HELMAND-ARGHANDAB VALLEY IRRIGATION SYSTEM

A CHANGE ASSESSMENT: 1973 - 1990

Prepared by:

DEVELOPMENT ALTERNATIVES, INC.
and
EARTH SATELLITE CORPORATION

February 1993

AFGHANISTAN AGRICULTURAL SECTOR SUPPORT PROJECT/PRIVATE SECTOR AGRIBUSINESS
FUNDED BY THE UNITED STATE AGENCY FOR INTERNATIONAL DEVELOPMENT
Contract No: 306-0204-C-00-9829-00

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The cover shows a Landsat Thematic Mapper (TM) satellite image of the Helmand River Valley taken on 27 April 1990.

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LIST OF ACRONYMS

ASSP	Afghanistan Agricultural Sector Support Project
ESRI	Environmental Systems Research Institute
FCC	False Color Composite
GCP	Ground Control Point
GIS	Geographic Information System
HACU	Helmand-Arghandab Construction Unit
HAVA	Helmand-Arghandab Valley Authority
mmu	Minimum Mapping Unit
MSS	Multispectral Scanner
NGO	Nongovernmental Organization
O/AID/Rep	Office of the AID Representative
PSA	Private Sector Agribusiness
TM	Thematic Mapper
UNDP	United Nations Development Programme

EXECUTIVE SUMMARY

The Helmand-Arghandab Valley irrigation system in southern Afghanistan is one of the country's most important capital resources. Prior to the civil and military conflict that has engulfed Afghanistan for more than 15 years, agricultural lands irrigated by the system produced a large proportion of the country's food grains and cotton. Donor support for the rehabilitation of this system will be a critical step in restoration of Afghanistan's post-war agricultural productivity.

With the support of the Office of the A.I.D. Representative (O/AID/Rep) for Afghanistan, a Development Alternatives, Inc. (DAI) and Earth Satellite Corporation (EarthSat) study team has employed satellite imagery, geographic information system (GIS) computer software, and field surveys to assess changes that have occurred in a portion of the Helmand-Arghandab irrigation system since 1973 as a consequence of the war. Changes detected over time in the extent of vegetation were used as indicators of the current condition of the irrigation system.

The study team followed these steps in developing the change assessment:

- Satellite images of the Helmand-Arghandab region were acquired for 1973 (pre-war) and 1990 (post-war), and enhanced to highlight vegetation;

- A 91,103-hectare "command window" corresponding approximately to the area irrigated by the system in Helmand Province was delineated from 1973 imagery and topographic maps; this window was superimposed on the pre-war and post-war satellite images;

- Areas of irrigated agriculture were identified within the command window, manually mapped using both 1:100,000- and 1:250,000-scale satellite images, digitized, and entered into a GIS to generate statistics of change in irrigated agriculture between the pre-war and post-war images;

- Sixteen sites within the command window that demonstrated significant change in the extent of irrigated agriculture between 1973 and 1990 were identified;

- A team of agricultural experts employed by the Private Sector Agribusiness (PSA) component of O/AID/Rep's Afghanistan Agricultural Sector Support Project (ASSP) visited most of the 16 sites to

determine the reasons for changes that were observed in the comparison of satellite images; and

- Specialists in remote sensing and satellite image interpretation, irrigation engineers, specialists in arid lands agriculture, and other technical specialists familiar with the Helmand-Arghandab system were consulted to corroborate the findings of the DAI/EarthSat study team.

The results of the study indicate that between 1973 and 1990 the major change in land use in the Helmand-Arghandab system was a decline in the amount of land under cultivation. In 1973, approximately one hectare in four was idle — that is, not under cultivation. By 1990, idle land accounted for one hectare in three. By 1990, 20 percent (14,000 hectares) of irrigated agricultural land active in 1973 was not cultivated. This phenomenon is particularly prominent in the downstream portions of the Shamalan and Marja sub-project areas of the system. By 1990, scattered areas of irrigated cultivation of lands not cultivated in 1973 were apparent throughout the system. These areas combined to total over 6,400 hectares. Thus, the net loss in irrigated agriculture for the study area as a whole was 7,600 hectares, or 11 percent of the 1973 irrigated area.

The averaging of agricultural decline disguises the fact that certain areas of the system have suffered more dramatic losses of irrigated agriculture than others. For example, the study found portions of the Marja sub-project area where over one-quarter of the area farmed in 1973 was out of production by 1990.

The loss in irrigated agriculture can be attributed to the following factors:

- An increase in soil salinity due to blocked drains — a likely result of lack of infrastructure maintenance;

- A breakdown of gates and other water-control devices within the system that prevented the control of water distribution; and

- Abandonment of the land by farmers because of civil and military conflict in the region.

It is perhaps surprising that the Helmand-Arghandab system functions at all after 15 years of war. The fact that downstream users now produce irrigated crops suggests that water is being delivered, and that major portions of the system (such as the diversion dam, main canals, and siphons) have not been completely destroyed.

This assessment of agricultural change in the Helmand-Arghandab irrigation system demonstrates the utility of remote sensing and geographical data management in identifying persistence and change in phenomena over a wide area.

With the ability to detect dramatic variations over time in agricultural land use within the Helmand-Arghandab system, the study team has been able to identify portions of the system that are likely to require immediate rehabilitation.

A rehabilitation plan for the Helmand-Arghandab system should include these elements, in order of priority:

- A survey of the condition of major water-control facilities including the main dam, the diversion dam, the headworks to the main canals and associated structures, and the levees and cross-drainage facilities;

- A work plan and estimate of the costs of rehabilitation required to ensure that these facilities can be operated safely and reliably;

- A plan for arresting the advance of salinity and for reclaiming affected areas that focuses on maintenance of the drainage system;

- An inventory of irrigation water-control structures, such as diversion gates and cross regulators, that have been damaged or are currently inoperative;

- An inventory of existing heavy equipment that requires repair or replacement to carry out rehabilitation and maintenance of the system;

- A survey of the existing skilled labor resources available to carry out system operation and maintenance; and

- A work plan and estimate of the costs of rehabilitation or replacement required for proper water regulation.

Donors have begun to support system rehabilitation efforts, including surveys of the major water-control facilities, the development of work plans and cost estimates for the rehabilitation of portions of the system, as well as small-scale infrastructure repair. However, the rehabilitation of the Helmand-Arghandab system as a whole will require from donors a major capital investment, as well as a commitment to building a coordinated system of on-farm water management. Without a reliable institutional framework — public, private, or a partnership of the two — in place to manage the operation and maintenance of the system and to regulate the distribution of water, the preliminary efforts cited above will fall far short of their goals.

The baseline information established for this study is one element of an Afghanistan GIS developed by DAI for O/AID/Rep's Afghanistan ASSP/PSA project. This baseline data can be compared with satellite imagery obtained in the future to monitor land use and agricultural production in the Helmand-Arghandab region. A stratified field sampling system built into the GIS could provide accurate agricultural statistics on land use, cropping patterns, and production. A more-detailed GIS that incorporates the location of critical system infrastructure (such as diversion gates, siphons, and cross regulators), roads, and human settlement patterns would provide planners and project managers with an ability to:

- Determine the most cost-effective interventions to maximize rehabilitation of the system as a whole;
- Coordinate on-going, donor-funded rehabilitation efforts;
- Monitor the impact of these efforts;
- Monitor the operation and maintenance of the system as a whole; and
- Monitor the impact of system management on such environmental conditions as waterlogging and salinity.

Building this capacity into the Afghanistan GIS will require far more field data than ASSP/PSA project staff, because of the wartime conditions, have been able to gather to date. Field observations, or "ground truthing," are essential to the process of satellite imagery interpretation. Periodic ground truthing enables analysts to refine their interpretations of surface phenomena and to recalibrate statistical analyses of such surface phenomena as land cover, land use, agricultural production, and water distribution.

The methodology developed for this study can be applied not only to the evaluation of other irrigation systems in Afghanistan but for the planning and monitoring of all types of donor-assisted development. The Afghanistan GIS is a powerful tool for establishing development priorities and managing development activities effectively on a macro scale.

BACKGROUND

The Helmand and Arghandab rivers irrigate some of the most productive agricultural land in Afghanistan. Water from these rivers has enabled agricultural societies to flourish in the arid lands of southern Afghanistan over the past two millennia. According to historical sources, the Helmand Valley was the breadbasket of Central Asia over 1,000 years ago.

Construction of the modern Helmand-Arghandab Valley irrigation system began in 1935 with Japanese support to the Government of Afghanistan but World War II brought a halt to construction. After the war, the government used its own funds to contract with the American engineering firm Morrison-Knudsen to improve and extend the system's network of canals. In 1953, the U.S. government, working through the Point IV Program, provided assistance to establish the Helmand-Arghandab Valley Authority (HAVA), a river basin development project modeled on the Tennessee Valley Authority. Figure 1 shows the location of the HAVA project.

The governments of Afghanistan and the United States invested approximately $120 million in the HAVA system during the next 25 years. By the 1970s, HAVA was the largest of Afghanistan's three modern irrigation systems.[1] The HAVA command area was estimated at 231,000 hectares, and 144,000 hectares of that command area was estimated to be under cultivated agriculture.[2]

The HAVA system includes two major dams — one on the Helmand River and one on the Arghandab River — and downstream irrigation facilities in both Helmand and Qandahar provinces. Under HAVA, the government provided farmers with agricultural extension and agroprocessing (for example, cotton gins) services. The dam, penstocks, and turbines on the Helmand River also provided hydroelectric power for southern Afghanistan. HAVA staff, headquartered at Lashkar Gah in Helmand Province, managed the dams, the hydro-power facilities, the irrigation systems, and the extension services. As farmers began using improved seed, chemical fertilizers, and tractors, made available by HAVA, the Helmand Valley became synonymous with progress in Afghan agriculture. By the 1970s, Helmand and Qandahar provinces accounted for most of the mechanized farming and use of improved agricultural inputs in the country. As a result, the Helmand Valley became an important area for the production of wheat and cotton.

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[1] The other two systems are located near Jalalabad and the Ghaziabad farms in Nangarhar Province and at the World Bank-supported Kunduz-Khanabad Project in northern Afghanistan.

[2] Asim, H., and G.B. Schilz, *A Geography of Afghanistan*, Center for Afghanistan Studies, University of Nebraska, 1976, p. 80.

Figure 1 Location of the HAVA Project Area

The study on which this report is based focused on the portion of the HAVA system supplied with water from the Kajakai Dam located approximately 95 kilometers upstream from the Boghra Canal headworks.[3] Construction of the dam began in 1951-1952 and was completed two years later. The dam, 100 meters high by 275 meters long and 420 meters wide at the base, has the capacity to store 1,844 million cubic meters of water.

This portion of the Helmand-Arghandab system is sub-divided into four large areas of integrated irrigation development. Three of the areas are on the west bank of the river and are fed through the Boghra Canal by water from a diversion weir above Girishk to two high desert areas beyond the river flood plain: Nad-i-Ali and Marja.[4] The third area, Shamalan, is fed through a branch off the Boghra Canal. The fourth area, Darweshan, is on the east bank of the river and is fed through another canal beginning just above the river crossing near the town of Darweshan. Figure 2 shows the boundaries of these sub-project areas.

