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A VIEW FROM SPACE: MONITORING AND MANAGEMENT FOR WORLD HERITAGE SITES

The increasing global environmental awareness which has developed over the last twenty years is reflected by the existence of the World Heritage List, identifying sites considered of international importance for their environmental, archaeological, or historic values, and for this reason deserving particular care in their management. The diversity of environment, location and local infrastructure that provides the context for these sites, however, is immense.

For the purpose of this paper we are concerned with only those sites listed on account of their cultural heritage component. They are found in such diverse areas as arid deserts and rainforests, remote locations and urban centers; in fact almost anywhere that has supported significant human activity. That the cultural heritage is part of the broader environmental issue is reflected in the classes of threat which can compromise the integrity or lead to the total destruction of the site itself. These factors can be summarized under five headings, the relative significance of which will vary from site to site:

- Environmental change
- Human-induced or natural catastrophe
- Tourist pressure
- Treasure hunting and other vandalism
- Development

If these sites are to survive, efficient and economic methods of site monitoring are required to identify threats to the monuments and their environments and assist those trying to provide a response to these threats. Just as sites are in very different environments, so resources for monitoring and maintaining these sites are unfortunately equally diverse, ranging from excellent to non-existent, with budgets in the order of several million dollars or a few hundred dollars. It is within this context that an approach was made from the World Heritage Committee to the Getty Conservation Institute and NASA to investigate the viability of current air and space-borne remote sensing technology for the purposes of global site monitoring. The current project, which is drawing upon data from a wide range of sources at a variety of resolutions, is concerned as much with the principles of this approach as with current data limitations. This is a rapidly changing field and improved data quality and resolution will continue to become available.

Ultimately the potential of any such monitoring mission is constrained by three factors:

- repeatability, necessary for undertaking change detection,

– resolution, which determines the scale of threat that can be identified, and
– registration, which allows problem areas to be precisely located.

Clearly 30 meter pixel data from Landsat images will not allow us to identify localized erosion or the effects of treasure hunters. Even data at this resolution, however, can be utilised for defining site context. Although the resolution of much digital data collected is low, ranging from 2.5m. to 30m. per pixel, the recovery of data in thermal wavelengths beyond the visible, and the image rendered by radar provides the opportunity for the recovery of new evidence of site function or activity not detected using conventional means. The poor resolution of space-borne remote sensing restricts our ability to identify sites smaller than 5.5 hectares in Landsat data, and 2.5 hectares from SPOT imagery. In the Southwest regions of the USA, only about 12% of the archaeological sites recorded so far are larger than 2.5 hectares (a pattern observed in other semi-arid regions of the world, such as the Middle East): this clearly limits our ability to fully appreciate the physical context of human occupation in this area, let alone the impossibility of "mapping" the archaeological landscape from space.

Present technology still cannot facilitate any form of automated monitoring system, for its low resolution, lack of repeatability, and cost. However, by incorporating the remotely sensed data with other sources in a geographic data management system (GDMS) a monitoring management tool could be prototyped to test the potential usability and cost effectiveness of a fully integrated approach to site monitoring, management, and site definition. The fully integrated data management system should be both easy to use, provide the day to day functionality required by both site managers and researchers, should run on relatively cheap and widely available hardware and cost less than $10,000 in a basic implementation. G-Sys GDMS was selected as the working tool for integrating the data set.

It is economic, runs on a PC under Windows, is easy to use, handles multiple data sets at any resolution, has been used on a number of heritage management projects in Britain and the USA and supports the use of the full range of available data. The project comprises five stages of data collection, processing, analysis, documentation and integration. The largest task of all, digital data collection and assembly, was undertaken by NASA through the commercial remote sensing program based at the Stennis Space Center; the remaining tasks are being undertaken in tandem as the project progresses. Work is still in progress and so the present paper should be viewed as an interim statement.

1. The test case

The primary test site chosen for the current project, the major Anasazi complex at the Chaco Culture National Historical Park, in New Mexico, USA is in an essentially arid environment which is liable to flash flooding. Additional evidence has also been examined from another project supported by the National Environmental Research Council (NERC) and English Heritage in the UK which concerns the application of low level multi-spectral survey on an intensively farmed multi-period landscape around West Heslerton in North Yorkshire, England, and provides valuable data from a completely different environment in which most of the archaeological features lie beneath ploughed fields.

Chaco Canyon contains hundreds of site foci, besides 13 major archaeological complexes representing the highest point of the Anasazi Pueblo culture, which flourished in the south-western areas of the USA between the seventh and the thirteenth centuries AD. Chaco Canyon was an ideal test site for the project, given its complex topography, the variety of archaeological site types present in the area, the long history of archaeological research and data collection and the delicate balance between indigenous values and tourism that now prevail; in addition the site is a World Heritage Site and was readily accessible for both fieldwork and for air-borne data collection.

The data collected comprise a representative data set from the various available and suitable data gathering platforms from air photography to satellite imagery. The wealth and coverage of survey and other detailed data recovered in more than half a century of research at Chaco provides the cultural context for the data which is perhaps unparalleled.

