIS industry needed to overcome to fully realize the promise of geodesign, Miller noted a fundamental contextual obstacle: our traditional approach to abstracting the landscape severely limited our ability to move forward with geodesign. We couldn't fully realize the vision of geodesign without a framework for a more holistic, comprehensive understanding of the world around us.

A New Canvas

Different levels of understanding often require different levels of abstraction, and it's clear that's what was happening with geodesign. As TED founder Richard Saul Wurman has so succinctly stated, "Understanding precedes action." Design

The geoscape provides us with a new canvas for designing a better future.

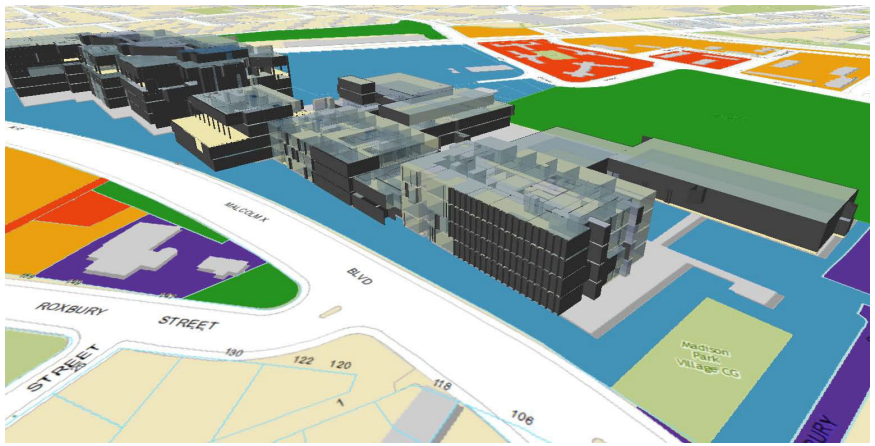
is action, and before we can design, we must understand. Geodesign—the act of thoughtfully creating the future for the mutual benefit of humans and the natural environment—requires a heightened level of understanding.

Understanding the world for the purpose of geodesign necessitated extending our view of geographic space. "This meant moving from 2D to 3D and to 4D, coupled with the idea that most data, at some level, is spatial and that all types of spatial data (physical, biological, social, cultural, economic, urban, etc.) can be georeferenced," states Miller. "This ultimately led to an expanded view of what is typically envisioned, or imagined, when referring to the geo portion of geodesign."

Extending our traditional methods of abstracting the landscape to include 3D "provides us with the ability to georeference what

lies below, on, and above the surface of the earth, including what exists inside and outside buildings, as well as 4D geographic space, or how things change through time," Miller notes. "This gives us the added ability to georeference time-dependent information such as population growth or the migration of a toxic plume through a building."

Miller likes to define *geoscape* as the planet's "life zone," including everything that lies below, on, and above the surface of the earth that supports life. The geoscape expands the view of what constitutes the content of geography as well as the dimensional extent of the geographic space used to reference that content. It gives us the context we need to actually do geodesign, "ensuring that our designs consider everything that supports or inhibits life."



The geoscape extends our thinking and understanding of the world around us.

The concept of the geoscape gives us a framework for extending our thinking about and understanding of the world around us. As we move from thinking just about the surface of the earth to now including what's below and above the surface, we take into consideration the full spectrum of the earth's life support system. This represents a significant transformation in the way people think about geography, geodesign, and the application of geospatial technologies.

Designing a Better World

The geoscape gives us a new canvas for understanding, for moving beyond traditional mapping for navigation and location, and for using our maps for active designing and decision making. Moving from the landscape to the geoscape gives us the canvas we need for designing a better world. After all, as Miller is fond of saying, "The purpose of design is to facilitate life."

The New Explorers

As the scientific foundation of GIS, geography has for many years been concerned with exploring and describing our world. Historically, explorers led grand expeditions to the farthest reaches of the globe. This golden age of exploration contributed greatly to our understanding of how our world works.