Prior to the Soviet invasion of Afghanistan in 1979, the HAVA system was well maintained. Parts of the system were closed down for 40 days each year during the period of mid-winter rains (January-February) to clear silt from the canals and make repairs. The Helmand-Arghandab Construction Unit (HACU) maintenance center provided heavy equipment for dredging and cleaning the irrigation canals and drains and for repairing headgates, weirs, and other structures. The smaller irrigation canals within each of the sub-project areas were maintained by hand with contract labor. Despite this regular maintenance, HAVA authorities were beginning to encounter serious problems with adequate drainage and soil salinity in parts of the system command area by the mid-1970s

Since 1979, however, the system has received little or no maintenance. Because of civil and military conflict, regular canal and drain cleaning has not been possible. Blocked drainage has led to waterlogging, salinization, and the abandonment of land by farmers. Many of the irrigation structures have been damaged or dismantled and no water flow regulation has been possible.

Rehabilitation of the Helmand-Arghandab system will be a crucial step in restoring Afghanistan's agricultural productivity. For this reason, an assessment of the feasibility of rehabilitating the system to its pre-war operating capacity is critical. Thousands of Afghans are returning to the Helmand Valley and farming with water from the canals which, even with negligible maintenance during the war, are still in some state of operation.

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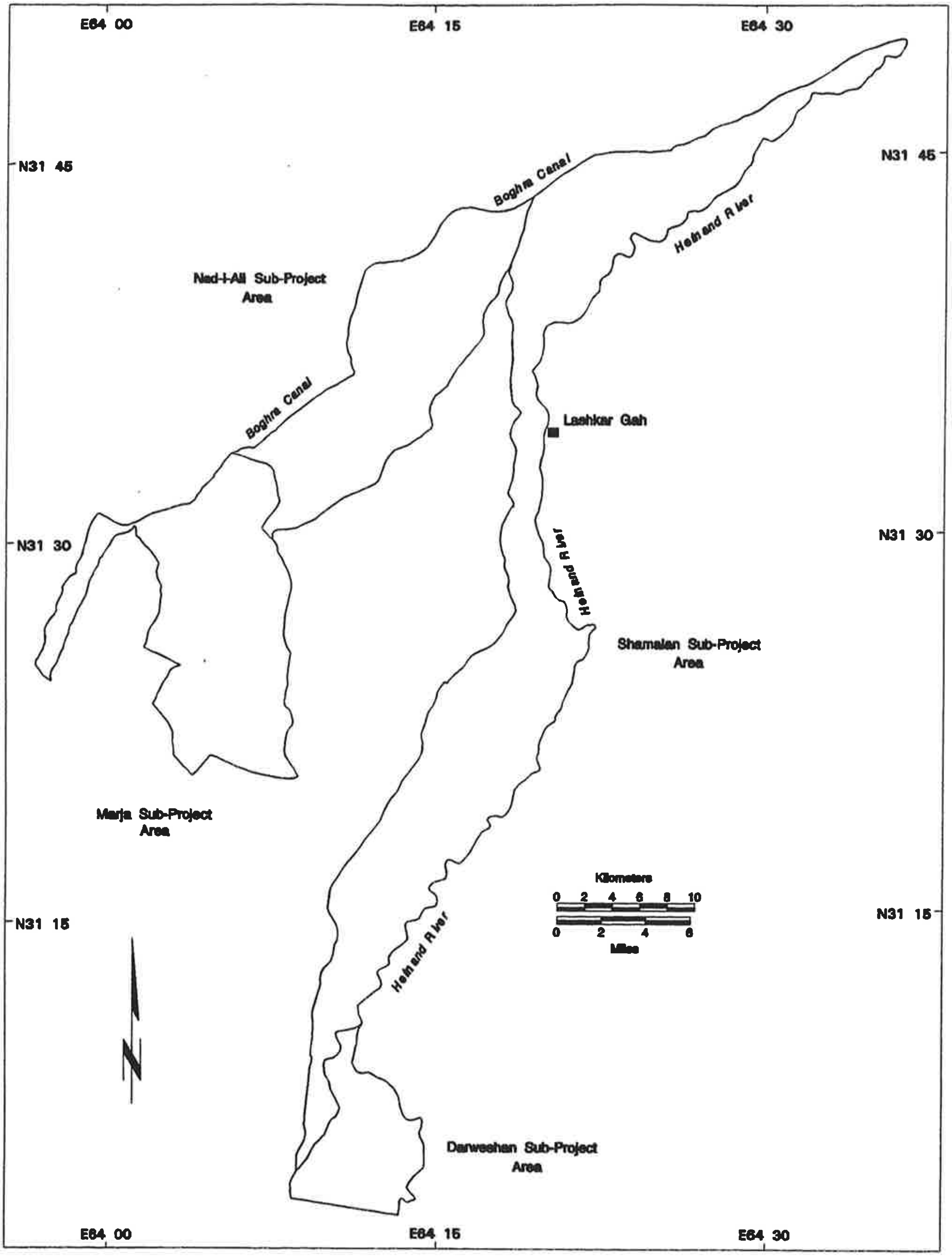
[3] The reservoir behind the dam is visible in the northeast corner of the satellite images of the Helmand Valley (figures 3a and 3b).

[4] Construction of the Boghra Canal began in 1946 and was completed in 1952. The canal is 74 kilometers long and has a capacity of 70 cubic meters per second.

Figure 2 Helmand Valley Irrigation Sub-Project Areas



METHODOLOGY

This report is based on a reconnaissance-level study of a portion of the Helmand-Arghandab irrigation system. A DAI/EarthSat study team employed remotely sensed data (Landsat satellite imagery) to detect land use and environmental changes over time (referred to as change detections) in the command area of the system. For the analysis of this area, the study team relied on a country-wide GIS developed by DAI for the PSA component of the Afghanistan ASSP project funded by O/AID/Rep. With the help of the GIS, the study team identified 16 sites within the command area where land use has changed significantly between 1973 and 1990. The study team employed visual interpretation methods and a field survey to determine reasons for changes in irrigated agriculture, and link those changes with requirements for irrigation system rehabilitation. This section reviews the methodology followed to carry out this study.

Satellite Imagery

The satellite imagery used for this study was obtained from the U.S. Landsat series of orbiting satellites. The advantages of using satellite imagery for this study are clear: the satellite provides information on areas that are difficult or dangerous for field teams to survey accurately; a single image provides a synoptic view of large land areas, such as the Helmand Valley; and, the image provides a permanent record of conditions within the synoptic view at the time of acquisition.

Landsat satellites have been operating since 1972. That duration of operation gives analysts the opportunity to compare imagery of the same land area over time to detect changes in predetermined variables (such as river bank soil erosion, deforestation, and desertification). Landsat data can be collected for nearly any area on the entire globe every 16 days. Cloud cover and the existence of ground receiving stations are among the constraints to Landsat data collection.

Successive Landsat satellites have been equipped with different types of data sensors. Data from two related but different sensors were used in this study. The 1973 data (Figure 3a) is taken from the Multispectral Scanner (MSS) sensor and the 1990 data (Figure 3b) is taken from the Landsat Thematic Mapper (TM) sensor. MSS collects data in four spectral regions: visible green, visible red, and two near-infrared bands. A single Landsat image contains data for approximately 35,000 square kilometers (185 kilometers on each side). The MSS sensor uses four numerical, or digital, values to measure the amount of energy reflected within each band from the ground for each image element (pixel). The pixel size corresponds to the spatial resolution of the sensor. For MSS, the pixel size is nominally referred to as 80 meters. TM is an advanced sensor which has more spectral bands, better spatial resolution (30 meters), and some other advantages over the MSS, such as improved radiometric and temporal resolution. TM data have been collected since the launch of Landsat 3 in 1982.

In Figures 3a and 3b, the Helmand River can be easily seen flowing from the northeast to the southwest. The Arghandab River enters from the east and joins the Helmand just below the center of the images. As in most Landsat images, areas of healthy green vegetation appear as the color red. Irrigated (red-toned) areas are easily seen along the rivers. Extensive tan-toned regions of sand dunes are visible in the southeast. Darker-toned mountains and rock outcrops are visible in the northeast and northwest quadrants of the figures. Most of the scene is barren or sparsely vegetated rangeland as indicated by white to blue-grey tones. Saline areas and the loose gravel and stones of dry streambeds are visible as high-reflectance white areas. Drainage patterns indicated by streambeds are clearly visible. A land cover map of Helmand Province produced from the ASSP/PSA Afghanistan GIS (Figure 4) provides a reference to the satellite images.[5]

The digital values from Landsat MSS and TM can be processed by computer software to classify features on the ground such as bare soil, water, or vegetation. This process is referred to as automatic classification, digital processing, or numerical analysis. Photograph-like images can also be produced from the digital values for visual interpretations very similar to the mapping procedures for aerial photography. These images can be single band, black and white imagery, or, more commonly, three bands can be selected and processed with different colors to produce a false color composite (FCC), such as figures 3a, 3b, 7-15 and 17 in this report. Different band and color combinations can produce different FCCs. Visual analysis and interpretation of FCCs were the principal methods used in this study.

Geographic Information System

A GIS is a system for the storage, processing, organization, analysis, and presentation of spatial, or geographic, data. GIS is an extremely valuable tool for any study that uses mapped information. A GIS can be as simple as a base map with a series of manually produced overlays in the same scale that display discrete sets of geographic data, such as road networks, political and administrative boundaries, temperature variations, and population settlements. More commonly, a GIS is a computer software and hardware system that stores each of these overlays as discrete data sets.

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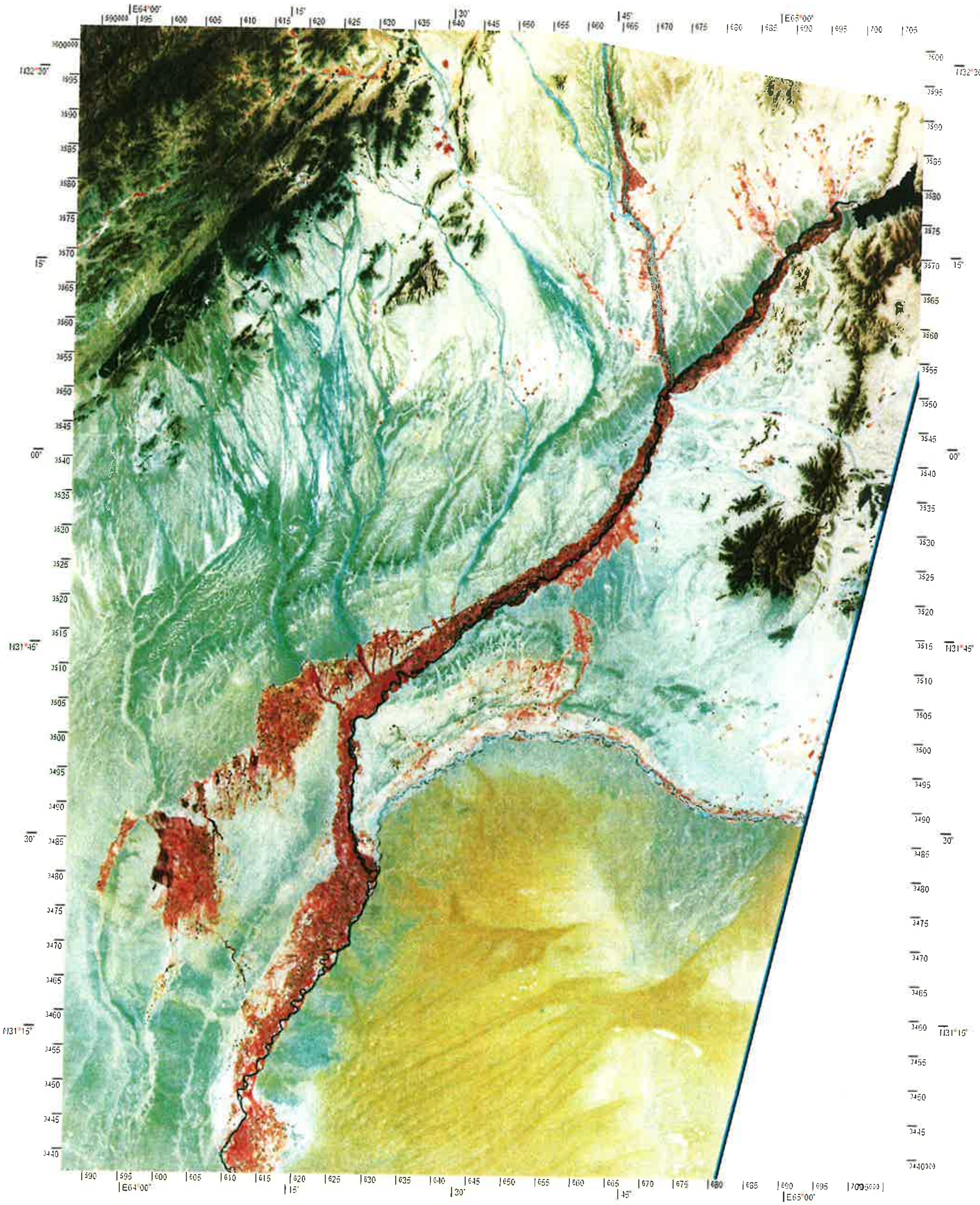
[5] This map is one of 29 provincial maps prepared by DAI and EarthSat for ASSP/PSA using the Afghanistan GIS. All maps and data for land cover classification appear in the *Afghanistan Land Cover and Land Use Report*, prepared by DAI and EarthSat for O/AID/Rep (March 1993).

