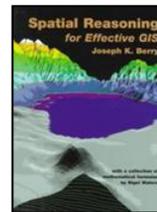


Topic 9 – Putting GIS in the Hands of People



[Spatial Reasoning](#) book

[Put Things in Their Proper Places with GPS](#) — identifies the basic concepts, principles and theoretical underpinnings of the Global Positioning System (GPS)

[GIS and Remote Sensing Share a Lofty Marriage](#) — identifies the basic concepts, principles and theoretical underpinnings of Remote Sensing (RS) technology

[Heads-Up and Feet-Down Digitizing](#) — discusses the design components of a GIS/GPS/RS field unit

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Put Things in Their Proper Places with GPS

(GeoWorld, September 1995)

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GIS is awesome. It allows you to view maps in the blink of an eye, visualize spatial patterns in datasets, and even model complex relationships among mapped variables. But its abstract renderings (i.e., maps) require a real-world expression to make GIS a practical tool. For years, "field folk" have been swatting mosquitoes and lusting for a simple way to figure out where they are and where they're going. Celestial navigation methods used by early mariners as they gazed at the heavens eventually gave way to surveying and mapping sciences. But such solutions still seem beyond the grasp of average bushwhackers. What's needed is a simple field unit that puts the awesome power of GIS in their hands.

That's where the Global Positioning System (GPS) comes in. Based on a constellation of 21 satellites, each of which circles the globe every 12 hours, GPS links GIS maps and their datasets to real-world positions and movements. In effect, a set of man-made stars supports the electronic equivalent of celestial navigation. How does it work? And will it work for you?

Figure 1 shows important GPS considerations. The system employs the same principle of triangulation commonly used in scout camp and high school geometry. Circles of a calculated

distance are drawn about a set of satellites whose precise positions are known through orbit mathematics described in satellite almanacs. The intersection of the circles determines your position on Earth. In trigonometric theory, only three channels (satellites) need to be monitored, but in practice four or more are required to cancel receiver clock errors. The radii of the circles are determined by noting the time lag for a unique radio signal from a satellite to reach you, then multiplying the elapsed time by the speed of light at which the radio waves travel. The world of electronic wizardry (involving technical stuff like pseudo-random code, carrier phase, ephemeris adjustments, and time hacks) allows timing to one billionth of a second (.0000000001), producing extremely accurate distance measurements in three-dimensional space. Generally, averaged stationary measurements (static mode) tend to be more accurate than those made while moving (kinematic mode).

Global Positioning System (GPS)

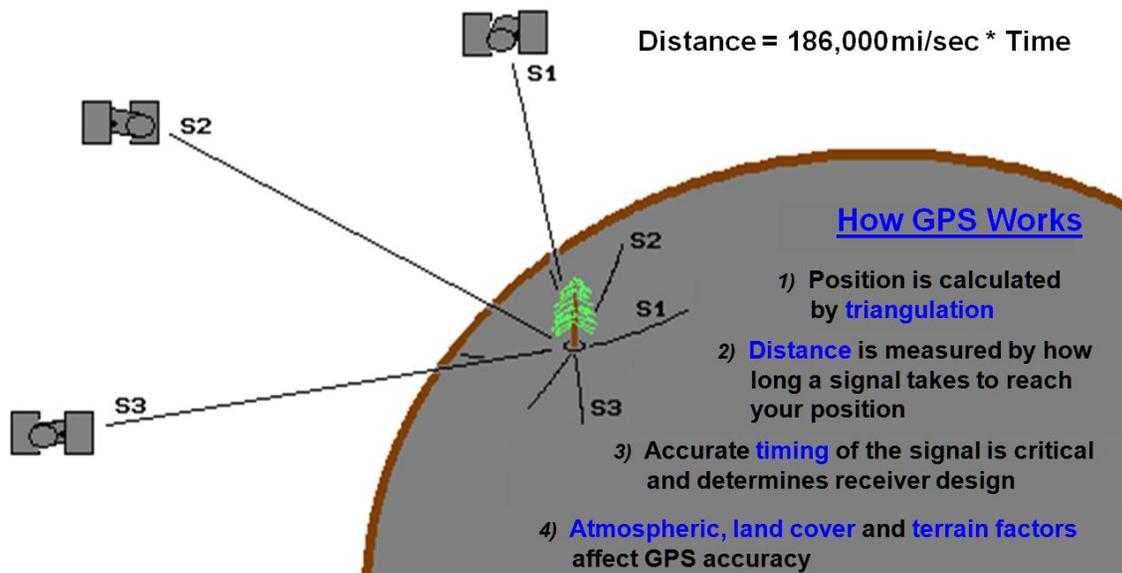


Figure 1. The basic elements and considerations of the Global Positioning System.

