Mapping of Canal and Drain Layouts for Modelling Irrigation Distribution Systems in Egypt
Irrigation Management Systems Project  
Planning Studies and Models Component  

MAPPING OF CANAL AND DRAIN LAYOUTS  
FOR MODELLING IRRIGATION DISTRIBUTION  
SYSTEMS IN EGYPT  

Task 1 FINAL REPORT  

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LIST OF SYMBOLS

Abbreviations

ERDAS  Earth Resources Data Analysis System
ESRI  Environmental Studies Research Institute
DoD  Department of Defense
DBASE  Database software
HRV  High Resolution Visible
GCP  Ground Control Point
GIS  Geographic Information System
GPS  Global Positioning System
MPWWR  Ministry of Public Works and Water Resources
PDM  Planning Distribution Model
PFINDER  Pathfinder Software for GPS Data Analysis
SPOT  Le Systeme Pour l'Observation de la Terre (a French satellite system)
TM  Thematic Mapper Instrument on Landsat Satellite
USU  Utah State University
UTM  Universal Transverse Mercator
VGA  Video graphics array

Measurement Units

Byte  Eight bits (binary digits)
cm  centimeters
m  meters
mm  millimeters
MByte  1024 KiloBytes (megabyte)
MHz  megahertz (millions of cycles per second)
feddan  a unit of area equal to 0.4250 ha, or 1.050 acres
GLOSSARY OF TERMS

Geographic Information Systems: An organized collection of computer hardware, software, geographic data, and personnel designed to efficiently capture, store, update, manipulate, analyze, and display all forms of geographically referenced information.

Base Map: A representation of a plane surface, at an established scale, containing planimetric information used to establish baseline data.

Image Rectification: The process by which the geometry of an image is made planimetric.

Global Positioning System: A method used in surveying that uses a constellation of satellites orbiting the earth at very high altitudes. Through the geometric calculations of triangulations, the coordinates of the point on the surface of the earth are determined.

Attribute: A characteristic of a map feature described by numbers or characters.

Vector: A coordinate-based data structure commonly used to represent map features.

Raster: A cellular-based data structure composed of cells or pixels of equal size and arranged in columns and rows.

Digitization: A process to automatically determine geographic coordinates from a map using an electronic tablet linked to a computer.

Topology: The spatial relationships between connecting or adjacent coverage features.

Arc: A continuous string of x,y coordinates pairs.

Polygon: An two-dimensional feature bounded by arcs.
Executive Summary

The objective of Task 1 was to develop base maps from satellite imagery and create layout maps of the canal and drain system of a pilot area. These layout maps would be used to support the Hydraulic Models as well as the Planning Distribution Model being developed in other Tasks.

A Geographic Information System (GIS) environment was chosen to conduct the computer based mapping and serve as a database (in addition to maps of the spatial layout of the canals) of canal and drain system physical characteristics i.e. slope, cross-section etc. was necessary for the hydrologic models.

A simple definition of a GIS is an "organized collection of computer hardware, software, geographic data, and personnel designed to efficiently capture, store, update, manipulate, analyze, and display all forms of geographically referenced information." (ESRI, 1990). A GIS links spatial data with non-spatial data to form a powerful modeling tool for resource management. Most GIS software have the capability of storing non-spatial attribute data such as canal and drain physical characteristics and relate it to specific areas of the spatial layout. Both the spatial layout and attributes can be easily edited and changed to reflect changes in the physical system or the update of the database with more accurate information.

The PC ARC/INFO Geographic Information System (GIS) was selected as the commercial GIS software of choice for this project to develop the canal and drain layout maps and corresponding database. ARC/INFO is a vector based GIS environment with powerful database capabilities. The "linear" nature of the features to be represented i.e. canals and drains are well suited to be represented by a vector based GIS. In addition, the powerful database capabilities of ARC/INFO as well as simple and advanced macro capabilities make it the best choice for this task.