Figure 3a Landsat MSS Scene of the Helmand Valley (1973)

MSS Bands 1,2,4 1340-054750 P167 R38 28 JUN 73 N31-45 E064-04 Helmand, Afghanistan



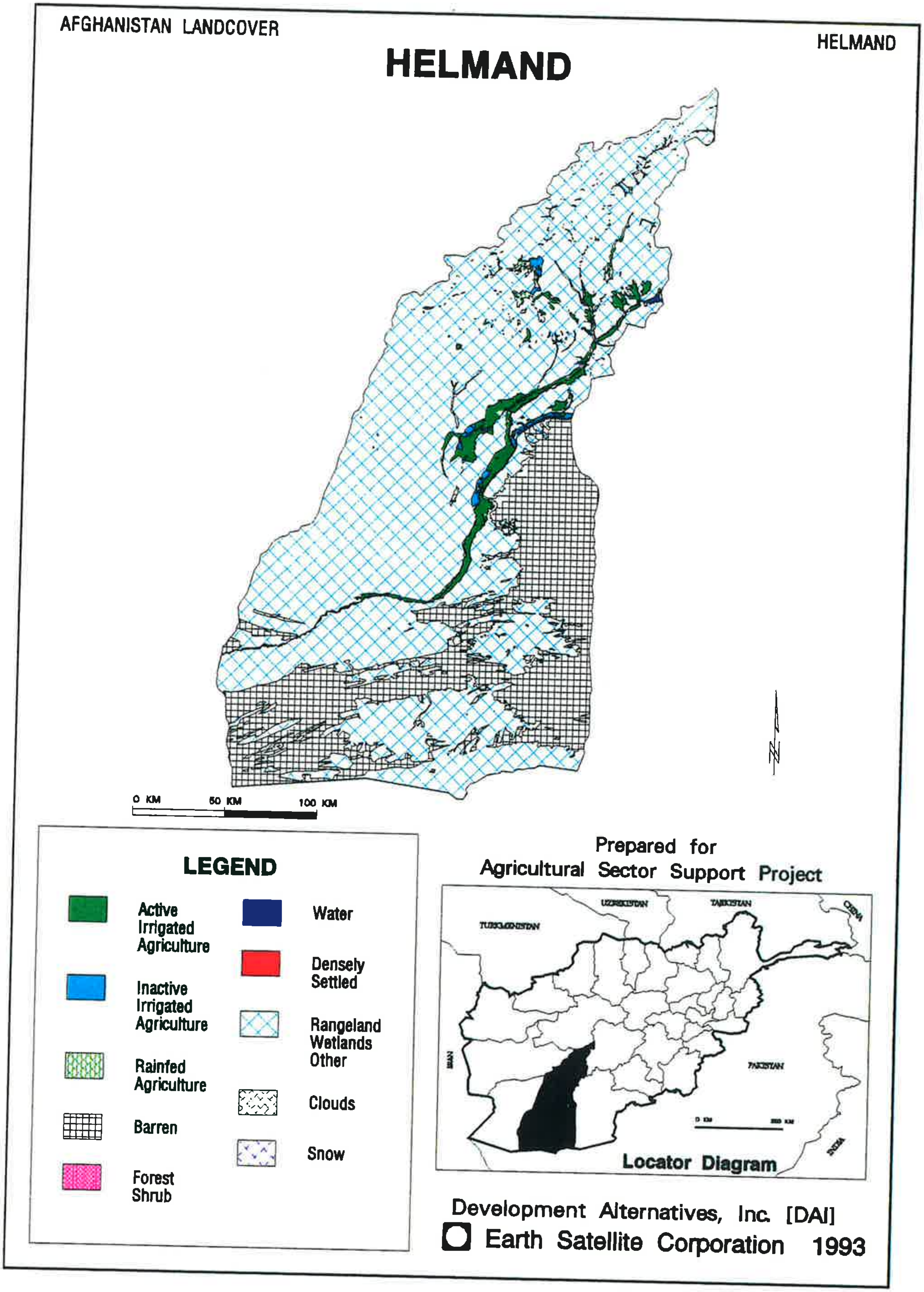
10 0 10 20 30 40 KM

Map Projection UTM Zone 41 New International 1967 Spheroid

Figure 3b Landsat TM Scene of the Helmand Valley (1990)

TM Bands 2,3,4 52248-05335 P155 R38 27 APR 90 N31-45 E064-43 (57m x 57m pixel size) Helmand, Afghanistan

Figure 4 Land Cover Classification for Helmand Province



Since late 1989, DAI and EarthSat, under the Afghanistan ASSP/PSA project, have been developing an Afghanistan GIS. With EarthSat technical assistance, a trained staff of Afghan and Pakistani specialists have gathered, processed, and stored in this GIS an enormous amount of spatial and attribute data (for example, agricultural, economic, and sociological information characteristic of specific locations) for all of Afghanistan. These data sets include: land use or land classification for the entire country, resident and refugee population distribution by province and sub-province, roads, settlements, irrigation canals, elevation, temperature ranges, soil classifications, and provincial and sub-provincial boundaries.[6] These data sets have been and can be used for a broad variety of applications including: the production of base maps, the selection of appropriate sites for development project activities, project monitoring and impact assessment, modelling and sensitivity analysis (that is, "what if?" analysis that estimates the impact of changes in one variable on a set of other related or nonrelated variables), and change detections, such as the subject of this report. The Afghanistan GIS can also be used on personal computers with peripheral devices. The primary GIS software used for the Afghanistan GIS and this study is the Environmental Systems Research Institute (ESRI) ARC/INFO package.

The study team used the Afghanistan GIS to produce a change detection map of agricultural land use in the Helmand Valley. The team interpreted the pre-war and post-war Landsat images of the region visually, and converted these interpretations into digital data files, or data sets, for inclusion in the GIS. The GIS software enabled the team to superimpose the post-war data set as a layer over the pre-war data set for comparison. The comparison of the two layers revealed changes in agricultural patterns over time, as illustrated in Figure 5. This process is described in greater detail below.

Data Selection

A crucial issue in remote sensing is the date or season of data acquisition. Generally, an analyst's ability to identify or classify specific features in a satellite image varies with the date of that image's acquisition. To identify agricultural areas, and especially to identify specific crops, the analyst must refer to the crop calendar for a region to determine the optimum date for satellite data collection. To carry out a change detection in cropping patterns using two or more images of the same area, the analyst must attempt to obtain remotely sensed data when crops are at the same stage of growth. Ideally, all imagery acquired subsequent to the original or baseline image should be acquired as close as possible to the same anniversary date as that of the baseline image.

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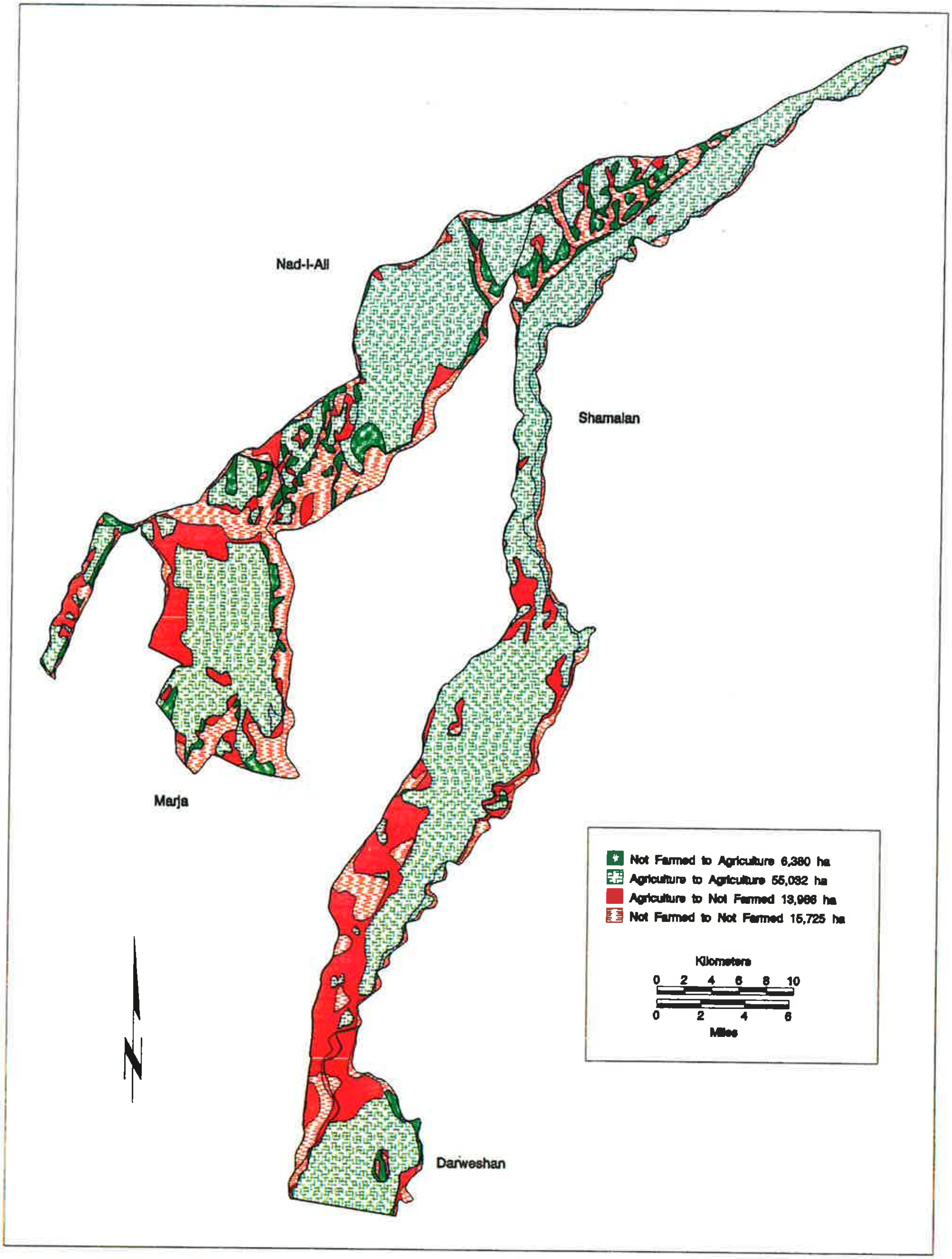
[6] A full listing of data sets contained in this GIS is described in the ASSP/PSA *Afghanistan GIS Data Dictionary*, available from the DAI project office or O/AID/Rep in Islamabad, and from the DAI home office in Bethesda, Maryland.