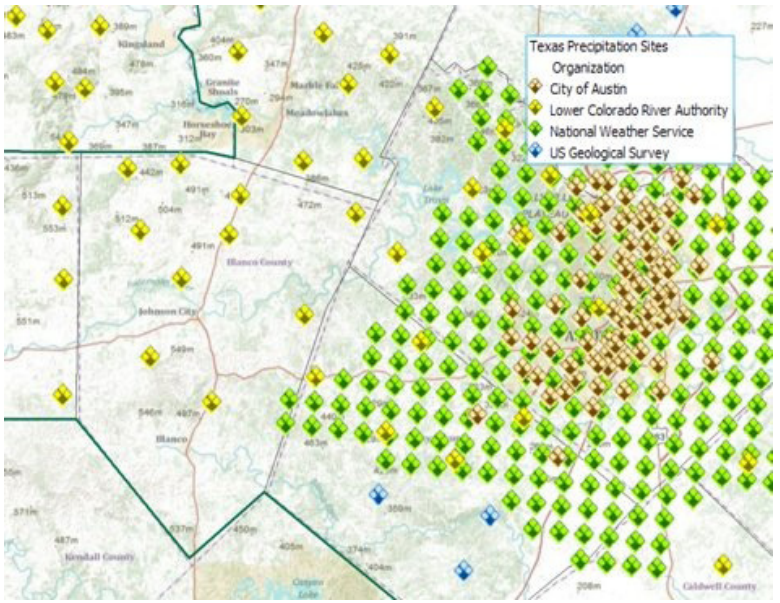
This was followed by the space age—an era where we completely left the planet and turned our cameras and sensors to look back on our home, giving us an entirely new perspective of ourselves, our planet, and the opportunities for exploration that await us. No longer bound to the surface of the earth as our species had been for untold millennia, the view from a few hundred miles up in space gave mankind its first glimpse of our planetary system as a whole.

While data remotely sensed from satellites continues to play an important role in monitoring and understanding our planet, "earth observation" has more recently taken on a whole new dimension, thanks to the deployment of an increasingly more complex and pervasive network of earthbound sensors. These sensors are practically everywhere you look—and in places you could never imagine. From stream gauges to seismographs, from weather stations to air quality monitors, from ocean buoys to even ourselves, countless sensors are measuring and collecting important data about our planet at a rate that was inconceivable just a short time ago.

Modern science and advanced technology have resulted in unprecedented access to global environmental information through the placement of countless sensors across the planet—and the linking together of this information through the Internet.

We're collecting more information about the geography of planet Earth today than ever before. New data sources, along with the sheer volume of data being collected, are spawning a new age of exploration. But the new explorers are navigating a vast, uncharted sea of data. What do we do with all of this sensed data? How can we make sense of the sensor web?

This new sensor web has inundated us with data that needs to be stored, managed, analyzed, and used to inform better decisions about our many environmental challenges. Integrating and synthesizing all this disparate sensor data into a single,



GIS enables real-time integration of sensors from multiple sources, using maps as a means to help us understand our world.

comprehensive view—a global dashboard—is our next great opportunity for exploring our world.

A global dashboard is a decision support tool that helps monitor current conditions, identify change, and drive informed action. It enables exploration at scales from local to global. It allows people to visualize large, complex spatial datasets in the context of their neighborhoods, their streets, and their houses. The ability to explore a world of data from a personal perspective is a very powerful idea.

Thanks to the rich information flow provided by our new world of sensors and the availability of new mapping tools to display and analyze this information in context, now everyone can be an explorer. This has far-reaching benefits to both society and the environment, ushering in a new era of science-based understanding and leading us toward more informed, equitable, and sustainable action.

> *The world, indeed the whole universe, is a beautiful, astonishing, wondrous place. There is always more to find out.*
>
> *—Derek K. Miller*

Designing Our Future

Design is always and necessarily an art as well as a problem-solving activity.

—*David Pye,* The Nature of Design

The key to developing a true understanding of our complex and dynamic earth is creating a framework that allows us to take many different pieces of past and future data from a variety of sources and merge them in a single system. GIS is a sophisticated technology already in widespread use by planners, engineers, and scientists to display and analyze all forms of location-referenced data about the health, status, and history of our planet.

