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GPS and GIS: From Forests to Factories

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The single largest factor affecting the success or failure of a Geographic Information Systems (GIS) project is usually data—without it a GIS cannot but fail to meet its intended objectives. In most professional GIS agencies, data capture and quality control are tasks with high institutional priorities. Great expenses are incurred in equipment and staffing to provide high-quality data. In TDRI's case, on average, almost 70 percent of project time and budget is usually devoted to data-gathering tasks. It is, therefore, not surprising to find many GIS agencies in a constant search for ways to improve data-capture efficiency and quality.

Many GIS organizations devote much of their data-capture efforts to the automation of existing map manuscripts. Often, however, new, previously unmapped information must be gathered, or out-of-date maps updated. In many line agencies, this gathering of new data is routine. The Department of Land Development's (DLD) land use maps, for example, are updated periodically, according to priorities and budgets. Other agencies, such as TDRI, must rely on outsiders to provide this service—with sometimes questionable results.

GIS users looking for solutions to their data problems usually look to the heavens for answers—remote sensing techniques of one form or another. Remote sensing, in theory, allows the gathering of spatial data over large areas at a reasonable cost. Experience, however, conflicts with this theory—data supply queues are long, clouds often obscure the earth's surface at critical times, image interpretation is still more of an art than a science, precision geocoding is difficult and time consuming, actual production surveying costs are high, and important attributes of many spatial objects are undetectable using remote sensing techniques. Remote sensing techniques, despite practical difficulties, are still appropriate solutions in many, but not all, situations. In searching for an adjunct or replacement for remote sensing, people still look skyward, but they are now turning toward NAVSTAR satellites and Global Position System (GPS) technology.[1]

GPS, often called the *survey technology of the nineties*, is a military-developed system. In its final form it will consist of 24 orbiting satellites and three spares, that can deliver accurate navigation information to anyone possessing a GPS receiver anywhere on the surface of the earth. It is a passive receiver system—the information flow is one-way, from satellite to receiver. There are, therefore, no fees associated with receiving the GPS signals. The GPS consists of three elements:

Space segment which, at the moment, consists of about 16 satellites, or space vehicles (SVs), orbiting the planet at an altitude of 19,600 kilometers. Each of these SVs contains highly-accurate atomic clocks (one second in every 30,000 to 300,000 years). Each satellite continuously broadcasts its exact time of transmission.

Ground segment consists of user-operated receivers. Once a receiver picks up a NAVSTAR time broadcast, it can calculate its distance to the transmitting satellite, based on the delay in the radio signals. The signals are time stamped by the satellite and the receiver can simply calculate the distance light would have had to travel since that time. Once time signals have been received from three or four SVs, the receiver can calculate its position, based on the orbital information of each SV.

Control segment is the final component of the GPS. This is operated by the U.S. military and includes a master clock in Colorado, with which all SVs clocks are synchronized. Each satellite's orbit is observed and that data is passed up to the SV, which in turn broadcasts it back to the ground segment.

This paper presents a brief look at how TDRI uses GPS technology in its GIS work. Two current TDRI projects will be discussed: The Uthai Thani Provincial Natural Resources Information System, including the Huai Kha Khaeng World Heritage Site; and the Environmental Quality Information System (EQUIS) for Samut Prakan province.

UTHAI THANI NATURAL RESOURCE INFORMATION SYSTEM

The Canadian International Development Agency (CIDA) is funding an attempt to develop a prototype provincial-level Natural Resources Information System (NRIS). Uthai Thani province (Figure 1), the site one of Thailand's three World Heritage Sites, Huai Kha Khaeng, was selected as the site for this project. There were several reasons for selecting this province as a test bed. Foremost among them is that Uthai Thani is the site of many well-known environmental *hot spots*. The province is also economically under-developed, making it a potential social *hot spot* as well. Uthai Thani is thus an excellent test tube for discovering what impact information technology can have on environmental issues at the provincial level. In addition, it can be argued that the province's more environmentally-sensitive sites will **directly** benefit from having a well-developed GIS database available. TDRI, the former National Environment Board (NEB), Ministry of Interior (MOI), Royal Forestry Department (RFD), and Uthai Thani's governor's office are the principals involved in this effort.