Figure 5 Helmand Valley Irrigation Study: Agricultural Change Analysis 1973-1990



Wheat, the primary food crop in the Helmand Valley, is planted in late fall or early winter for harvest in May. The best period for identifying agricultural areas in Helmand is March or April when the wheat is at its peak growth and can be easily delineated from surrounding bare soil in a satellite image.

Using standard Landsat FCCs, healthy green vegetation appears bright red because of its high reflectivity in the near-infrared wavelengths. In arid and semiarid environments such as Afghanistan, these red tones contrast markedly with the light gray and tan tones of nonagricultural bare soil or rangeland. Fallow and recently harvested agricultural fields are similar in tone to bare soils and dry rangeland. For this study, analysts visually identified rectilinear field patterns and their geographic associations to the irrigation system to differentiate between areas of recent cultivation and those that have been abandoned or areas that are nonagricultural.

The initial data acquisition strategy for this study was having the study team obtain anniversary date imagery for April representative of pre-war conditions (before 1978) and recent post-war conditions. The team would then examine these two images to detect change in the extent of irrigated agriculture, which would indicate possible changes or damage to the irrigation infrastructure. An archival search of Landsat data for the Helmand area determined that only four images prior to 1978, all from the MSS sensor, were available. These included a June 1973 image, and three images from the period May through June 1977. None of these data sets fell within the optimal season for identifying irrigated wheat cultivation in the Helmand Valley (March-April). The earliest frame the study team acquired was for 28 June 1973 (see Figure 3a).

The team became concerned about how representative of the agricultural conditions and cropping patterns prevalent in pre-war Helmand Valley is the June 1973 data. Had there been imagery for more than one pre-war year, the team could have assembled a series of images to resolve the question. However, because there was imagery for only one pre-war year (1977), the team did not consider the acquisition and processing of any of the 1977 frames useful.

The most recent imagery in the optimal time frame for this study originated on 27 April 1990 (Figure 3b). The study team acquired these data to carry out the change detection for this report. Again, there was concern about the representativeness of the 1990 image for post-war or even recent conditions because of significant flooding in the Helmand Region in 1990. However, a visual comparison of the 1990 image with imagery for the region available to the team from 1991 and 1992 indicated close similarity in agricultural conditions and cropping patterns.

In selecting June 1973 imagery for comparison with the April 1990 imagery, the study team faced a major concern: how comparable are these two images given that a wheat crop in the ground will be in a different stage of growth in each of the two months? This anniversary date issue was resolved through a comparison of a 14 June 1990 image at a scale of 1:100,000 with the April 1990 image. Using visual interpretation methods, the team found that the April and June 1990 images are essentially similar. Recent agricultural land use, including evidence of fields recently harvested, was readily apparent in the June image. As a result, the team concluded that a comparison of June 1973 and April 1990 data would be acceptable using visual interpretation techniques.

Command Window and Project Areas

Having selected the appropriate imagery, it was necessary for the study team to carefully delineate the portions of the Helmand River irrigation project that could be used for change detection. A command window corresponding approximately to the area within the satellite imagery that is irrigated by the Helmand-Arghandab system was delineated by using 1:100,000-scale topographic maps and locating major canal systems and headworks. The team then compared these boundaries to the 1973 image also at a scale of 1:100,000. The final boundaries were drawn on an overlay for the image so that all the significant areas of agriculture, 91,103 hectares, were included in the command window. The team then converted these boundaries into a computer map or file by digitizing the overlays as a GIS data layer. The GIS layer was then reproduced at the 1:100,000 scale and again overlaid on both the 1973 and 1990 images for verification of correct boundaries.

The team further sub-divided the command window into four sub-project areas corresponding to the major divisions of the Helmand-Arghandab system in the Helmand Valley: Shamalan, Nad-i-Ali, Marja, and Darweshan (see Figure 4). Each area is served by a major canal headworks. The Darweshan area is truncated on the south because the Landsat imagery did not extend over the complete sub-project area. Therefore, changes discussed in this report apply only to a small portion of Darweshan.

Image Interpretation

The primary change detection strategy of the study team was to visually compare the June 1973 and April 1990 images. The two basic components in this process were to:

- Generate statistics on agricultural change and produce a map highlighting areas of significant change for further analysis; and

- Undertake a detailed examination of the change areas highlighted using visual interpretation of paired images and field surveys.

In general terms, analysts use two methods for satellite image interpretation. The digital, or computer based, method uses the computer to recognize surface conditions with little or no human intervention. This method includes determining spectral signatures for the features of interest and then applying a statistical decision rule to classify all the pixels in the study area by cover type. However, for change detection required for the Helmand study, digital processing would require anniversary date imagery when field conditions are similar.

Instead of the digital interpretation methods, the study team used visual interpretation. The visual process relies on the human analyst's ability to incorporate contextual information in identifying active or recently active agriculture. For example, observation of rectilinear field patterns in conjunction with other information was used to classify some land as active agriculture, even though color tones did not indicate the presence of green vegetation.

For visual interpretation purposes, the study team had the original digital data for the two dates processed as photographic images. First, each data set was geometrically corrected or geocoded to fit the latitude and longitude geographic grid. Second, the data were visually enhanced to maximize their usefulness for manual interpretation based on band and color selection for the respective FCCs. This process provided film products of the two dates from which large format image prints were produced at both 1:100,000 and 1:250,000 scales.

The team had several concerns in comparing these two image products. The most obvious is the difference in the agricultural conditions due to the crop calendar as previously discussed. A second concern is the difference in the spatial resolution of the sensors — 80 meters for 1973 and 30 meters for 1990. Given the size of the agricultural areas and individual fields, the team did not consider this difference significant.

A third issue is that slightly different spectral regions (band combinations) and color assignments were used for the two dates. The standard MSS FCC was used for the 1973 image.[7] A slightly different FCC for the 1990 TM data was produced because it has greater utility in arid and semiarid regions.[8] Use of

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[7] This is bands 2 (visible green), 3 (visible red), and 4 (near infrared) in blue, green, and red. The MSS image is similar to color infrared aerial photography where areas of healthy green vegetation appear as red tones.

[8] Band 3 (visible red), band 7 (mid-infrared), and band 4 (near infrared) in blue, green, and red. The changes of this image from the MSS are not significant as the green vegetation appears in very similar red tones on both FCCs.

different band combinations did not affect our comparison of the two images for changes in irrigated agriculture.

The interpretation procedure consisted of placing clear overlay material on each image at the 1:250,000 scale. On this overlay, the study team's image interpreters mapped areas of current agriculture for the sub-project areas. The resulting map was a two-class map of agriculture or nonagriculture. The interpretation used a minimum mapping unit (mmu) of .25 centimeter per side, which, at this image scale, is about 40 hectares. No individual feature smaller than this mmu was mapped.

The interpreters identified agriculture based on a combination of tones, patterns, and associations. Irrigated vegetation would be red toned and have distinctive rectilinear spatial patterns. To account for changes, due to the lack of anniversary date imagery, the June 1990 image was examined as necessary.

After the maps were completed, they were converted to ARC/INFO GIS layers with a digitizing tablet. During this process the maps were spatially registered using the latitude and longitude marks on the image perimeter. The GIS agriculture data layers were printed on transparent mylar sheets at both image scales. These overlays were edited for any error in digitizing or interpretation clarification at the 1:100,000 scale. Once both data sets and the sub-project areas were properly edited, additional geometric registration was accomplished by the selection of precise ground control points (GCPs), such as canal intersections, identifiable on all data sets. This is an iterative process of adding and deleting GCPs and producing overlays of the data sets to assess the precision of the registration by looking at identical features in all data layers. The process resulted in precisely registered GIS layers of the sub-project areas, indicating 1973 and 1990 agriculture.

The study team then used the GIS to examine and manipulate individual data layers to provide:

- The hectarage for each sub-project area;

- The hectarage of irrigated agriculture and not-farmed land in each year by sub-project area;

- A four-way statistical matrix comparing the two years of information (agriculture to agriculture, agriculture to not-farmed, not-farmed to agriculture, and not-farmed to not-farmed); and

- An overlay map showing where the changes have occurred (Figure 5).

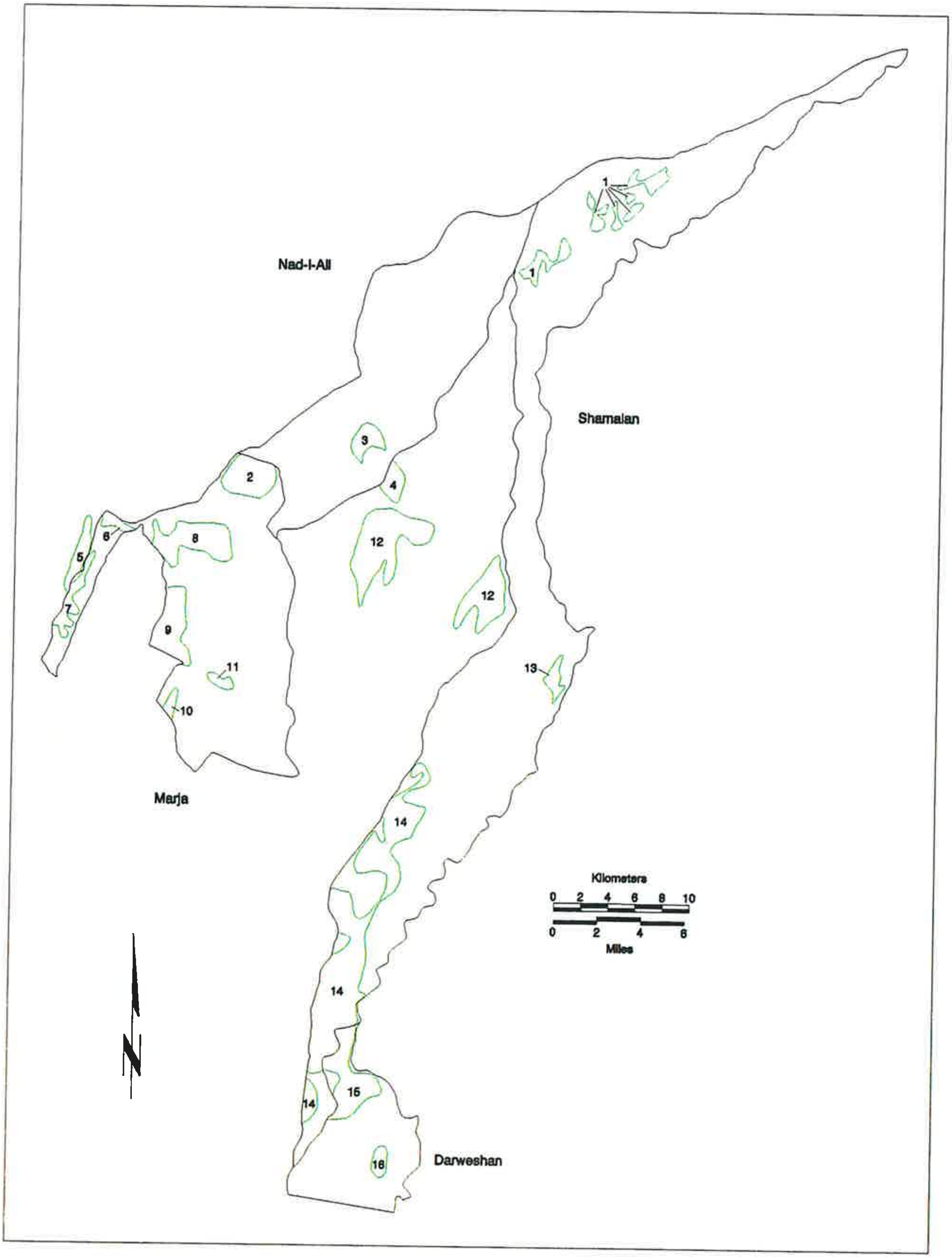
The map showing the occurrence of change was overlaid on the 1:100,000 scale images to identify areas of change on those images. The team then examined each area to determine its significance and probable cause of the change. In addition, other features of interest were identified. Some features were not necessarily related directly to changes in agriculture but to other factors such as flooding, salinization, or condition of the irrigation infrastructure. The team delineated principal areas of interest on the image overlay and then digitized the area boundaries to produce a GIS layer showing locations of significant change (Figure 6). This GIS layer identified 16 sites for further examination by a field survey team.