GIS enables a geodesign framework for analyzing and managing anthropogenic earth issues by allowing us to inventory and display large, complex spatial datasets. We can also analyze the potential interplay between various factors, getting us closer to a true understanding of how our dynamic earth systems may change in the coming decades and centuries.

Geodesign borrows concepts from landscape architecture, environmental studies, geography, planning, regenerative studies, and integrative studies. Much like GIS and environmental planning before it, geodesign takes an interdisciplinary, synergistic approach to solving critical problems and optimizing location, orientation, and features of projects both local and global in scale.

Design is art within the framework of limitations—limitations that arise as a result of function, world view, bias, and other factors, but also limitations that arise as a result of place. Design considering place was at the core of Ian McHarg's beliefs, and it is the basis for research and development efforts in the emerging field of geodesign.

To a certain extent, this is already done today by numerous GIS practitioners in fields like urban and regional planning and environmental management. But geodesign makes this easier by making it an integral part of the workflow, both shortening the cycle time of the design process and improving the quality of the results.

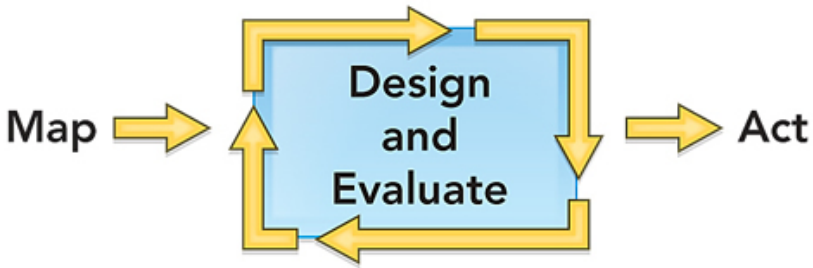
The Geodesign Process

When an idea is proposed with geographic consequences—a housing development, a shopping center, a road, a wildlife preserve, a farm—it first goes through a design process. After

it is initially designed, a project is vetted against geographic constraints.

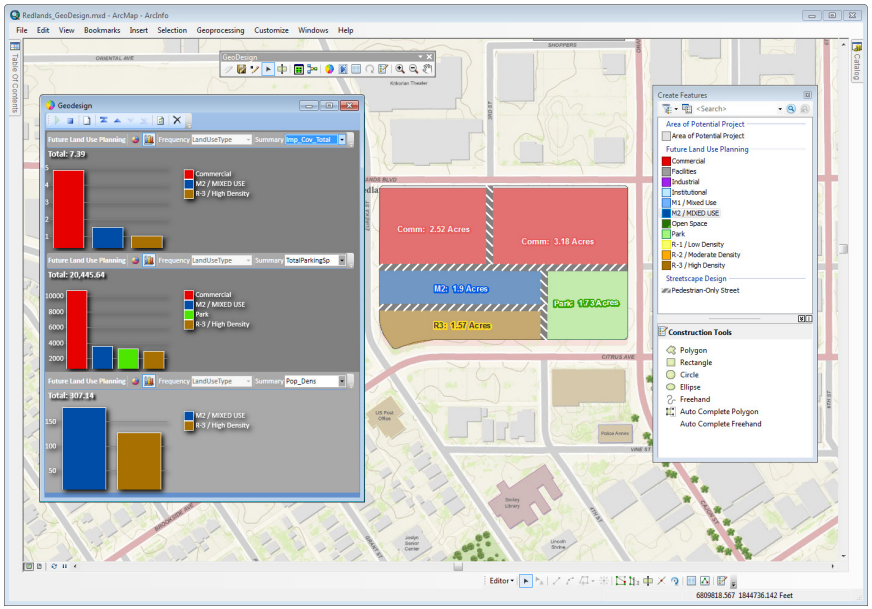
A typical project will go through many iterations of design and evaluation. As the constraints of geography on the project—and the impacts of the project on geography—are revealed, the design is continually refined. Because design and evaluation have traditionally been separate disciplines, this phase of a project can be time-consuming, inefficient, and tedious.

What if we could reduce the time and tedium of these iterations by integrating design directly into the GIS workflow?