2. Data collection

The data assembled by NASA for Chaco Canyon includes Landsat and SPOT satellite imagery, Russian KFA "spy photographic imagery", air-borne multi-spectral data (ATLAS), high resolution infra-red photographs, digital vector maps, ground based Global Positioning System (GPS) surveys and digital elevation models (DEM). In order to provide good georeferencing data, a very detailed differential GPS survey was undertaken at the site, establishing hundreds of bench-marks all over the National Park including a number of permanent base stations with accuracies within a few centimeters. In addition a number of other organizations including the Chaco Center at the University of New Mexico, the New Mexico State Archaeology Service and the National Park service archives have contributed important survey and excavation data in addition to historic photographs and plans.

The air-photographic archive for Chaco is particularly impressive starting with the pioneer flier Charles Lindbergh and followed by a number of vertical photographic surveys which have been conducted over the last 50 years; these are of the greatest significance as they allow us to examine the potential for undertaking change detection arising from known events.

This data has been gathered together for integration in the GDMS and includes databases in a variety of formats including dBase, Paradox and Oracle, scanned maps and plans and a sample of field drawings which are now being digitized. The quantity of data is vast and since this project is concerned with assessment of potential rather than long term research, attention has been focused on sample areas and particular problems such as visitor pressure and erosion. The collected archive is an important resource in which the assemblage is greater than the sum of its parts. The data collection phase of the project is now complete.

3. Data processing

The digital image data has been processed using Erdas Imagine and PCI image processing software on Sun workstations and PCs running Windows 3.11 and NT. The primary exercise undertaken by NASA was the georeferencing of the data which has isolated some unexpected problems in a project of this kind, mainly due to the difference in absolute coordinates between the georeferenced satellite imagery, the GPS survey stations, and the digital USGS maps of this area. The low resolution satellite images and KFA photographs provide an environmental backdrop for the high resolution data and could be used for monitoring broad environmental change in some environments such as the removal of vegetation cover with the consequent problems of erosion and deposition.

Basic classification of these data can assist in identifying the true environmental boundaries of a site, witness the boundary between the area fenced off as the national park and the overgrazed and eroded areas beyond the park boundary at Chaco. This is an example of the risk of delimiting a site on the basis of considerations which have little to do with historical or environmental considerations, so that features that lie outside of the protected zone will suffer damage simply as a result of being "beyond the fence".

For the high resolution air-borne multispectral data, of which there are several gigabytes, only very limited classification has so far been undertaken and more work is in progress in this area. Some data processing problems have been encountered due to the size of the images being worked upon: the primary rectified multi-spectral image, including data from a single wavelength, has a file size of more than 270MB.

Using a combination of map data and stereo photography, a medium resolution DEM of the area has been generated with high resolution surface models being constructed covering the key sites chosen on account of their easy accessibility to the general public which are therefore subject to the greatest risk from erosion.

4. Data analysis

The analysis of the digital images is being approached from two sides, through visual scanning and through digital classification. Visual scanning of the data reveals that in the arid climate of Chaco Canyon thermal data offers great potential for the identification of site components which cannot be seen using conventional air reconnaissance. Digital classification which relies upon the presence of unique spectral signatures within a multi-spectral image is possibly useful for site identification at Chaco since the black and white pottery that is characteristic of Anasazi culture and frequently covers large midden deposits, contrasts with the naturally occurring spectra.

Using a combination of trained and untrained classification procedures we are attempting to isolate archaeological features which can be verified against the vast body of survey data and ultimately by verifying on the ground the presence of features recognized through the automatic classification, a procedure known as ground truthing.

5. Documentation

One of the objectives of the project is to produce a CD-ROM based management tool and archive which can form the basis of a prototype site management system for the National Park Service. In addition it is hoped to produce a CD-ROM sampler which can demonstrate the potential and limitations of the various different data sets.

A hypertext project help system is being developed which gives the full details of data resolution, collection and manipulation so that a novice user can quickly get to grips with and use the data. It is not good enough simply to collect together an eclectic group of data and provide access to it, the user must be given as much information as possible regarding each data set if they are to use the data to its fullest capabilities.

6. Integration

This stage of the project coupled with the publication of the assessment of potential provides the ultimate test of applicability of both the data collected and the method of data management. In addition this step demonstrates the problems of data registration which increase massively as the resolution increases. The project aims at demonstrating that the generation of a fully integrated data set is neither difficult nor expensive once the primary data sets have been established, as is already the case at Chaco. One issue of considerable importance with regard to the data integration is the difficulties presented by the use of multiple different grid systems and map projections and the use of GPS survey which provides a level of accuracy not found in the primary data. This has been collected and georeferenced using standard cartographic methods in which the relative locations of one feature to another are, no doubt, correct but the relationship to the global position is not.