Field Survey

The use of remote sensing is always enhanced by field work. The initial strategy of this study was to identify locations of significant change based on satellite imagery. The satellite imagery was used to scan a large area for change, and to do so quickly and more cost effectively than by field survey methods alone. The results of this scan enabled the study team to pinpoint areas for a subsequent field survey.

In late November and early December 1992, a team of ASSP/PSA agricultural specialists visited the Helmand region to survey the 16 sites of significant change identified from visual interpretation of satellite images. The team travelled with topographic maps and copies of the paired satellite images for each site. The team visited most of the 16 sites, and, through discussions with residents of the sites and local officials, attempted to determine the causes of change identified in the remote analysis. The team used hand-held global positioning systems to determine their precise location from navigational satellites. The field team's findings are incorporated into the analysis of the imagery for each of the 16 sites that follows.

Figure 6 Helmand Valley Irrigation Study Locations: Significant Change 1973 to 1990



ANALYSIS OF PAIRED IMAGES

This section describes each site of significant change. Image pairs are used to focus attention on physical features on the ground. The description for each figure incorporates information obtained from the field survey together with information from visual interpretation of satellite imagery and data analysis using the Afghanistan GIS.

Sites 1 to 16, the locations of which are shown in Figure 6, are shown in more detail in the paired images: figures 7 to 15, and 17. Each pair consists of a portion of the June 1973 image (shown at the top or the left), and a corresponding portion of the April 1990 image (shown at the bottom or the right). The scale of these images is 1:100,000 (that is, one centimeter equals one kilometer). In all cases, north is to the top of the page.

The correspondence between tones (colors) and type of feature on the ground is as roughly follows:

- Red: actively (growing) vegetation;
- Black: water;
- White: high reflectance areas (for example, rocks or saline areas); and
- Green/blue: bare soil, dry vegetation.

Figure 7

Site 1 in northern Shamalan is unusual in that it shows an increase in cultivated area of more than 1,000 hectares. Beginning in the mid 1970s land was distributed to farmers and this is still continuing. Improvements were carried out to the drainage system and lands were cleared and levelled. Cotton, maize, wheat, and poppy are all cultivated in the area. There are also smaller pockets of uncultivated land that are waterlogged and full of reeds.

The area is affected by cross drainage (from the northwest to southeast). Levees contain and channel cross drainage across Shamalan to the Helmand River. As it crosses Shamalan, the western-most streambed appears much wider and more diffuse than the others, which may indicate some damage to the levees controlling that particular streambed system. A siphon in the Boghra Canal (the dark line in the northwest portion of the image) appears as a gap in the solid dark line of the canal. The siphon is apparently functioning.

Some of the apparent increase in vegetation may be due to rainfed crops established in a wet year. In some areas, vegetation is not in rectilinear patterns, which supports the notion that some of the vegetative growth is rainfed, or weed growth, and not irrigated agriculture.

The Helmand River carried much more water in April 1990 than it did in June 1973. This is evident from the width of the river (in black) and flooding of areas adjacent to the river.

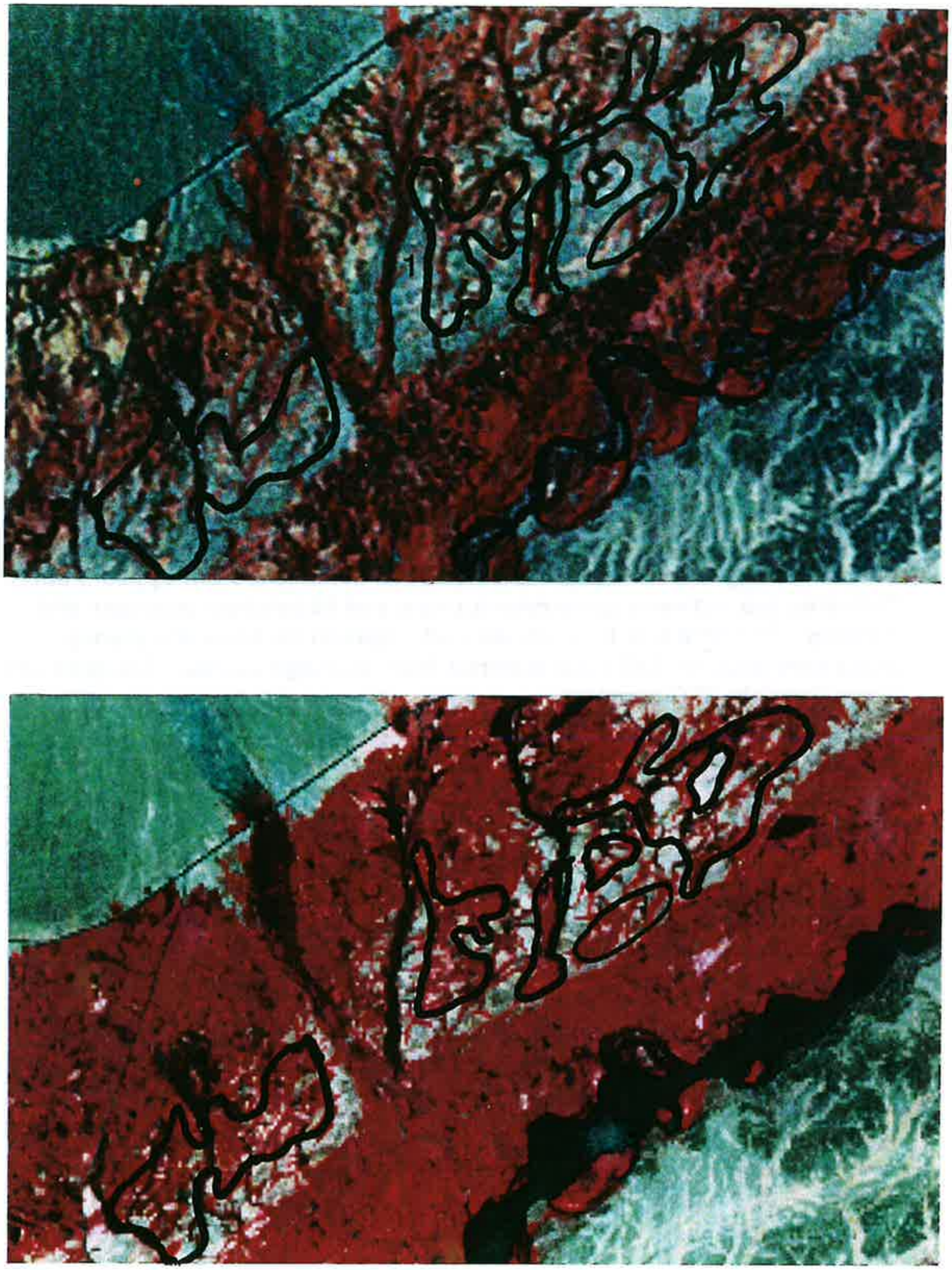


Figure 7 Study Site 1 - Northern Shamalan

Figure 8

Site 2 (the western portion of the image) is located in the northern portion of Marja. An increase in irrigated cropping of approximately 950 hectares is evident. In 1973 the land was not farmed and a portion of it appears waterlogged. Drainage was subsequently improved and land distributed to supporters of the communist government and today it is heavily cultivated with maize, cotton, fodder, wheat, and poppy.

Site 3 (the northeast portion of the image) is an area of 400 hectares located in the southeastern portion of Nad-i-Ali, which has shown an increase in irrigated cropping. At one time this area was government-owned forest that was later cut down and the land distributed amongst settlers. Land is heavily farmed although there are some pockets of salinity.

Site 4 (the east-central portion of the image) is adjacent to, but outside of, Nad-i-Ali. The area was not farmed in 1973. In the 1990 image, a rectilinear pattern of irrigation infrastructure has been established but appears abandoned. This area lies between government posts and Mujahiddin positions and saw much fighting. The land has been mined and irrigation facilities are damaged. The few areas cultivated in 1990 are watered from drainage canals. The area covers approximately 350 hectares.