This integration—which we refer to as the geodesign workflow—is a promising alternative to traditional processes. It allows designers and evaluators to work closely together to significantly lessen the time it takes to produce and evaluate design iterations.

Cycle time is shortened because geodesign moves analysis to an earlier stage in the design process. Rather than analyzing the potential effects of a proposed project after the design phase, critical factors are instead taken into consideration up front. The quality of the results improves because the project is designed around, in concert with, and/or to fully leverage certain geographic, environmental, and social features while simultaneously minimizing undesirable impacts to those same features.



Interactive geodesign tools let us design the future while considering geographic constraints.

Combining the wealth of available data about our world with sophisticated analysis and management tools is the prescription

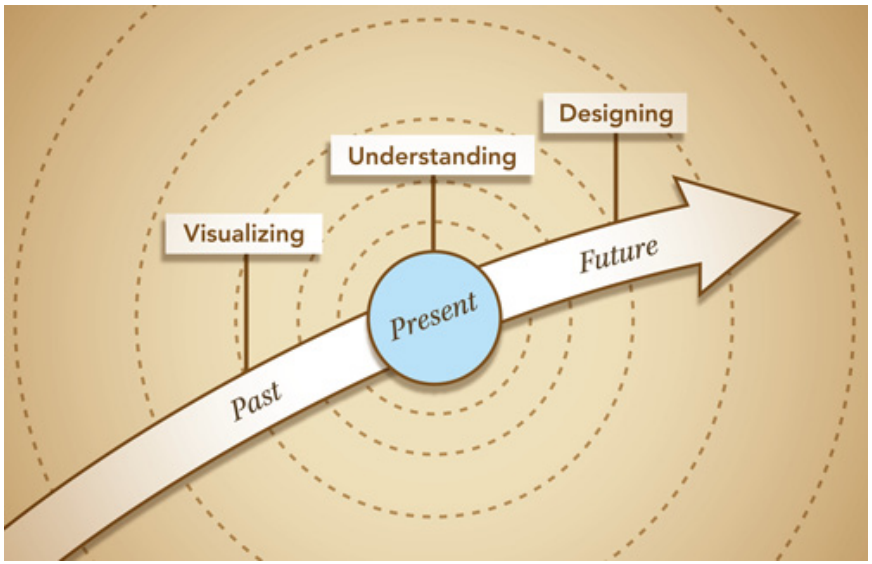
for understanding and shaping the future of our planet—an anthropogenic future where advances in human society, technology, and so on, are designed in close collaboration with nature, resulting in the best of the possible future worlds. And this is what "designing our future" means. It's a huge task and a delicate balance, for sure, but with help from GIS and geodesign tools, we readily accept that challenge. Because, frankly, we have no other choice.

Traveling through Time

The concept of a time machine as used in science fiction has certainly captured our collective imagination. But the science behind time travel is dubious at best. Although we can't actually physically move backward or forward in time, we can at least experience some of the thrills—and benefits—of time travel with GIS.

Geospatial professionals are well versed in the visualization of spatial relationships and dependencies. But it is equally important, when looking for relationships and dependencies, to examine proximity in time. McHarg put great emphasis on chronology, or the placing of geographic layers in chronological sequence to show relationships, dependencies, and causation through time.

"We found the earliest events, mainly of geological history, had pervasive and influential effects, not only on physiography, soils, and vegetation, but also on the availability of resources," McHarg states, describing an early environmental planning study in his book *A Quest for Life*. He calls his discovery of chronology, or the order or sequence of geographic features through time, "a most revelatory instrument for understanding the environment, diagnosing, and prescribing." McHarg's chronology is an important concept to grasp, as it can lead us to a deeper understanding of structure and meaning in the landscape.



We need to move beyond passively trying to "predict" the future toward actively creating or "designing" the future.

Using chronology to visualize the past is certainly an important tool to help us understand the present. But can we do even more

with this geographic knowledge? Can we use it to predict the future?

The Problem of Prediction

Predicting the future is an elusive exercise. Just pick up an old magazine from the 1960s that talks about what life will be like in the year 2000, or watch a movie or read a book set 50 years out. While highly entertaining, nobody ever gets it right. Very few get even remotely close.