The Huai Kha Khaeng World Heritage Site is globally unique in its bio-diversity, location, and evolutionary heritage, as it intersects three Asian evolutionary zones. As one of the last remaining fully-functioning forest ecosystems in the Kingdom, its value to Thailand is immeasurable. Culturally its is also important, as it contains numerous important Thai-Burmese archaeological sites of the Ayudthaya Period, many yet to be fully-investigated. It is also very large, covering an area of over 1.7 million rai.[2] From north to south, the site measures some 88 kilometers, and 43 kilometers east to west.

This project was developed in close consultation with the province's governor to serve his primary natural resources management needs. In addition, RFD staff within the Huai Kha Khaeng (HKK) Sanctuary were canvassed as to their information needs in managing and protecting this World Heritage Site.

The work to date has concentrated on information within HKK, primarily because the roughness of the terrain and the rainy season make work difficult and eventually impossible. The remainder of the province is scheduled for the next phase of the project. The following section will, therefore, concentrate on work done inside the HKK World Heritage Site.

Spatial Information

HKK, while rich in bio-diversity, is relatively poor in information content. Very little is actually known about the site beyond some basic data layers, such as topography and surface hydrology, a basic wildlife listing inventory, and some ad hoc wildlife surveys. All of the available data is on a scale of 1:50,000, the same scale as the Kingdom's topographic base maps, and adequate for most management needs. Table 1 lists some of the major spatial data layers over the site.

Prior to this project, there was very little detailed, comprehensive data on the area. The main thrust of the RFD's efforts in this area have been policing. Poaching and illegal logging were serious problems in the recent past. The situation has now more or less stabilized and RFD is turning its attention to other tasks.

In assessing the available spatial information over HKK and the information needs of the RFD officers charged with protecting and managing this important site, the TDRI research team determined that there was a serious lack in content and *accuracy* of important management information layers. The locations of many roads, for example, were later found to be as much as 1.5-2 kilometers in error. Considering that many of the interior roads are very deep, under solid forest cover, this is perhaps to be expected. However, if one also considers that some of the roads on the site's periphery were being used as de facto boundary markers, the seriousness of these kinds of errors should become apparent. Several salt licks used by **elephants**, very important to the site's ecology, had never been mapped, while others were inaccurately mapped. Spatial data over the five kilometer **buffer zone** along the eastern borders of the site—which may well hold the key to the future of this site—was also deficient.

GPS to the Rescue

The TDRI research team brought GPS technology to the project to supplement these data needs. In examining the available survey options—theodolite ground survey, aerial photo and satellite image analysis—no other technology approached GPS in flexibility, speed, ease of use, position accuracy, survivability[3] and, perhaps most importantly, **attribute** integration. It was **the** choice in terms of cost effectiveness.

There are no data queues for users to languor in when using GPS-based surveying. NAVSTAR satellites do not take holidays or long weekends. With the exception of some *windows* of low SV availability, GPS is generally ready when you are.[4] When the full suite of SVs are launched, there will be world wide, 3D coverage, 24 hours a day. This offers users unparalleled freedom of choice in surveying tasks, unconstrained by the whims and glacial pace of various agencies. Agriculture areas encroaching on the site, for example, were surveyed along a line of more than 110 kilometers in a leisurely four days, using a helicopter from the Agriculture Aviation Division and vehicle-based cross checking. The HKK and RFD staff were acting on this data by the fifth day.

As survey conditions and needs change, so can GPS-based surveys. The flexibility presented by GPS technology lends itself to any situation where unforeseen survey opportunities might arise. While surveying the roads in the interior of HKK, for example, TDRI's survey team often encountered various wildlife, many of them rare or endangered. These unplanned sightings were *instantly* mapped, without interfering with the *planned* purpose of the survey. These sightings will help form the basis for a full wildlife survey that will be conducted by HKK site staff.