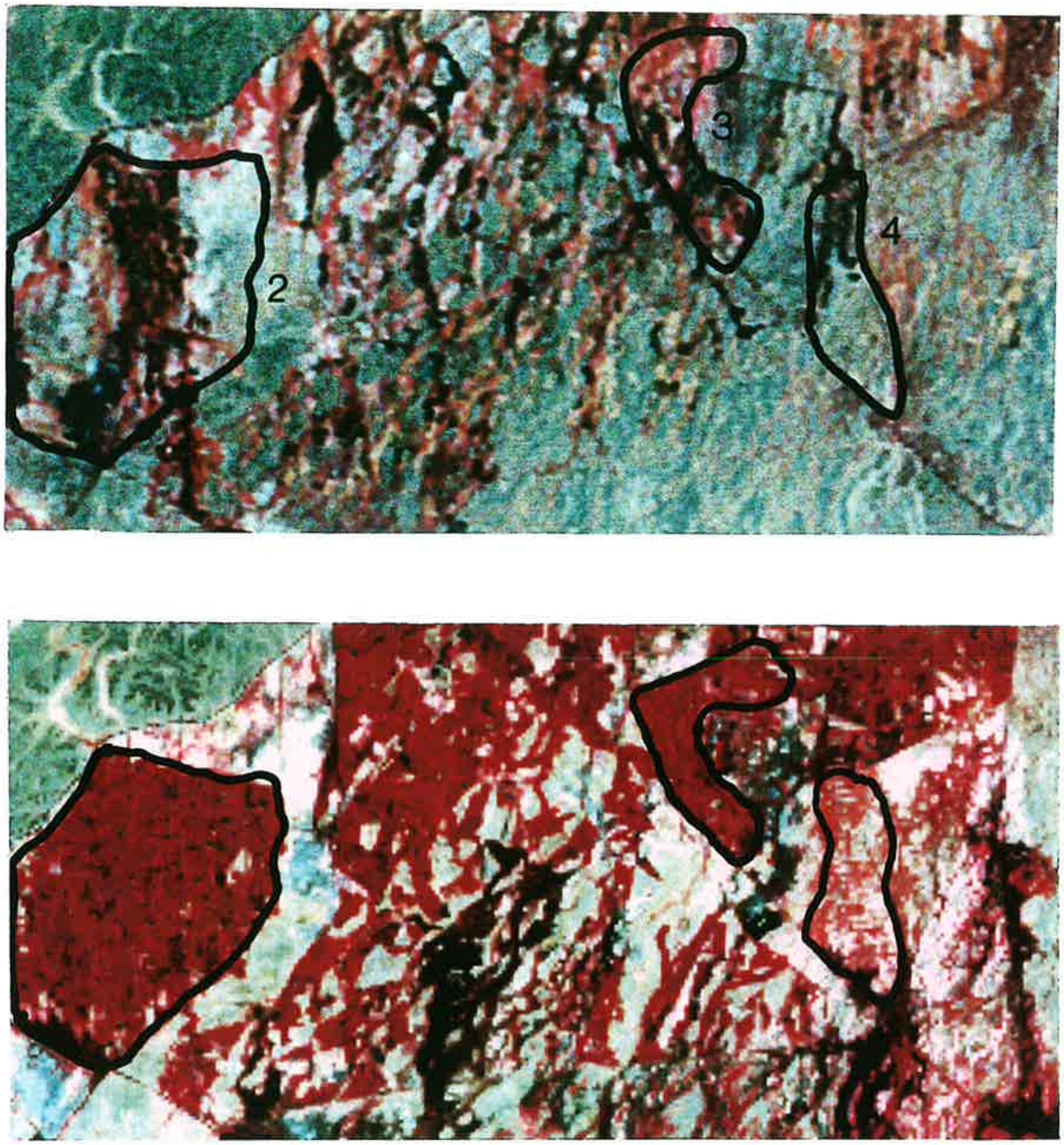


Figure 8 Study Sites 2, 3 and 4 - Northern Marja and Southeastern Nad-i-Ali

Figure 9

Sites 5, 6, and 7 are located on the peninsula to the west of Marja. Site 5, covering 400 hectares, is an area that was not cropped in 1973. Irrigation infrastructure appears to be newly developed. Site 6, covering 200 hectares, had irrigation canals in 1973 but these were not used. The area is cropped today. Gains in irrigated cropping in Sites 5 and 6 may have come at the expense of downstream water users in Site 7, which shows a decrease in irrigated area of approximately 450 hectares.

Figure 9 Study Sites 5, 6 and 7 - West of Marja

Figure 10

Site 8, in the northwest portion of Marja, encompasses 1,250 hectares. In the 1973 image, the area appears wet, but cropped. In the 1990 image, four large rectilinear blocks of land can be seen. None are cropped as indicated by their highly reflective white tones, an indication of salinity. It is likely that maintenance has not been performed on drains. These are probably blocked with silt and weed growth. With drainage blocked, there has been a rise in the groundwater table. The area is naturally saline and evaporation from the groundwater table has likely salinized the soil surface. This may be the principal reason why the land has been abandoned.[9] Salinization may or may not be reversible depending on the nature of the salts involved.[10] In 1991, a nongovernmental organization (NGO), Mercy Corps International, cleared one drainage canal and cultivation has started again.

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[9] A report by P.J. Riddell, *Rehabilitation of Irrigated Agriculture in Afghanistan's Arghandab and Helmand Valleys*, Mercy Corps International, March 1992, states that the Marja sub-project area is especially affected by waterlogging and salinity problems which have led to farm abandonment (page 8).

[10] Sodium salts are particularly harmful. Sodium concentrations can lead to soil impermeability and an inability to remove salts through leaching.

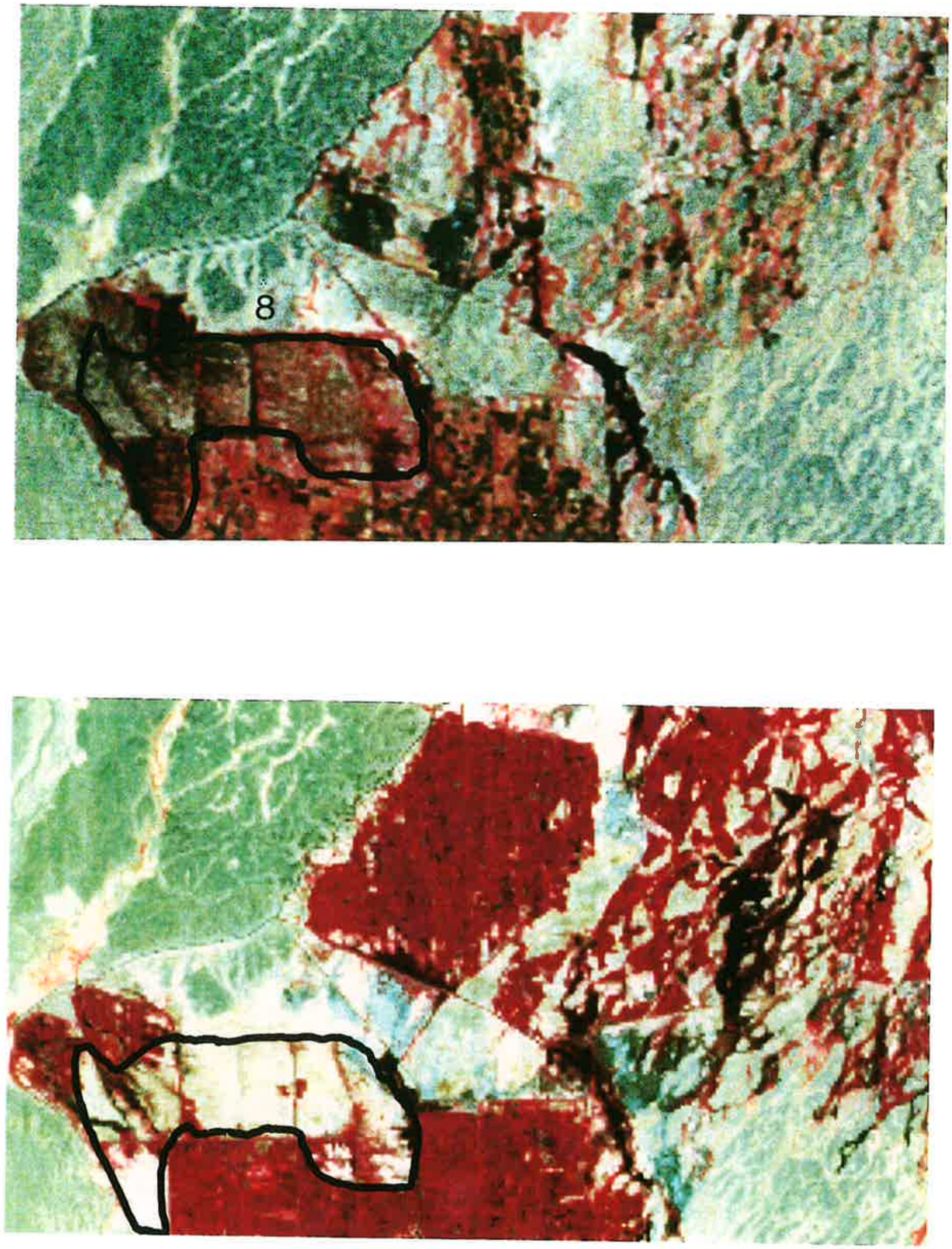

Figure 10 Study Site 8 - Northwest Marja

Figure 11

Patterns in Site 9, the west portion of Marja, appear similar to those in Site 8. In the 1973 image, evidence of recent cultivation and waterlogging can be seen. In the 1990 image, the land is abandoned and appears salinized. This can be due to blocked drainage outlets. Approximately 1,000 hectares are affected. Parallel lines visible in the imagery may be abandoned canals.

Figure 11 Study Site 9 - Western Marja

Figure 12

The northwestern part of the image shows Site 9, which is discussed in Figure 11.

Site 10 is at the southwest portion of the image and shows a gain of some 130 hectares in irrigated area. The area was not within the original Marja project area. It is recently settled and is irrigated with water from a drainage canal.

Site 11, near the center of the image, shows a loss of approximately 150 hectares. Prior to the war this area was devoted to a state-owned fruit orchard, a nursery, and research farms. During the war years the trees were cut down and the farms abandoned. In the last two years cultivation has begun anew.

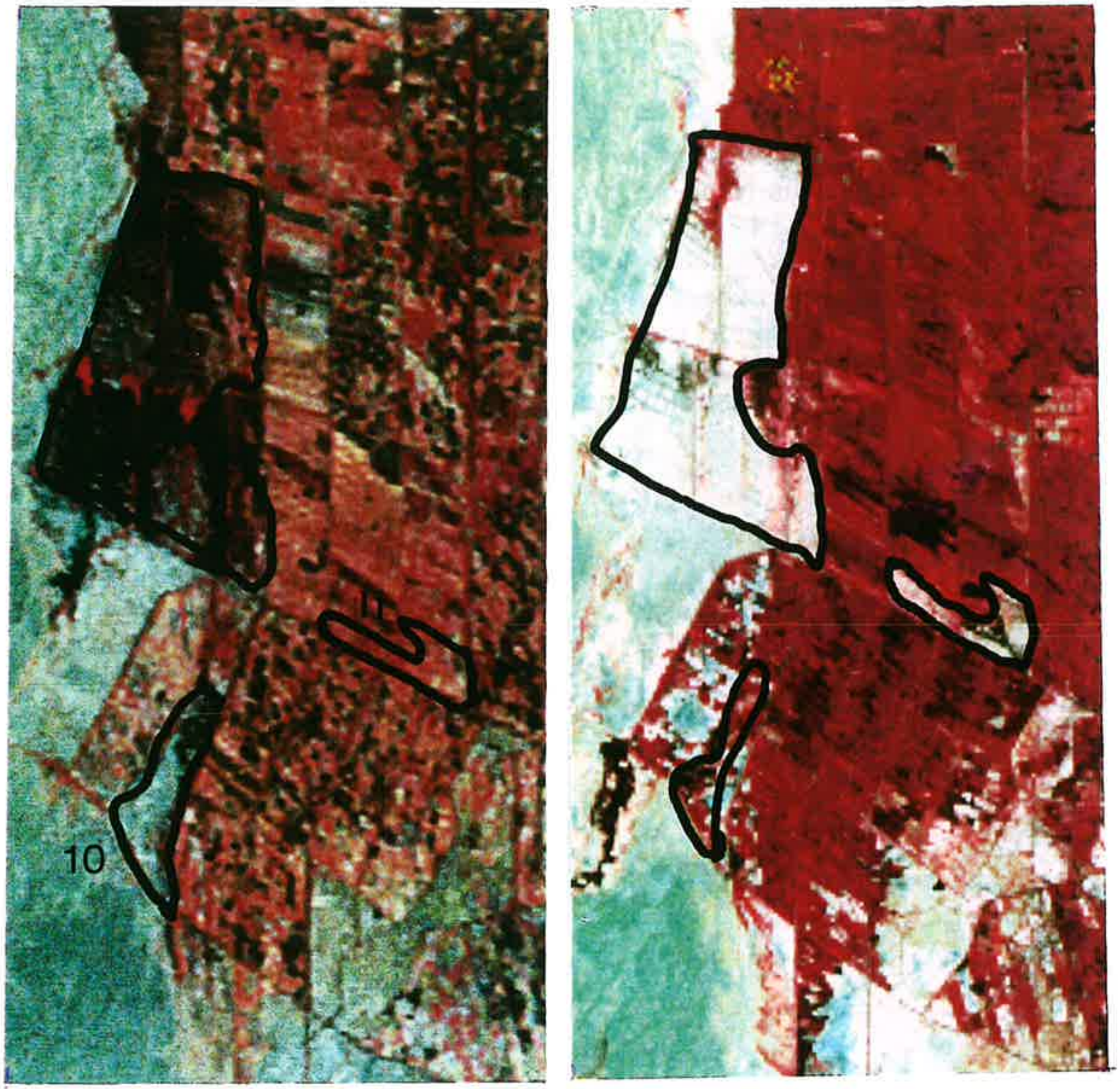

Figure 12 Study Sites 10 and 11 - South Marja

Figure 13

Site 12, composed of two blocks of land totaling almost 3,100 hectares, is located between the Nad-i-Ali and Shamalan Project areas. Almost no vegetation appears in the 1973 image. In the 1990 image the red tones indicate vegetation and the black colors indicate flooded areas or active waterways. A systematic pattern of cultivation characteristic of irrigated agriculture is not evident. This may be rainfed agriculture, or, more likely, natural vegetation established when drainage water or runoff spilled from the irrigation system. This could indicate that water availability is not a constraint and that additional cropping can be supported.