The real problem of predicting the future is one of complexity. "There really is only one past," notes Stephen Ervin of Harvard University's Graduate School of Design, "but there are multiple futures." So if predicting the future is so difficult, impractical, or downright impossible, should we even bother trying? Is there anything to gain from such folly?

Perhaps we need to move beyond prediction and find a different way to think about our relationship with the future. "The future can't be predicted," says environmental scientist and systems thinker Donella Meadows, "but it can be envisioned and brought lovingly into being."

Envisioning the Future

As McHarg states in his book *To Heal the Earth*, "Processes, laws, and time reveal the present." Meadows echoes this idea, noting, "We experience now the consequences of actions set in motion yesterday and decades ago and centuries ago." Projecting this same concept of chronology forward in time, we can study the past to both understand the present and envision the future. As someone said at the 2012 GeoDesign Summit, "By designing geography, you're designing history." We need to embrace this idea.

"In a very real way, designers create the human environment," says William McDonough in *Twenty-First Century Design*. "They make the things we use, the places we live and work, our modes of communication and mobility." From a building to a highway, from a city to a utility network, geographic design decisions we make today can have huge consequences for the lives of future generations.

We have the geospatial tools and techniques in place to understand how the past has created the present, and through the thoughtful and careful application of these same tools and techniques, we can more actively design the future. Trying to shape our current actions to ensure the best possible future is a delicate balancing act, and there are many complex factors to consider. But achieving that balance offers hope for a future ideally suited to both humans and the environment.

Instead of asking what the world might look like in the future, we should begin asking ourselves: What do we want the world to look like? And how can we make it happen?

A New Relationship

Our use of and reliance on technology has moved us toward a new relationship with the environment. In countless ways, both seen and unseen, the ecosystems we once saw as "natural" have become strange hybrids—part natural, part man-made, struggling for balance under the watchful eye of human management.

As we move forward in this more mutually beneficial relationship with the environment, the dynamic is evolving—from using technology to merely exploit our surroundings toward the thoughtful application of technology to actively manage, design, and sustain our surroundings. This new relationship with the environment features a much tighter integration between humans and technology, where all decisions are carefully designed to maximize the benefit—and minimize the harm—to both humans and natural systems.

An Informed Environment

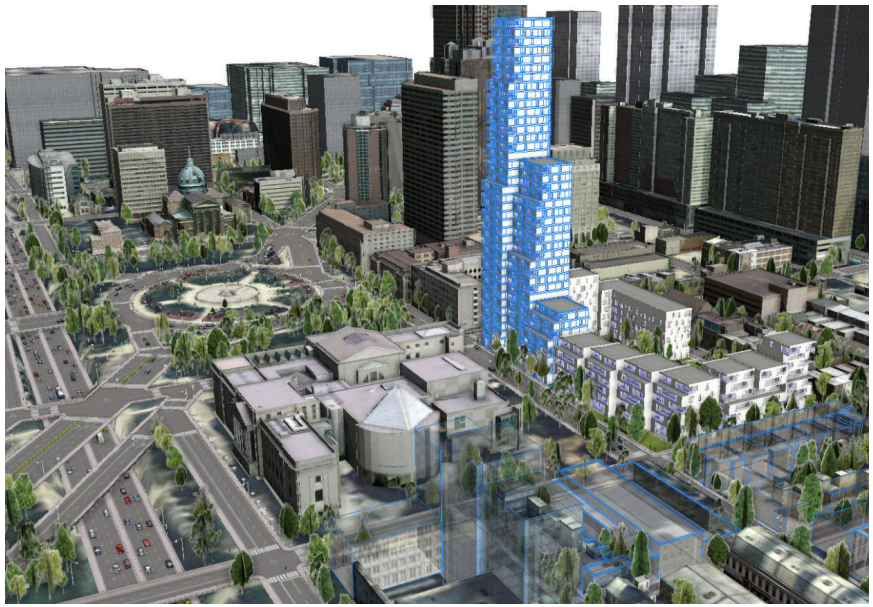
When man began to understand the overwhelming effects of mass exploitation on natural earth systems, he reacted with conservation. This era began with the preservation of significant, dramatic, and unique examples of ecosystems, perhaps best exemplified by national parks such as Yellowstone and Yosemite. This trend continued with the preservation of remnant pieces of ecosystems—the setting aside of the last remaining bits of wildness.