As with everything in the real world, actual GPS performance depends on several muddling factors, the most influential of which is GPS's history as a U.S. Department of Defense program. The government financed the \$10 billion system for military purposes and feels uncomfortable if just anyone, such as terrorists or enemy troops, can simply tap into the system. The government purposely degrades the signal by using an operational mode, Selective Availability (S/A), which provides only 100-meter accuracy. With S/A turned off, 30-meter accuracy is common.

The degraded signal can be improved by a differential correction. A differential GPS uses a local reference receiver whose exact position is known. When the reference receiver gets a satellite signal, it calculates its implied position, then quickly "reverse calculates" the error

correction needed to place it where it should be. The correction is broadcast to field units or stored for post-processing back at the office.

In general, there are two main hurdles in processing GPS signals: jitters and jumps. As with any instrument, inherent error for a set of readings at a fixed location yields a *jittery cluster* of possible positions, termed the “sphere of uncertainty.” Also, satellites come and go with time; as one is dropped and another picked up, the positions often take a *temporary jump*. Processing software uses running and dampened averages of several readings to cope with jitters and jumps. Keep in mind that the silicon in all GPS receivers is about the same— creative software separates one receiver from another.

A well-tuned differential GPS system in static mode can place you within a meter horizontally and five meters vertically, while a simple autonomous system for \$200 or so can place you somewhere within a ball park—that is if atmospheric, ground cover and terrain factors permit— signals deteriorate under dense forest canopy or at the bottom of steep canyons. Also, the satellites aren't always available in a nicely dispersed pattern. That means you need to plan to be in the field at the times the satellites' celestial charts dictate. (Try explaining that one to your field crew.) Finally, it's important to keep in mind that GPS isn't intended to fully replace conventional surveys. Rather, it augments cadastral records with real-time and real-world positioning.

GPS's ability to locate positions on Earth's surface rapidly and accurately is a powerful addition to GIS. For example, the boundary of a wildfire can be digitized quickly with a GPS simply by walking (or flying in a helicopter) over the burn's perimeter— putting the fire in the GIS while it's still hot. From a forester's perspective, the GPS'ed map can be overlaid on existing inventory information to quantify timber lost and plan for salvage logging and forest regeneration. From a wildlife biologist's perspective, the burned area can be translated into habitat loss estimates, affected animal populations and ecosystem recovery plans. That means the forester, biologist, and others can be locked in honest debate regarding accurate and fully integrated data within hours of a geographic event.

In addition, a GPS receiver can be attached to a vehicle to generate an accurate map of important features and roads en route to various locations. According to rangers working in the U.S. Forest Service's Rocky Mountain region, GPS has reduced the time they spend in the field 50 to 80 percent, with minimal crew instruction. For example, a two-man team using GPS completed a section subdivision in less than a day— a task that normally takes a week with conventional survey techniques.

GPS's contribution to generating and updating GIS maps is obvious. Yet GPS is more than a data collection device— it's a practical tool to navigate GIS results. As GIS matures, more of its applications will involve GIS modeling, such as variable-width buffers around streams that allow for terrain steepness, ground cover, and soil erodibility. Although such relationships follow common sense, their spatial expression is complex. The contractions and expansions of a

variable-width buffer on a paper map are practically gibberish to a field crew' If the coordinates of the buffer are loaded into a GPS, however, the result delineates the spatial reasoning and its complicated expression in the actual landscape.