Digital maps generated from old air photographic surveys and provided by the USGS include errors greater than 100m with reference to the GPS georeferenced digital image data. The discrepancy between GPS and map coordinates is certain to become a major issue anywhere GPS is used for gathering point locations in an environment for which the available cartographic data is not GPS referenced (presently most of the world). Further issues being addressed are the need for some degree of data protection since the more detailed the data that is made available through interactive and integrated Geographic Information System (GIS) applications the higher is the risk of that data being abused by treasure hunters and other cultural vandals.

Other data sets have also been reviewed although they do not cover the key test site. Synthetic Aperture Radar (SAR) data, currently collected by the space-shuttle (the last mission was conducted in October 1994), offers the best long term capabilities for automated change detection. Radar data, incorporating three wavelengths, is not constrained by weather or day/night conditions in the way that thermal and visible wavelength data is, and one of the three collected wavelengths has some ability to penetrate vegetation, only to be reflected from solid surfaces. In an arid region SAR data can be used to identify buried features as, with a sufficiently dry environment, sand penetration can be greater than 5 meters.

SAR data is currently distributed as 20m resolution data. Within a few years data resolutions will be as high as 2m. per pixel, collected by satellites orbiting the Earth and providing total coverage on a weekly basis. This will offer the potential for automatic difference extraction provided problems of georeferencing and scan line repeatability can be overcome.

As increasingly high resolution data is collected the potential returns for the cultural resource manager is higher; however, as resolution increases the problems of image registration and image processing will magnify, if just due to the sheer volume of data available. Currently high resolution data is only available using air-borne scanners, which presently operate only in limited areas. Improvements in resolution up to a single meter in panchromatic and 4 meters in multi-spectral will be possible with the new generation of EarthWatch and Space Imaging satellites which will be launched between 1997 and 1998.

Our joint experiments with NASA generated 2.5 m data for Chaco and at Heslerton in England the NERC collected 1.8m. data. Clearly this is not sufficient to indicate the presence of any but the most determined treasure hunters activities, or larger scale land-use changes. These data when combined with information on geology, drainage and a DEM of matching resolution may allow us to identify areas which may be subject to erosion or flooding, and to provide information on land use modifications. The effect of visitor traffic could be monitored using data at this resolution since pathways and other areas subject to human erosion can clearly be seen. A series of historic vertical photographs in the Chaco archives show clearly the widening of tracks used by visitors to get to the monuments with pathways doubling in width between the late 1960's and early 1970's.

While the possibility of using air – or space – borne data to undertake automatic global monitoring of anything other than large scale damage to World Heritage sites cannot be feasibly applied for a few more years, using presently available remote sensing platforms, the application of this type of technology can already offer real benefits to the heritage management community.

High resolution multi-spectral data, particularly thermal data, provides us with an opportunity to identify and extract features which do not show using conventional air photographic survey techniques. The disturbed nature of the soils filling buried features or the contrast between structural debris and undisturbed ground frequently provides an environment that responds well to recording in the thermal bandwidth.

The low-level multi-spectral surveys at Chaco and Heslerton both show detail not available from conventional air-photography. In the latter case, in an intensively farmed environment, a single multi-spectral scan has recovered more site-specific data than 15 years of oblique crop-mark photography. Many features not previously known could be identified and detail added to already known crop-mark complexes. At Heslerton, ground based geophysics have further enhanced the picture built up from air photography and the multi-spectral survey.

Once sub-meter resolution photography, radar and multi-spectral data are available from space the benefits of this technology will increase exponentially. In the meantime experimentation as at Chaco and Heslerton should be continued so that we can develop and test the right tools and approaches to the data as resolution quality and bandwidths are improved. Already hyper-spectral instruments recovering data across more and narrower spectral bandwidths are being launched; it is only a matter of time before suitable instruments for site monitoring are available.

In conjunction with our experimental application of remotely-sensed data, the GIS management project will be geared towards the construction of predictive models to assist park managers in being pro-active in attempting to reduce the negative impact of human and natural agents threatening the delicate cultural and natural resources of these sites.

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ABSTRACT

NASA and The Getty Conservation Institute are conducting an experiment in the application of remotely sensed multispectral and radar data for monitoring change at World Heritage Sites. The project is concerned both with the principles of this approach and with current limitations. The latter have clearly demonstrated that automatic monitoring cannot be easily achieved, due to problems of low resolution, lack of repeatability, and cost, but the integration of this remotely sensed data with other data types into a geographic data management system may provide a monitoring management tool that can be used to test the potential of a fully integrated approach to site definition, monitoring, and management. The test case being adopted covers the area of Chaco Culture National Historic Park, in New Mexico, USA, a major Anasazi complex which is registered in the UNESCO's World Heritage List. Data assembled included a variety of remotely-sensed information, GPS surveys, and the preparation of a baseline GIS, but also historic aerial photographs and excavation data. The resulting data management system, which also includes basic classification conducted on some of the multispectral data available, is an example of a relatively simple system of archaeological data management which could serve the needs of site managers and archaeologists.