For all the successes of conservation, this technique is not without its problems. It has resulted in fragmented and incomplete ecosystems that in some cases are no longer self-sustaining and continue to be heavily impacted by the hand of man.

Technology's Role

Despite all this, technology isn't all bad for the environment. As the human world becomes universally instrumented, we are amassing vast amounts of data. We need the ability to manage this ever-increasing volume of data so that we can discover, we can learn, and we can use this valuable information to act in more responsible ways. The key to solving this vast information problem is information technology—and specific to addressing ecosystem issues and managing the human-influenced landscape is GIS technology.

It's true that technology has made our world more complex. But technology can also serve the purpose of managing this complexity. GIS technology now permits a science-based approach to ecosystem management that was unthinkable until recently. We use it to predict the likely locations of endangered animals, to model how plant communities might shift due to climate change, and even to design places where man and nature can coexist more peacefully. Mapmaking and geographic analysis are not new, but GIS technology helps perform these tasks better and faster than was possible using the old manual methods—an increase in efficiency and accuracy sorely needed to address the tough problems we face in our increasingly complex world.



GIS technology helps us make sense of a complex world.

The New Natural

In the twenty-first century, information technology is becoming our most valuable tool for managing complexity and designing a better world. "Technology offers a continually, if unevenly, expanding domain of increasing human control and power in the world, and in the process, technology continually transforms the natural and social worlds," say Braden Allenby and Daniel Sarewitz in *The Techno-Human Condition*. "Technology embodies the modern ideal of applying rationality to the betterment of humankind."

We tend to think of "natural environment" and "human technology" as two opposing, almost mutually exclusive ends of the spectrum. But as technology becomes more pervasive in our world and more tightly integrated with our very existence, in fact the opposite is true. If we do it correctly, this integration will allow humans to enter a more mutually beneficial relationship with the environment. We are moving forward as a species, toward a time when technology will play an essential role in sustaining the habitat of all species—including humans—and actually help us to design that habitat.

As Marina Gorbis notes in *Human Plus Machine*, technology amplifies our capabilities, "enabling us to do things we never dreamed of doing before." For us to meet the monumental challenges of the future, David Kirkpatrick, author of *The Facebook Effect*, states that "We will only be successful if we unreservedly embrace technology and innovation as essential tools." Yet as Louis Gerstner, notes, we need to approach this relationship carefully: "Computers are magnificent tools for the realization of our dreams, but no machine can replace the human spark of spirit, compassion, love, and understanding."

From a simple spear to a smartphone, tools extend our abilities, but we need to be careful to not lose touch with what actually makes us human. As technology becomes more tightly integrated into virtually everything we do, we need to understand that it's not a blessing, nor is it a curse—it's simply a tool of our own creation, a tool to help us move down the path toward our

destiny. Or, as Allenby and Sarewitz note, "Technology is neither the answer nor the question, it's just the condition."

The Future of Cities

Seven billion. That number has received a lot of attention recently as global population has grown past this mark. But lost in the media coverage of this milestone was another, perhaps even more fascinating global statistic: more than 50 percent of those 7 billion people now live in cities, a number projected to grow more than 75 percent during this century. In fact, there will be at least 19 cities in the world with a population greater than 20 million by the end of the twenty-first century. Cities are human destiny.

Clearly, cities will play an increasingly important role in our future survival. Cities offer easier access to services, and urban dwellers are more efficient consumers of limited resources. But as our cities become more populous and more numerous, how do we best manage this complexity?