Task 1 comprised the generation of updated maps of the canal and drain system. These maps are be represented as spatial layers within the GIS environment. Some attribute data naturally results from the preparation of the spatial layout maps i.e. canal and drain length. The GIS database is to be expanded in Task 7 to include data required for the hydraulic models and other models being developed for this project.
Accurate base maps were required in Task 1 for the digitizing of the canal and drain layout. At the time the proposal for this project was prepared, we did not have knowledge of accurate maps at the appropriate scale which could be used for this purpose. Orthophotos being produced by the surveying and mapping project only recently became available. Thus, we proposed to develop our own base maps from high resolution satellite imagery.

SPOT satellite imagery was purchased to identify canal and drain structures in the study area. The satellite imagery that was purchased was not referenced to a geographic coordinate system. Geo-corrected imagery can be purchased from the data vendor. However, the quality of this geo-correction is a direct result of the quality of base maps available. We felt that the available base maps were too old, and therefore did not represent surface features accurately. The SPOT imagery therefore needed to be given map coordinates (latitude/longitude coordinates for example) to become a base map for canal and drain digitization. This process is called image geo-rectification and consists of identifying pixels or features on the image for which map coordinates are known on the ground. These pixels are called ground control points. In the absence of existing base maps, we decided to obtain map coordinates for our control points using Global Positioning Systems (GPS).

GPS is a satellite-based positioning system which can be used to obtain latitude/longitude coordinates on the surface of the earth. Its basis is the use of trigonometric triangulation between satellites with known positions in space and the location on the ground for which the position coordinates are desired. A portable GPS unit consisting of a small datalogger connected to an antenna and receiver calculates the ground position from the information received from the satellite.

A field campaign was conducted during the PI's second visit to Egypt to train Egyptian engineers on the use of GPS and to collect the coordinates of the ground control points for image rectification.

The report describes this unique methodology developed to obtain base maps from SPOT High Resolution Visible (HRV) satellite imagery using map coordinates obtained with Global Positioning Systems (GPS). Two aspects of the methodology
used should be emphasized: (1) the use of enhanced multispectral imagery obtained from filtering and processing SPOT HRV multispectral and panchromatic imagery to serve as a base map for interpreting and digitizing the canal and drain system of the pilot area, and (2) the geographic control and rectification of this image using GPS technology to obtain ground control point coordinates. To our knowledge, the use of satellite imagery for canal and drain mapping is original. In addition, we have not found citations in the literature so far, dealing with the use of differential GPS techniques to rectify satellite imagery. However this is a matter of time, as GPS is presently being used to control aerial photography and for surveying. Therefore we foresee this technology being used in the future in the same framework we applied it.

Section 1 describes the problem and the rationale of using the developed methodology, outlines some of the major characteristics of the selected pilot area and explains some of the basic elements of Geographic Information Systems. Section 2 summarizes GPS technology and the rationale involved in purchasing and testing the units as well as the initial testing of the methodology.

Section 3 describes the image processing methodology including the pre-processing, enhancement and preparations for the field campaign in November, 1992. Section 4 describes all elements of the field campaign which included the test of the benchmarks to be used for differential correction of the GPS coordinates, the sampling of the ground control point coordinates and the location of the hydraulic structures, turnouts and pumping locations along the main canals and laterals. Finally, the digitization of the canal and drain system and the building of the GIS overlays is described in Section 5.

With the completion of Task 1, all elements were in place for the continuation of the project with Task 7. Final maps developed with the methodology described have been included with the report. The GIS environment allows for the easy update and modification of the maps if necessary. Additional smaller canal systems can be added at a later date on the existing database or, new canal systems beyond the pilot area can be incorporated using the same methodology. The expansion of the canal and
drain layout GIS can proceed in the future using the 1:10000 orthophotos to be produced by the Surveying and Mapping project.

This flexibility for modifying and expanding the spatial and attribute database is one of the main reasons why we felt that the GIS environment was the most appropriate to conduct this mapping and data collection effort.
Introduction

1.1 Description of the Problem and Rationale for the Proposed Methodology

The main objective for this project is the development and/or adaptation for Egypt of irrigation water management software (i.e. canal hydraulic modelling, planning distribution models, water command area models.) Many of these models require as input data, information on the physical characteristics of the irrigation and drainage system to be modelled as well as the precise layout of the canals and drains.