In *absolute* accuracy, GPS surveys, especially differential surveys, usually provide accuracy and resolution beyond that needed for a 1:50,000 scale database. This proved to be troublesome at the beginning of the survey period as a GPS has very high *absolute* position accuracy but low *relative* accuracy. In took some trial and error before the survey team was able to come up with a suitable, common coordinate database. Differential GPS surveys, it was determined after some experimentation, were unnecessary at the project scale of 1:50,000. One stretch of road, for example, was surveyed using two GPS receivers. One was configured as a base, the other as a *rover* that actually surveyed the road. Corrections of from less than one meter to a maximum of 27 meters were made after applying differential corrections. These sorts of results were found consistently over a variety of terrain types and times. At a scale of 1:50,000, such errors can usually be safely ignored. Map scales greater than 1:50,000 would require differential GPS surveys if accurate data were expected.

One important benefit of GPS surveys, at least to the TDRI research team, was the ability to quickly and accurately assess a spatial object's **attribute data** as it was being mapped.[8] Having all of an object's features recorded and linked in one digital database while in the field, provided large time savings and high-quality data. A bridge's dimensions, construction type and material, for example, could be quickly recorded and tied to that bridge's position as it was being mapped. In the case of villages in the site's 5 kilometer buffer zone, the village's location, name, head man, population and any relevant notes were all recorded at the same time in the field while still in the village. This provided one continuous and, therefore, accurate link between the actual information in the field and the final form within the project's database. Attribute and locational data never went astray, never diverged from one another, as sometimes happens in large, complex surveys using manual methods.

It was discovered during the course of this survey that there was one village positioned exactly on the

Sanctuary's boundary, a dangerous situation. This surprising discovery proved to the HKK site staff, beyond doubt, the usefulness of GPS surveys as realistic day-to-day management tools. The people who have migrated to the areas around HKK come from the Central and Northeastern regions. They bring their local culture with them. Villages in the buffer zone, therefore, take two different forms—higher density, clustered Northeastern-style villages and less dense, spread out Central-style. It should be noted that the villages which appear to be outside the buffer zone actually have some portion of the village within the buffer zone. These are all Central-style villages.

Proposed Canal Project

GPS technology also provided an excellent *ad hoc* survey tool to answer questions arising during the course of the project work as RFD perceptions and attitudes about information needs changed. During the project's field work, a plan was suggested to construct a canal from Huai Kha Khaeng stream to Huai Thap Salao stream to supplement water in the Huai Thap Salao Reservoir. The study team was able to supply critical information on the proposed route of the canal within days:

- Elevation, slope, and aspect
- General wildlife signs by GPS survey along the canal route. It was found the proposed canal would cut several heavily-traveled elephant trails
- Forest type and quality by GPS survey
- Cut volume calculations
- Excavation budget estimates (7, 4, and 2 **billion** *baht* respectively for 100, 50 and 20 meter wide canals)
- Three dimensional views of the area before and after construction of the proposed canal

The combination of the GPS survey and GIS analysis provided a factual basis for evaluating this proposal.

Practical Suggestions

GPS surveys were carried out on foot, from four-wheel drive vehicles, helicopters, and boats, and covered every practical situation conceivable. Overall, more than 1,000 surveys were carried out in a period of less than two months. From this work, some practical guidelines were developed:

You can never have enough GPS batteries. Using only a single GPS battery, or having only one spare, proved a logistical nightmare. Batteries were never adequately charged, surveys had to be cut short of planned targets, staff time at night was occupied with arranging batteries and charging equipment rather than resting or evaluating the day's survey work, etc. Fortunately, video camera batteries proved excellent and affordable substitutes after some wiring modifications. The team usually used seven batteries, three in the field and four at base being charged. On longer surveys, without the option of charging along the way, all batteries were used for survey work and a day devoted to charging before and after the survey.

Walking is always better. GPS signals, being microwaves, are disturbed by trees, bamboo in particular. Under heavy forest canopy, vehicle-based surveys were almost never satisfactory, simply because the truck went too fast. It was found, however, that by slowly walking over the same ground, we could almost always achieve reasonable results. To carry out this foot survey, the survey team needed to be physically separated from the vehicle. Psychologically, being *tied* to a vehicle almost always prevented the team from getting good data. They usually gave up after a few minutes and got back in the vehicle. Removing the vehicle removed the problem.