We need to start thinking about cities in a different way:

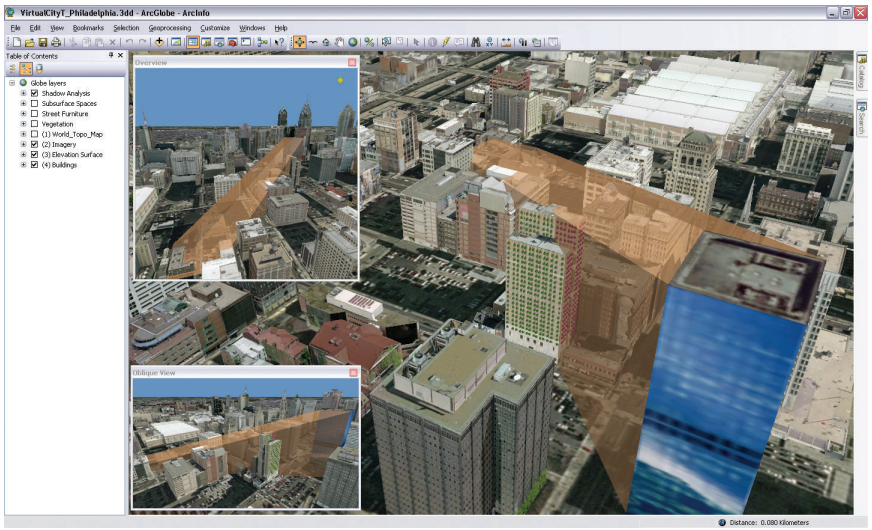
- Reimagining the canvas—Fundamental to changing the way we think about cities is a reimagining of the way we abstract them. GIS technology gives us a powerful new context for extending our traditional methods of abstracting the geography of cities—a new canvas that includes everything that lies below, on, above, and around the city, including what exists inside and outside buildings, as well as how things connect to the city and how all of these things change through time.
- Cities as ecosystems—Cities are the places where most of us now spend the vast majority of our lives. They have in fact become man-made ecosystems. Recognition of cities as the primary habitat for the human species is leading to new approaches to their management and design. GIS technology has long been used to map, study, analyze, and manage natural ecosystems. It only seems logical to manage, model, and design our new man-made ecosystems with the same tried and true tools.
- Buildings as microcities—As our cities are growing in size and complexity, so too are the buildings that make up much of the fabric of the city. In effect, many buildings and facilities are becoming small cities themselves, and they need to be designed and managed as such. GIS tools, used successfully for many years in fields such as environmental analysis and landscape planning, also support a broad range of applications inside and outside buildings and facilities.
- An engaged citizenry—Smart cities of the future will be those where citizens are engaged in their design and evolution, where the collective intelligence of the masses is leveraged and everyone can actively participate in shaping the community. GIS technology has already proved to be an

effective tool in supporting citizen engagement. Intelligent web maps are acknowledged as catalysts for solving key challenges in creating a dialog through informed citizens. As web and cloud-based GIS continues to evolve and social media and mobile devices become more pervasive, governments will continue to deliver innovative forums through interactive information and participatory citizen applications.

- Designing future cities—Geodesign is a concept that enables architects, urban planners, and others to harness the power of GIS to design with nature and geography in mind. Geodesign results in more open participation through visualization, better evaluation of proposed scenarios, and a deeper understanding of the implications of one design over another. Combining the strengths of data management and analysis with a strong design and automation component is fundamental to designing the cities of the future.

Cities are intricate collections of materials, infrastructure, machinery, and people, with countless spatial and temporal relationships and dependencies. They require progressively more sophisticated tools for their design and management. They are complex systems where we humans spend an increasing amount of our lives.

Our challenge is to design our man-made ecosystems to achieve the maximum benefit to society while minimizing short- and



GIS helps us think about cities in a different way.

long-term impacts on the natural environment. As an integrative platform for the management and analysis of all things spatial, GIS technology can help meet this challenge.

Cities are our new man-made ecosystems, and it's time we start to think about them, manage them, and design them as such.

The Climate Challenge

Earth's climate has undergone radical changes in the distant as well as the recent past and is almost certain to undergo more radical changes in the not-too-distant future. As industrialization, population, and urbanization continue to increase, so too will stressors on the environment, such as pollution. Such change in

climate and environmental quality could have huge implications for quality of life. Regardless of where each of us stands on the often politically charged issue of global climate change, we owe it to ourselves and our children to take an informed look at the scientific data and develop actionable, intelligent alternatives.