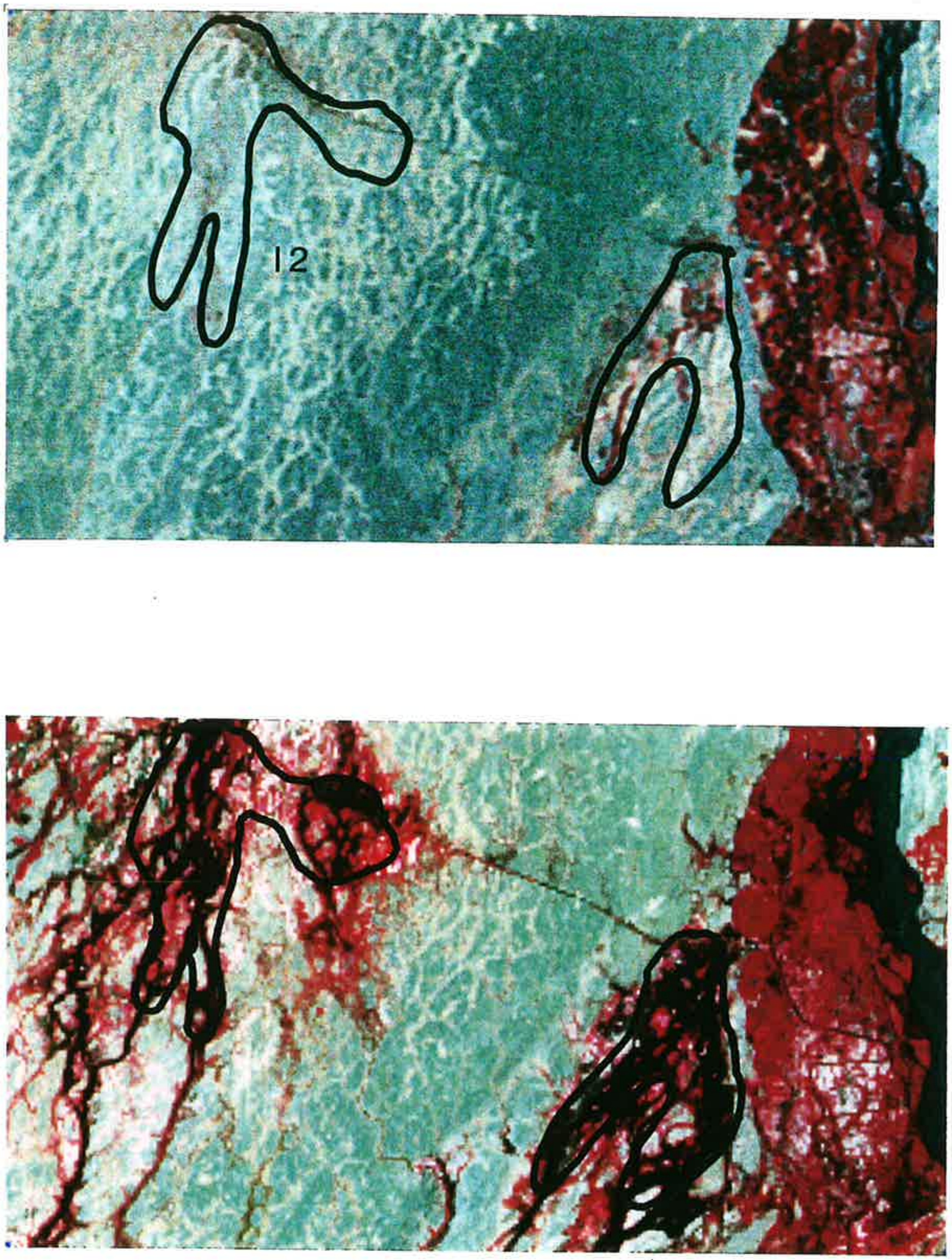

Figure 13 Study Site 12 - Between Nad-i-Ali and Shamalan

Figure 14

Site 13 (west of the river in the lower right portion of the image) is an area of 250 hectares in the east-central portion of Shamalan. Farmed in 1973, the area appears abandoned and possibly salinized in 1990. A drainage channel to the north and west appears to be active. It may be dumping water into this area. Drainage out of this area may be blocked.

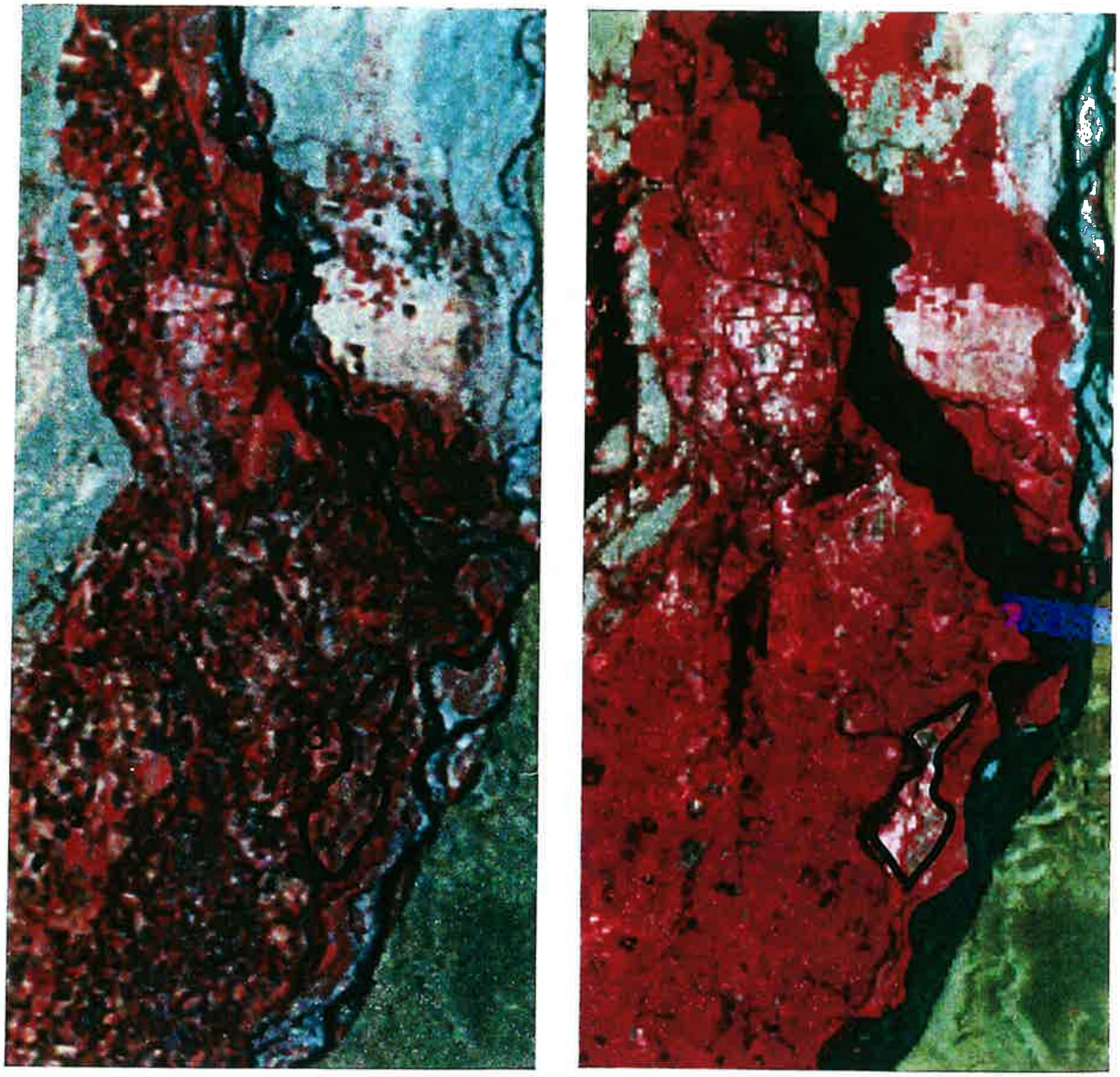

Figure 14 Study Site 13 - East-central Shamalan

Figure 15

Site 14 (portions of which are shown on both Figures 15 and 17) is the largest area of change in the Helmand system. The area is located in the downstream/southwestern portion of Shamalan. Abandonment of irrigated agriculture between 1973 and 1990 encompasses more than 5,000 hectares. Most inhabitants have left the area. Rectilinear patterns of irrigated agriculture which are seen in the 1973 image have been replaced in the 1990 image by a background mosaic which appears strongly salinized. Only scattered/limited agriculture can be seen, particularly along canals and drains. Prior to the war, the area had been irrigated by the Shamalan Canal which was damaged by military activity and by floods. Inadequate canal maintenance led to constraints in water supply. Lack of maintenance of drains helped give rise to pockets of salinity. The field team that visited the area in December 1992 brought back photos which showed patches of salinity and adjacent standing water (groundwater) that was nearly at the level of the soil surface. (See Figure 16.)

Better-drained land is currently being distributed in 2.4 hectares blocks to new settlers. Some farmers are irrigating their land with water from drains. The United Nations Development Programme (UNDP) and Mercy Corps International presently have a canal repair and cleaning project in the area.

Figure 16. Photograph taken near Site 14 which shows standing water and adjacent patches of salinity.