Make use of the materials around you. In areas where signal reception proved impossible, attaching the GPS antenna to a long bamboo pole cut from the surrounding area and raising this above or near the canopy roof proved successful. The bamboo could be discarded when finished and need not be carried to the next survey position. If bamboo was lacking (this was rare), climbing a likely tree with the antenna usually worked. A cable of about 30 meters was used for this purpose and proved adequate.

1:50,000, 1 GPS. As mentioned above, the TDRI research team found that at scales of 1:50,000 or smaller, differential surveys were not normally required. If surveys are to be carried out at mixed scales (1:5,000 and 1:50,000), the second GPS unit can be used to survey in parallel when not needed for differential survey work. Note that this does not include monument surveys, where benchmarks, control points, etc., will be established. Differential GPS surveys will almost always be required in these types of surveys.

A picture is worth a thousand words. One of the most powerful pieces of equipment used in the GPS surveys was a lightweight video camera. By synchronizing the date and time stamped on the video image with the GPS receiver's time, this allowed the survey team to conduct fast and effective airborne reconnaissance of large areas. The time/date link also allows the user the ability to include video images as part and parcel of the GIS database by specifying the exact location of that image. If any of a surveyed feature's attributes are called into question, a video can sometimes provide answers.

It's always later than you think. Helicopter-based GPS surveys are simple to plan if one keeps in mind two things: the helicopter is traveling at 100-200 kilometers per hour, therefore waypoints that are too close together (less than 10 kilometers apart) are usually impossible to visit and helicopter pilots are quite literal about directions—if you tell him a certain course he will almost always fly that course no matter what the conditions ahead. You can avoid rough rides by planning courses around high mountains whenever possible. One certain way to waste valuable helicopter time and enrage a pilot is to keep the aircraft flying in useless circles looking for the last waypoint. It is simpler to space them farther apart. Sharp, sudden course changes should be avoided when possible, as the body of the helicopter will rotate and block the GPS signal.

Use the almanac. In light of battery constraints, windows of no GPS availability, and survey targets, planning is essential. The GPS's predictability, provided by downloading the orbital almanac, can be of great use in planning surveys. Good GPS planning software should also let the user play *cat and mouse* games with the planned survey routes by blocking various elevation ranges and azimuths to simulate mountain ranges, buildings, etc.

Conclusion

The above is a brief look at the various ways TDRI used GPS technology during its Huai Kha Khaeng database building efforts. It should thus be obvious that GPS has an important place in almost every similar GIS project. It provides high-quality location and attribute data in a quick, flexible, and easy to use manner. Few GIS shops would not immediately benefit from using GPS technology.

The following section will examine the ways TDRI put GPS to work in an entirely different GIS project setting, in the industrialized province of Samut Prakan, mapping factories, waste water, and the other attendant ills of a modern industrial area.

ENVIRONMENTAL QUALITY INFORMATION SYSTEM IN SAMUT PRAKAN

The face of Thailand is rapidly changing. In many cases, we are able to see it occurring before our eyes. Everywhere one looks, one sees changes. Farms are being replaced by housing estates and fish ponds by factories. The recent economic boom is the root cause of this shift in land use away from an agriculture-based economy toward a more urbanized one. The rapid growth in Thailand's economy is also reflected in rapid changes in the quality of the environment. Population shifts occur quickly as more rural people come to live and work in urban areas.

Abrupt land use changes tend to be unplanned. Serious damage to the environment and a lowering of the quality of life usually follows. Overcrowding and traffic jams; noise, air, and water pollution; floods, fires, and worse, can and do result. Like the paddy lands of the highland areas, urbanized land has a finite carrying capacity. The amount of people and pollution it can absorb is limited. It can collapse and become uninhabitable as easily as the highland areas. Urban land's carrying capacity can be improved by upgrading public infrastructure (analogous to improving the farming techniques of the hilltribes to improve paddy yields), and by reducing the amount of privately generated waste being dumped into public air, water and land.[9]

To strike a balance between population, economic activity and environmental quality, planners must possess information. *Where do people live? How many people live there? In what directions is the city spreading? How has land use changed with time? What are the dimensions of urban spread? What is the quality of water flowing out of this municipality? Is the air here safe to breathe? What is the state of the environment here?* A thorough understanding of the state of an area's environment is fundamental to solving its problems in a timely and efficient fashion.