It was our belief at the time this project was conceived, that accurate and recent maps of the canal and drainage system layout were not available. In order to obtain an accurate and up-to-date image-based map of the pilot area, the methodology of using SPOT satellite imagery rectified with control points obtained with ground-based Global Positioning Systems was proposed. This imagery could be used for obtaining the canal and drain layout information as well as the command areas for the main canals and drains and other spatial features.

It was proposed that the development of maps for the system would be better handled within a GIS environment as, along with the spatial layout information, we could include in a database physical information on the canal and drain system and structures. In addition, as the collection of system physical data (cross section of canals, carrying capacities of canals and drains, slopes, roughness coefficients, control structure calibrations etc.) was to be conducted by local consultants with us having very little control on time tables, a GIS database seemed to be the solution which now comprises Task 7. In this way, any data collected in the field during the Task 1/Task 7 period would be incorporated into the database prior to the end of the task. The Egyptian engineers would be trained to update and maintain the GIS database, incorporating any data collected in the lifetime of the project, even after the end of Task 7.

1.2 Description of the Pilot Project Area

The pilot project area was selected during the workshop in Port Said, coinciding with the first visit of the PI's to Egypt in late June, 1992. The MPWWR had selected
the command area of three tertiary canals in the Sharkiya Directorate as candidates to serve as the pilot project area. These three canals, supplied by the Bahr Moweis canal were: (1) the Bahr Mashtoul, (2) Bahr Barnabai and (3) the Mussalameia canal.

After analyzing the advantages and disadvantages of the three canal systems, the Bahr Mashtoul canal system was selected as its command area was similar to many command areas in the Nile delta system. In addition, it contained most of the elements which were desirable for testing of the USU hydraulic models as well as the development of the planning distribution model.

The Bahr Mashtoul command area is a complex web of canals and drains covering an area of 26,800 feddans. The Mashtoul canal is 29.9 km in length and starts at the weir several hundred meters downstream from the diversion at Bahr Moweis and ends at a flume that crosses the Bahr Saft El Qibli drain. Though the hydraulic modelling of the main system will be conducted down to the gates at El Hagarsa, the interpretation of the satellite image and the subsequent field work indicated that the command area of Mashtoul actually crossed the Bahr Saft El Qibli drain continuing with the Hanut canal and that both the Hanut and El Hagarsa canals are major laterals canal which cannot be ignored from the demand point of view. Thus we decided to map the command areas of both these canals in the spirit of database completeness.

The Mashtoul canal has six major lateral canals namely Gannabeia Kafir El-Hamam, Bahr Iweis canal, El Quftaniya, Bahr El Hagar, El Hagarsa and the Hanut canal. Smaller lateral canals consist of Bahr El Daker, Bahr Ads, and Shanaitah canals. The major drains are the El Ibrahimiya, El Mahmoudiya, El Sids, Muhsin and Menzil Haiyan drains.

Among the complexities of the system, is the fact that several canals cross the boundaries of the major drains, expanding the irrigated command area. In some cases, such as with the El Gedida canal, the water is shared 3 days a week, through a large syphon pipe, with the command area of the Umm El-Rish canal on the other side of the El Ibrahimeya drain and vice-versa. The Umm El-Rish canal is supplied by the Bahr Moweis canal. Areas irrigated on the other side of the El Ibrahimiya were not
considered in the command area of the El Gedida canal at this point in time, but can easily be incorporated once more is known on the operations of these canals. Other complexities include the diverse cropping pattern, the pumping of groundwater, and re-use of drainage water.

However, because of all these elements, we feel that the system is a good representation of other canal command areas in the Nile delta system and therefore adequate for a pilot area.