GIS and Remote Sensing Share a Lofty Marriage

(GeoWorld, October 1995)

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As noted in the previous section, GIS/GPS technology positions spatial data and reasoning on the landscape. But effectively identifying, measuring, and monitoring the landscape over extensive areas is an ongoing challenge. Remote sensing (RS), closely related to GIS, greatly enhances the technical mapping toolkit. Remote sensing is GIS's older brother, using relative variations in electromagnetic radiation (EMR) to identify landscape characteristics and conditions. In fact, so do your eyes. Sunlight, the form of EMR we see, starts off with fairly equal parts of blue, green, and red light. When sunlight is reflected from a leaf, the red and blue light is absorbed in photosynthesis and your eyes detect mostly the unused green light. Your brain interprets the subtle differences in the amount of blue, green, and red light to recognize the thousands of colors we relate to our surroundings.

A remote sensing satellite operates similarly. Its instruments focus for an instant at a spot on the ground measuring less than a quarter acre (see figure 1). Like your eyes, it records the relative amounts of the different types of light it "sees"— a lot of green for a dense, healthy forest; less green and more blue and red for bare ground. In addition to normal light (the visible spectrum), it can record other types of EMR our eyes can't see, such as near infrared, thermal, and radar energy. As the sensor sweeps from side to side and the satellite moves forward, it records the light from millions of spots, termed pixels for "picture elements." When the pixels are displayed on a computer, they form an image similar to an aerial photograph. Yet keep in mind that behind the image are millions of numbers that record the relative amounts of energy returned for various types of light at each spot.

That organized mountain of numbers is used to identify land-cover characteristics and their condition. First, the computer is "trained" by locating representative areas of the cover types to be classified— sort of rubbing the computer's nose in what it should know. Then that information is used to classify other areas with similar EMR responses. As shown in the center of figure 2, the computer examines the amount of light for each type from the hundreds of training pixels in the examples. It notes that forests tend to have high green and low red responses, while bare ground has low green and slightly more red. The big dot in the center of each data cluster is the average amount of green and red light the typical response for that cover type.

GIS and Remote Sensing (RS)

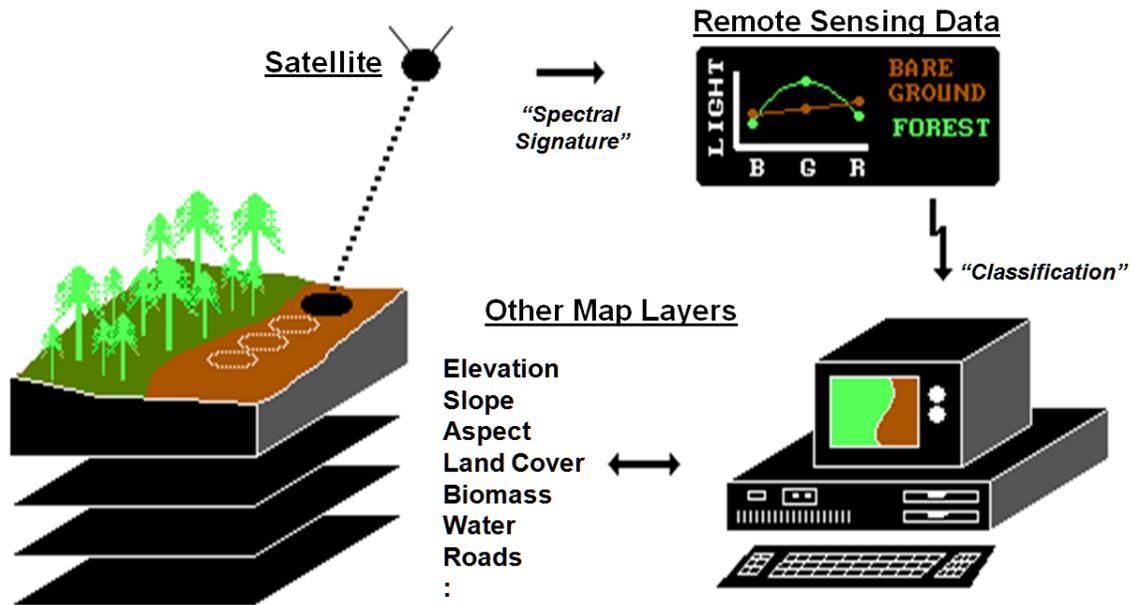


Figure 1. Remote sensing's basic elements and considerations.