The objective of this CIDA-funded project is the development of a **user-responsive**, GIS-based Environmental Quality Information System (EQUIS) for the province of Samut Prakan at a scale of 1:50,000. Samut Prakan province was chosen because it is industrialized, yet retains fairly large areas devoted to agriculture and aquaculture.

The end users of this information system are the Office of the National Environment Board (ONEB), Department of Industrial Works (DIW), Samut Prakan provincial officials, private-sector users, non-governmental organizations (NGOs) or others interested in **factual** information about the state of Samut Prakan's environment.[10] A major by-product of this system will be technology for the assessment of **pollution taxes**, following the present government's policy of "the polluter-pays." Once developed and thoroughly tested, this system will serve as a model for other systems around the Kingdom.

Case of the Missing Factories

In contrast to the dearth of information over Huai Kha Khaeng, there is a wealth of data for Samut Prakan province. Because of its proximity to Bangkok, it has been the subject of numerous national and international studies. The industrial areas of the province were mapped as recently as 1989. There is also a large tabular database of factories that includes attributes for name, ownership, products, raw materials, workers, capital, waste materials, etc. to complement this spatial data.

In developing an environmental quality information system, pollution sources, especially hazardous, industrial ones, must be precisely located and identified. Their spatial relationships to nearby human settlements and the demographics of those settlements must also be known. The rules and legal guidelines applying to each factory will also come into play. Exact locational data is, therefore, a prerequisite for developing this type of information system.

Despite this relative wealth of data, there is, however, a fly in the ointment. Much is known about the main sources of hazardous waste from this province's registered factories. But their locations are not known. While a land use map can cover the areas that appear to contain some type of factory, it cannot provide details about the individual factories within each area. It lacks the necessary attribute information. The tabular factory database does provide some addresses, but anyone trying automated address matching in Thailand will soon find that many of the street addresses do not follow any noticeable logic. In general, address matching usually fails in industrialized areas. Furthermore, the factory database contains only legal, *registered* factories. Yet there are many unregistered factories polluting the environment which need to be identified.

GPS: Once More Into the Breach

To fill this gap in the system's database, the TDRI research team applied GPS technology in a survey designed to establish a factory database with precise locations. This database was related to the existing tabular database to determine needed attributes. Over a period of about two weeks, more than 1,000 factories were surveyed. Beside the position of each factory, its name, street position, and any other noticeable attributes were recorded in the field.[11] As a bonus, tens of kilometers of new roads in the province were also surveyed.

Since much of the data over Samut Prakan comes from a variety of sources, with a corresponding variety of spatial location problems, about two dozen road intersections around the province were also surveyed to serve as "tics," or identifiable road intersections. These tics were then used to transform the system's various coverages to one common and accurate coordinate system.

Not unexpectedly, the biggest obstacle to this type of urban survey was traffic. The survey team estimated that the heavy congestion almost doubled the survey time. The survey vehicle's power supply was used to supplement the GPS's batteries, therefore batteries were not a problem for this survey, in contrast to Huai Kha Khaeng.

The final phase of this project's GPS survey work involves a survey of the province's canals. The survey team will travel by boat along the major canals and sample the water's color and, by implication, the state of the canal's water. This should take about one week.

Conclusion

GPS played an important, even crucial role in this GIS project. It provided an economical means to identify pollution sources and to develop a factory database, appropriate for inclusion in an environmental quality information system (EQUIS). It will also be used to develop information concerning the water quality of the province's canals. By supplying precise coordinates for identifiable road intersections (*tics*) around the province, a large, multi-source and spatially-questionable database was brought into a common and more accurate coordinate system.

This project and the work carried out in Huai Kha Khaeng should amply demonstrate the facility of this technology in solving one of the more serious problems in the GIS profession today, data. GPS-based surveys can cost-effectively supply high-quality position and attribute data in a rapid, flexible, and *user-friendly* fashion. It is worth repeating that there are very few GIS shops that would not immediately benefit from using GPS technology.