We live in an age of readily and freely available information. The Internet has given us unprecedented awareness of and access to vast quantities of climate data. Never before have scientists and nonscientists had such easy and open access to the data and tools needed to study the earth's climate. Both past observations and future predictions are useful in studying climate change. Examining and cross-referencing past and future data can help quantify changes already occurring as well as predict patterns and trends that could impact climate in the near- and long-term future.

For decades or longer, and for thousands of locations around the globe, humans have been keeping careful records of rainfall, temperature, lake levels, streamflows, and so on. Beyond these historical records, additional records of climate change stretch back even farther; consider the fields of dendrochronology, which measures the size of tree rings and reveals climate data stretching back for thousands of years, and palynology, which examines changes in the type and distribution of fossil pollen and gives us clues about climate that go back millions of years. The result of all this information collection and research is vast stores of data describing conditions at particular locations on the planet at particular points in time.

For years, scientists have been using sophisticated computer models in an attempt to visualize the future of earth's climate. The output of a particular model can be enlightening, but using GIS to combine data from multiple models and sources, both past and future, gives us the best chance for a comprehensive and accurate vision of what the future holds for our planet.

The Next Generation

Many industries have suffered during the current economic downturn. So why is it that during this same period, demand for geospatial technology professionals has grown significantly?

We think that this trend is due to the growing understanding of the value of spatial information and analysis. There are many reasons to implement GIS, but the benefits that we see driving organizations in lean times are cost savings resulting from greater efficiency. And as we come out of this economic downturn, the efficiencies realized from GIS will become a standard way of doing business, so the need for geospatial professionals will increase even more.

Government has long been at the forefront of this movement, and there will be opportunities here for people with geospatial knowledge, most notably in the area of homeland security and the agencies concerned with increased transparency and

accountability. But we're now seeing a huge shift in momentum in the commercial arena. Many of the future career opportunities for geospatial professionals will be in the private sector, as businesses increasingly realize the benefits that government has understood for some time.

The current high unemployment rate is sending a lot of experienced workers "back to school" to learn new skills more relevant to the twenty-first-century workplace. This is one factor driving the growth of focused geospatial programs at universities and community colleges, both at the degree level and the certificate level. These programs are doing a great service by training the geospatial work force of tomorrow. They are also providing many opportunities for seasoned geospatial professionals to take on new roles themselves—passing on their vast knowledge by instructing and teaching the next generation of geospatial professionals.

But the career opportunities here are not just for the people who sit in front of keyboards and "do GIS." It's much bigger than that. The real growth opportunity is in the area of spatial thinking. As people in all types of positions become more familiar with the value of geography, they begin to ask more intelligent questions about the world, and they begin to make better informed decisions.

The future looks bright for the next generation of spatial thinkers. And these are the people who are going to change the world.

As the reach of spatial information expands, new opportunities are created for spatial thinkers in many areas.

A New Understanding

Maps have long been used by man for communicating and understanding. Today, modern mapping and GIS technology drive a new relationship between humans and the environment, giving us the geographic understanding we need to proactively design a better future.

About the Authors

Jack Dangermond founded Esri with a vision—that computer-based mapping and analysis could make significant contributions in the areas of geographic planning and environmental science. The recipient of 10 honorary doctorate degrees, he has served on advisory committees for the National Aeronautics and Space Administration, the Environmental Protection Agency, the National Academy of Sciences, and the National Science Foundation.

Matt Artz writes for Esri about the value of using GIS technology to advance scientific understanding.

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Esri inspires and enables people to positively impact their future through a deeper, geographic understanding of the changing world around them.

Governments, industry leaders, academics, and nongovernmental organizations trust us to connect them with the analytic knowledge they need to make the critical decisions that shape the planet. For more than 40 years, Esri has cultivated collaborative relationships with partners who share our commitment to solving earth's most pressing challenges with geographic expertise and rational resolve. Today, we believe that geography is at the heart of a more resilient and sustainable future. Creating responsible products and solutions drives our passion for improving quality of life everywhere.

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