Now the computer can consider the green/red responses for the millions of other locations and classify them through "guilt by association" with the training set statistics. In effect, through complex computer mathematics it plots an unknown location's green/red numbers (the "x" in the right graph of figure 2) notes the distance to the typical responses, then classifies the location as the closest cover type. Then it moves to the next spot, and the next ...until the entire area has been classified. You could do that, but your patience would ebb at about the second location for a set of several million in a typical satellite image.

Just as you use more than color to identify a tree, so can the computer. That's where GIS lends remote sensing a hand. The GIS uses the example locations to check its database to see if there are other typical conditions for a cover type. For example, if two forest types have similar EMR responses, the knowledge that the unknown location is "a steep, northerly slope at high elevation" might be enough to tip the scales toward a correct classification between the two.

In return for its help, the GIS gets a copy of the classification results—a completed cover map. By comparing the maps from two different times, the computer can quickly detect and quantify any land cover changes. In the GIS, data on wildlife activity can be summarized for each cover type to see which is preferred. Once a preference is established, the loss (or gain) in an animal's preferred habitat can be inferred, measured, and plotted at megahertz speed. Keep in mind that remote sensing and GIS provide educated guesses at actual characteristics, conditions, and relationships. They aren't perfect, but they provide powerful and compelling insights.

Classifying Remote Sensing Data

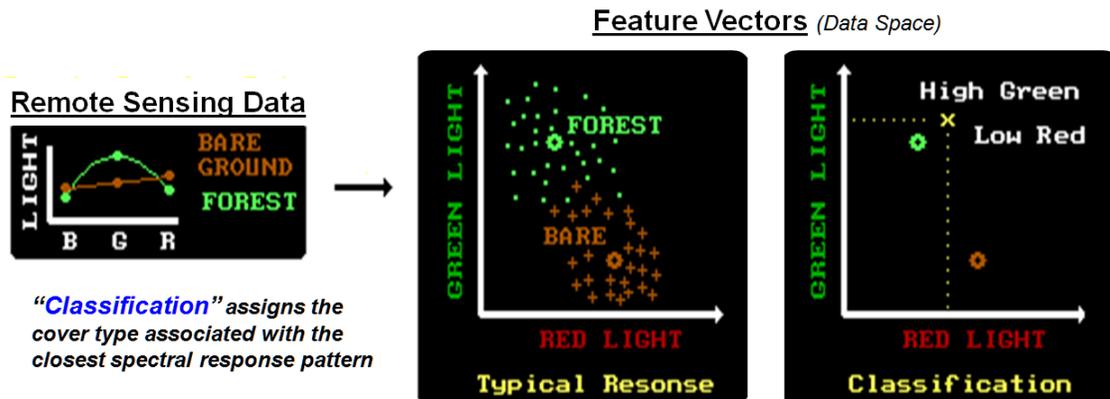


Figure 2. Classifying remote sensing data based on spectral response.

In fact, remote sensing provides an element that's unavailable with traditional mapping: uncertainty assessment. At the moment of classification, the computer knows which typical response is closest and how close it is. If it's very close, then you're fairly confident of the classification. As it gets farther away, you're less confident. Relating the closest distance to those of other possible cover types yields even more information— sort of a probability sandwich of a location's cover type. The next closest typical response identifies a second guess at classification, and how much farther away it is indicates the degree of confusion between the two possibilities.

If an unknown location sits halfway between the typical responses of two cover types, it's a toss-up. As an unknown's response moves closer to a typical response, classification certainty increases—maybe, maybe not. That's where things can get a bit confusing. Note the data patterns (dots for forest and crosses for bare ground) in the typical response plot in figure 2. The forest responses in its training set is fairly compact and circular, while the bare responses are more dispersed and elongated in the direction of the typical forest response.

The shape of the data cluster, as well as its positioning, provides even more information about classification accuracy. The more dispersed the pattern is, the less typical the typical response is. If the data have a trend (elongated), it means the data are more apt to be confused with other cover types in that direction. All this statistical stuff is contained in the training set's joint mean and covariance matrix— take my word for it, or go back for an advanced degree in multivariate statistics. The upshot is that remote sensing classification tells you what it thinks is at a location and honestly reports how well it's guessing. This shadow map of certainty is the cornerstone of thematic error propagation (see BM II Topic 4 for a related discussion). Without it GIS models just flap in the wind.