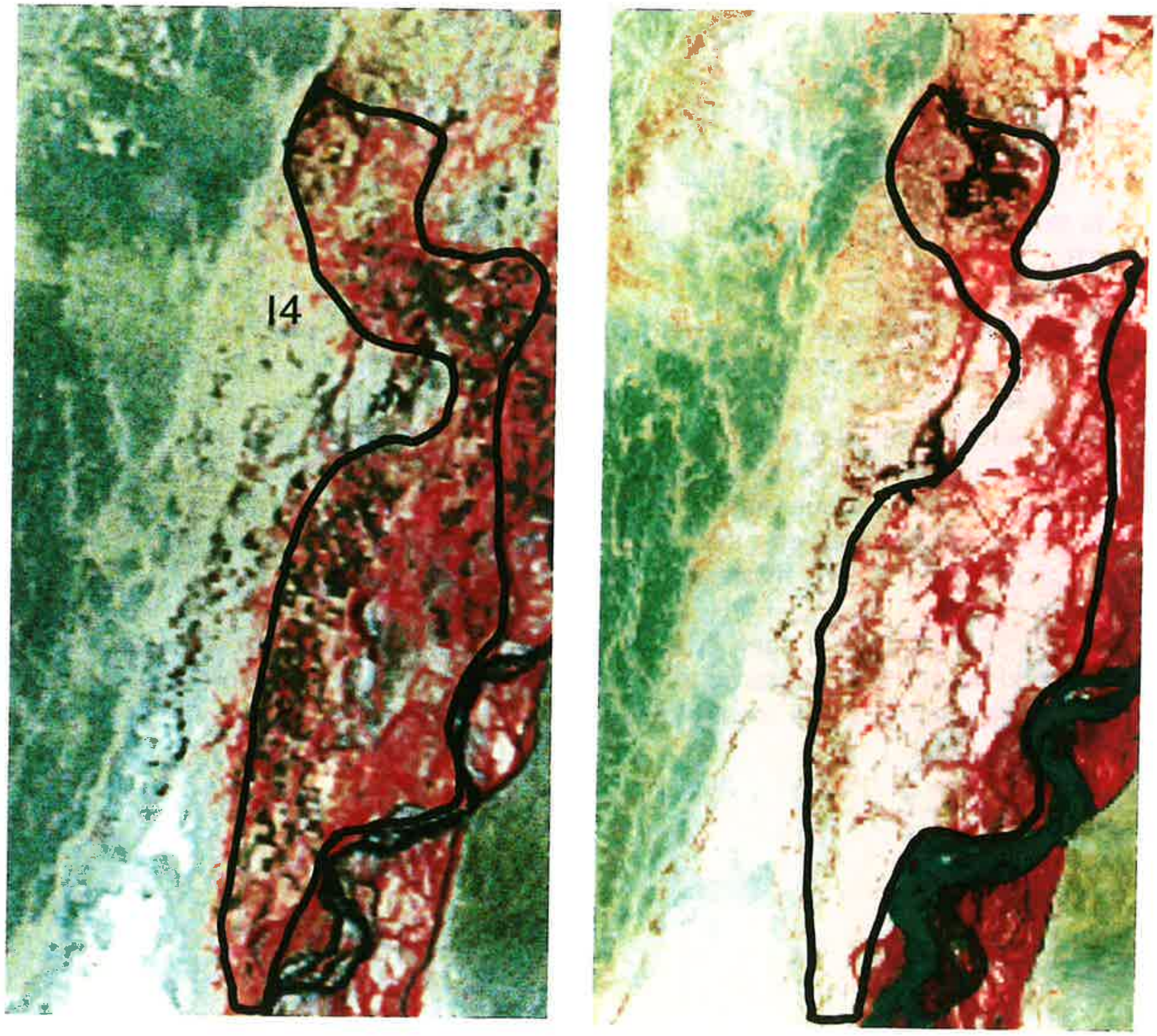

Figure 15 Study Site 14 - Southwestern Shamalan

Figure 17

The southern-most portion of Site 14 is shown in Figure 17. In the image it is the area to the west of the Helmand River. Refer to the description for Figure 15.

Site 15 is east of the Helmand River in the north part of the Darweshan Project area. This area saw severe fighting during the war. Farmers became refugees. Canals, watercourses, and drainage systems were not maintained and are presently silted up and choked with weeds. There was deliberate damage done to canal gates, and in 1990 floods further damaged the irrigation system. Very little water can be supplied to this area. In late 1992 there has been a return of refugees to this area and attempts are being made to repair the irrigation system. Approximately 1,270 hectares have been affected.

Site 16 can be seen in the central portion of the image. This is an area of approximately 200 hectares which has gone out of production due to blocked drainage channels and resulting salinity.

Figure 17 Study Sites 14, 15 and 16 - Southwestern Shamalan, Northern Darweshan

RESULTS AND DISCUSSION

The study team divided the change detection analysis data for the Helmand Valley into two land classes: irrigated agriculture, and not-farmed.[11] For each of the four sub-project areas, the team used the Afghanistan GIS to generate statistics for 1973 and 1990. Changes detected in land-use patterns were classified as: agriculture to agriculture, not-farmed to agriculture, not-farmed to not-farmed, and agriculture to not-farmed. The results of this classification are shown in Table 1.

The results indicate that between 1973 and 1990 the major change in land use in the Helmand-Arghandab system was a decline in the amount of land under cultivation. In 1973, approximately one hectare in four was idle — that is, not under cultivation. By 1990, idle land accounted for one hectare in three. By 1990, 20 percent (14,000 hectares) of irrigated agricultural land active in 1973 was not cultivated. This phenomenon is particularly prominent in the downstream portions of the Shamalan and Marja sub-project areas of the system. By 1990, scattered areas of irrigated cultivation of lands not cultivated in 1973 were apparent throughout the system. These areas combined to total more than 6,400 hectares.[12] Thus, the net loss in irrigated agriculture for the study area as a whole was 7,600 hectares, or 11 percent of the 1973 irrigated area.

The averaging of agricultural decline disguises the fact that certain areas of the system have suffered more dramatic losses of irrigated agriculture than others. The most severely affected sub-project area is Marja where more than one-quarter of the area farmed in 1973 was out of production by 1990. This area is concentrated in two large rectilinear blocks in the northwest and west portions of Marja. This decline in agricultural production is a result of one or more factors:

- Poor drainage from canals blocked with silt and weeds has probably contributed to an increase in surface soil salinity;
- Inoperative gates or water-control devices prevent the delivery of water throughout the entire system; and
- Farmers have abandoned the land for reasons related to the war.

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[11] The Helmand is an arid area and no crops can be grown without irrigation. In this discussion and in Table 1 and Figure 5, the label "agriculture" is the same as "irrigated agriculture."

[12] Some of the increase in agriculture may have occurred between the image date (1973) and the war, which began in 1978.

Table 1: Land Use Statistics, Helmand Irrigation Project: A Comparison of 1973 and 1990. (All numbers are in hectares.)

	SHAMALAN		NAD-I-ALI		MARJA		DARWESHAN		TOTALS	
	1973	1990	1973	1990	1973	1990	1973	1990	1973	1990
Total Hectares of Window	43,306		19,300		21,265		7,232		91,103	
Irrigated Agriculture	34,652	29,670	13,354	14,071	14,770	12,540	6,222	5,132	68,998	61,413
Not-Farmed	8,654	13,636	5,946	5,229	6,495	8,725	1,010	2,100	22,105	29,690
CHANGE FROM 1973 TO 1990										
Agriculture to Agriculture	27,473		11,995		10,823		4,741		55,032	
Not-Farmed to Agriculture	2,197		2,075		1,717		391		6,380	
Not-Farmed to Not-Farmed	6,457		3,871		4,778		619		15,725	
Agriculture to Not-Farmed	7,179		1,359		3,947		1,481		13,966	

In the Shamalan sub-project area, one hectare in five of land cultivated in 1973 was not cultivated in 1990. The southwest, or downstream portion of this area, was the most severely affected. In addition to causes cited above for Marja, downstream areas generally receive water **after** water has been distributed to upstream users. Typically, water delivery conflicts and most breakdowns in irrigation infrastructure will affect downstream water users the most. If gates are removed and irrigation authorities do not have the ability to regulate flows, increased cultivation in upstream areas and decreased cultivation in downstream areas are predictable. This pattern is visible in the distribution of green and red areas in Shamalan shown in Figure 5.

Upstream areas of Shamalan and parts of Nad-i-Ali had more land under cultivation in 1990 than in 1973. These areas may have been under the control of the Communist regime, where the effects of the war limited where intensive farming could be carried out. Or, in the absence of irrigation system control by HAVA officials or local authorities, farmers in upstream portions of the Helmand-Arghandab system simply diverted all the water they wanted, excluding deliveries to downstream users. With drainage outlets blocked (see below), excess water delivered to upstream users may exacerbate waterlogging and salinity conditions.

Although reports indicate that water deliveries cannot be controlled because there are no operative gates or water-control devices, it is perhaps surprising that the Helmand system functions at all after 12 years of war. The fact that downstream users in Marja and Darweshan are still cultivating irrigated crops indicates that water is being delivered and that major portions of the system, such as the diversion dam, main canals, and siphons, have not been completely destroyed.

One of the most severe problems likely to face the Helmand-Arghandab system is increased soil salinity. Soils in the area of the system are naturally saline. Leaching must be provided if lands are to remain productive. Effective leaching depends on good drainage, and good drainage depends on good system maintenance. If drainage is blocked, saline groundwater tables build up. Evaporation results in deposition of salts on the surface of the soil. The problem may or may not be irreversible, depending on the nature of the salts. But leaching is essential to reverse the process, or, at the very least, to keep salinity in check.

This assessment of agricultural change in the Helmand-Arghandab irrigation system demonstrates the utility of remote sensing and geographical data management in identifying persistence and change in phenomena over a wide area. With the ability to detect dramatic variations over time in agricultural land use within the Helmand-Arghandab system, the study team has been able to identify portions of the system that are likely to require immediate rehabilitation.

A rehabilitation plan for the Helmand-Arghandab system should include these elements, in order of priority:

- A survey of the condition of major water-control facilities including the main dam, the diversion dam, the headworks to the main canals and associated structures, and the levees and cross-drainage facilities;
- A work plan and estimate of the costs of rehabilitation required to ensure that these facilities can be operated **safely and reliably;**
- A plan for arresting the advance of salinity and for reclaiming affected areas that provides for monitoring the size and location of affected areas, determining the depth and quality of groundwater (and the impact of both on local salinity), and rehabilitating and maintaining the drainage system;
- An inventory of such irrigation water-control structures as diversion gates and cross regulators that have been damaged or are currently inoperative;
- An inventory of existing heavy equipment that requires repair or replacement to carry out rehabilitation and maintenance of the system;
- A survey of the existing skilled labor resources available to carry out system operation and maintenance; and
- A work plan and estimate of the costs of rehabilitation or replacement required for proper water regulation.

Donors have begun to support system rehabilitation efforts, including surveys of the major water control facilities, the development of work plans and cost estimates for the rehabilitation of portions of the system, as well as repair of small-scale infrastructure. However, rehabilitating the Helmand-Arghandab system as a whole will require a major capital investment from donors, as well as a commitment to building a coordinated system of on-farm water management. Without a reliable institutional framework — public, private, or a partnership of the two — in place to manage the operation and maintenance of the system and to regulate the distribution of water, the preliminary efforts cited above will fall far short of their goals.

The baseline information established for this study is one element of an Afghanistan GIS developed by DAI for the PSA component of O/AID/Rep's Afghanistan ASSP project. This baseline data can be compared with satellite imagery obtained in the future to monitor land use and agricultural production in the Helmand-Arghandab region. A stratified field sampling system built into the GIS could provide accurate agricultural statistics on land use, cropping patterns, and production. A more-detailed GIS that incorporates the location of critical system infrastructure (for example, diversion gates, siphons, and cross regulators), roads, and human settlement patterns would provide planners and project managers with an ability to:

- Determine the most cost-effective interventions to maximize rehabilitation of the system as a whole;
- Coordinate ongoing, donor-funded rehabilitation efforts;
- Monitor the impact of these efforts;
- Monitor the operation and maintenance of the system as a whole; and
- Monitor the impact of system management on such environmental conditions as waterlogging and salinity.

Building this capacity into the Afghanistan GIS will require far more field data than ASSP/PSA project staff, because of the wartime conditions, have been able to gather to date. Field observations, or "ground truthing," are essential to the process of satellite imagery interpretation. Periodic ground truthing enables analysts to refine their interpretations of surface phenomena and to recalibrate statistical analyses of surface phenomena such as land cover, land use, agricultural production, and water distribution.

The methodology developed for this study can be applied not only to the evaluation of other irrigation systems in Afghanistan but for the planning and monitoring of all types of donor-assisted development. The Afghanistan GIS is a powerful tool for establishing development priorities and managing development activities effectively on a macro scale.