Heads-Up and Feet-Down Digitizing

(GeoWorld, November 1995)

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The previous two sections described the GIS/GPS/RS mapping triad. GIS expresses relationships among maps; GPS links map coordinates to real-world locations; and remote sensing directly records and classifies current views of the landscape. For years, GIS and remote sensing have been the realm of specialists in segregated offices "down the hall and to the right." In part, the division between mapped data providers and users was technological. GIS and remote sensing are inherently complicated fields, with more than a smattering of statistics, mathematics, and computer science. Also, their data loading and processing demands required expensive, specialized equipment.

More recently, low-end computers have grown up with storage, processing, and display capabilities approaching those of expensive workstations sold just a couple of years ago. Concurrently, the user community is becoming more computer literate, at least in PC-based applications. Moreover, more users recognize the importance of spatial attributes in datasets. With all of these trends in place, why isn't integrated GIS/GPS/RS in the hands of more people?

Part of the answer lies in cultural lags for providers and users. The providers are close to the complexities of spatial data and their analysis. As a result, the providers focus on a capabilities "toolbox" that can do anything. The users, however, know exactly what they want the toolbox to do—usually automating current tasks. Anything more is simply confusing and esoteric theory. Both groups reflect their professional cultures and somewhat divergent views of the environments and the applications of spatial technology.

Another part of the answer lies in the delivery of spatial technology. By their nature, maps are abstract renderings of real-world objects. In its least abstract form, spatial processing mimics cartographic concepts that aren't well understood by most potential users. As a result, such users have an uneasy feeling about maps—particularly if they're on a computer. So what's needed to melt these spatial cold pricklies into warm fuzzies?

A fully integrated GIS/GPS/remote sensing field unit would help. For example, figure 1 shows an aerial photo (remote sensing) as a backdrop registered to a road map (GIS). The large star near the center of the figure identifies the GPS unit's current position. Now a skeptical user sees the road behind him and the clump of trees to the left. The integrated presentation takes the abstraction out of mapping and inserts human experience.

Important features can be encoded by tracing them on the screen with the aerial photo as a guide (termed "heads-up" digitizing, because your head is tilted up toward the screen). Or, as in this case, "feet-down" digitizing can be done by walking the perimeter of a field of interest to generate a GPS track log as you go. The proverbial "farmers from Missouri" can actually

experience the link between a map and the real world.

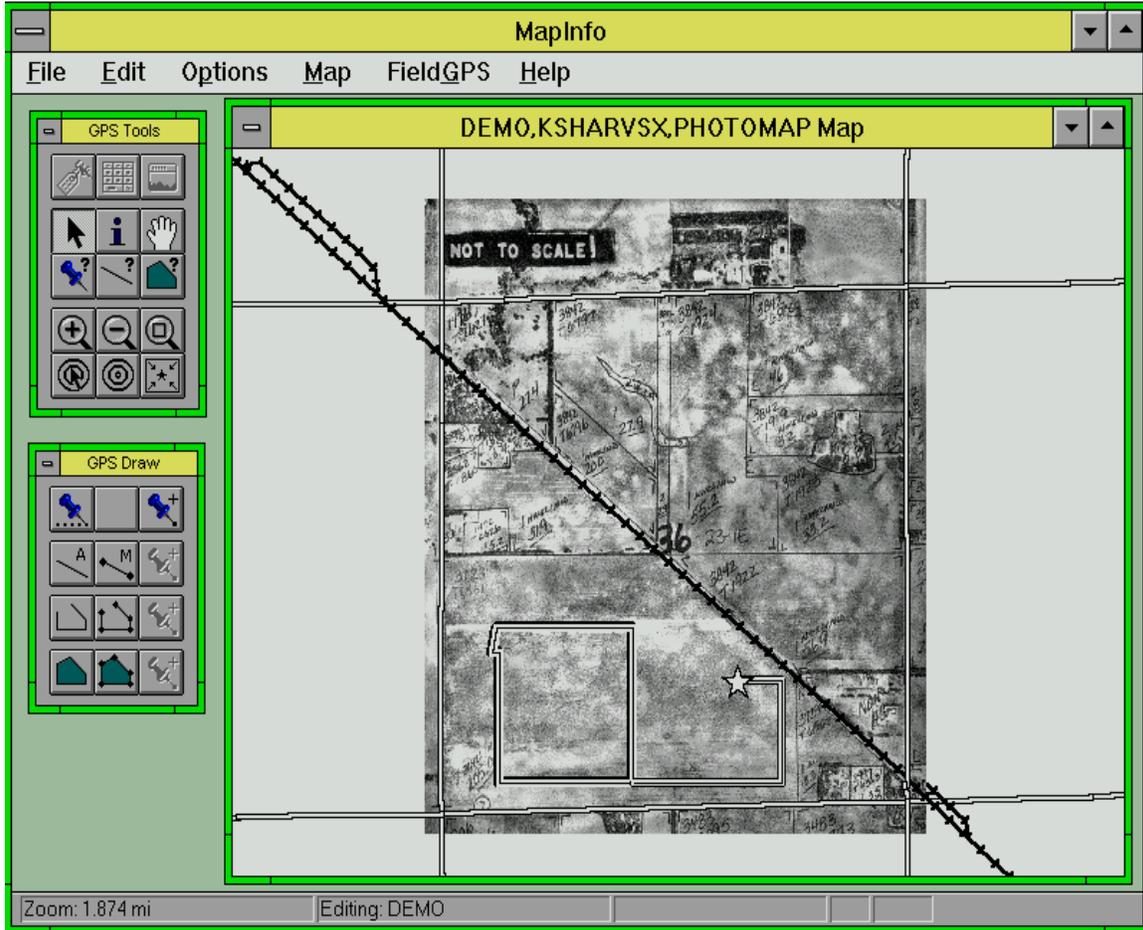


Figure 1. A GIs/GPS/remote sensing integrated display. Plot generated using MapInfoTM (MapInfo Corporation) and FarmGPSTM (Farmer's Software, Incorporated).

In fact, a field GIS/GPS/remote sensing unit forms the foundation of precision farming, an emerging technology that places the unit in a tractor's cab and position stamps its location as it moves through a field. In a harvester, the unit can monitor crop yield and moisture content and relate measurement variances to soil maps and other terrain factors. On a spray rig, the unit can vary the application of chemicals as the tractor moves across a field. In crop research, the dataset represents a complete census of field inputs and outputs—a giant step beyond a few similar research plots at the university 70 miles away. Imagine the impact on any of the spatially oriented sciences and their management expressions.

So what comprises a GIS/GPS/remote sensing field unit? Chances are you'll need more than simple coasters attached to your GIS workstation and a long electrical cord. When "blue-skying" the possibilities with clients, I begin with four initial considerations: applications, operating

environments, data loadings, and processing requirements. A clear, concise statement of what the device must do sets the stage for how it will be used and what capabilities are needed. For example, precision farming's application involves a mounted unit focused on precise kinematic GPS with extensive data loadings and on-board processing demands. A hand-held unit for timber inventory, however, focuses on a small set of field measurements, requiring minimal data storage and post-processing. But it all has to fit into a small, rugged shell.

Such considerations establish the scope of the application and its baseline requirements. The next step translates the requirements into the following design components:

- integrated software— GIS, GPS, remote sensing, statistics, office ...
- processor— '486, Pentium ...
- operating system/environment— UNIX, DOS, Windows, Next ...
- memory— RAM, EPROM, flash cards, disk, tape ...
- ports/slots— RS232, LTP, PCMCIA, SCSI ...
- screen— active/passive, reflective/transflective/backlighted ...
- input device— keyboard, pen, touch, voice ...
- peripherals— printer, plotter, sound, video, digital camera ...
- power— external/internal, protection, battery life, recharge rate ...
- durability— dust, splash, water, temperature, shock, electromagnetic fields resistant ...
- physical— mounted/portable, size, weight, construction...

Whew! That's a lot of techy stuff better left to the engineers (and there's a bunch of these new-wave GIS'ers hard at work). The trend toward a GIS/GPS/remote sensing field unit promises to revolutionize current spatial technologies. No longer can the spatial triad operate independently. No longer can a one-size solution fit all applications. GIS's comprehensive toolbox needs to be open to other systems, reducible to the subset of directly needed functions and designed for small boxes— in short, tailored to individual end-user applications. GIS can't stop with the colorful plot of a map generated in the GIS office down the hall and to the right; it needs to be extended into the field and placed in the hands of people to support the spatial decisions they make and implement.

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