1.3 Overview of Satellite Imagery and Geographic Information Systems (GIS) for Mapping

Satellite imagery has been used for mapping natural resources and agriculture for many years (Jensen 1986, Cheng et al. 1992, Welsh et al. 1992). High quality satellite imagery with fine spatial resolution such as the imagery provided by the Landsat Thematic Mapper (TM) or the SPOT High Resolution Visible (HRV) sensor are well suited for mapping very large areas of many hundreds or thousands of square kilometers with accuracies on the order of 10 to 30 meters.

Thematic Mapper imagery has seven spectral bands, of which six are in the shortwave part of the electromagnetic spectrum and one in the thermal infrared portion of the spectrum. The spatial resolution of the picture elements or pixels is 30 meters. The SPOT HRV imagery has only three spectral bands and one panchromatic band. However the spatial resolution of the spectral bands is 20 meters while the panchromatic imagery has 10 meters pixels. Due to its higher spatial resolution, we felt that the SPOT imagery was necessary for the mapping and identification of the smaller canals and drains.

We used a methodology (later described in section 3) of filtering and merging the multispectral imagery with corresponding panchromatic imagery for the same area. This resulted in a base image with 10 meter pixel resolution which retained the multispectral properties allowing for the easier identification of canals and drains.

A geographic information system (GIS) is designed to work with data referenced by spatial or geographic coordinates (Star and Estes 1990). The infancy of GIS began
in the mid-eighteenth century with the production of the first accurate base maps. These maps were soon followed with the first thematic maps (maps which identify one theme). It was not until the 1950’s that the first attempts were made at automating the production of thematic maps through the use of computers (Antenucci, et al., 1991). Since the 1950’s, computerized map making has evolved into a technology which allows researchers and managers to quickly evaluate information in a spatial context for decision making. While historically geographic information systems were not computerized, the use of an automated GIS has allowed a level of flexibility in overlaying maps that was not available before.

A simple definition of a GIS is an "organized collection of computer hardware, software, geographic data, and personnel designed to efficiently capture, store, update, manipulate, analyze, and display all forms of geographically referenced information." (ESRI, 1990). A GIS links spatial data with non-spatial data to form a powerful modeling tool for resource management.

1.3.1 Structure and Types of GIS’s

A GIS is composed of two basic systems; a spatial database which stores cartographic information such as transportation networks, hydrologic networks, place names, and surface cover characteristics etc., and a non-spatial database consisting of tabular data which is linked, or related, to the cartographic features.

Current GIS’s differ according to the way in which they format and organize data. There are two basic formats that a GIS uses to capture, store, and retrieve information. These formats are raster and vector and each tend to fit certain types of data and applications better than the other. For instance, raster data is better suited to deal with remotely sensed images such as those collected from the SPOT sensor and used for this project to identify canals and drains. The vector format is better suited to represent lines, polygons and point features. The best GIS is one that can effectively merge these two data formats and exploit the capabilities of each.

The raster data format divides the landscape into a regular grid of cells called pixels. These pixels form a matrix. Cells within the matrix are coded in a specific
sequence which forms an image or thematic map. Commonly in a raster gis each cell or pixel in the matrix contains only one value and has a defined size. The images used to identify canals and drains in the study area have a ground resolution of 10 meters. That is, the defined size or dimension of each pixel is 10 meters in the X direction and 10 meters in the Y direction. Therefore, a basic feature of raster GIS's is that the pixels that make up the thematic layer fills space. The matrix represents only one theme. To represent a second theme, a new grid has to be formed. All images collected from remote sensing instruments are stored in a raster format.

The vector format uses line segments made up of X and Y coordinates called vertices. The basic building block of a vector system is the single X,Y coordinate. These coordinates are combined to form line segments, which in turn combine to form polygons. In contrast to raster GIS's, vector systems do not fill space. The polygon that surrounds the space provides the coding for that area. Vector data structures can be very complex in their organization of points, line segments and polygons.

An important feature of vector GIS's is the ability to create topology. Topology is defined as "The spatial relationships between connecting or adjacent [map] features". Topological relationships are built from the simplest features to the most complex (i.e. points or vertices are related to arcs, and arcs are related to polygons.) Each point "knows" which arc (if any) it belongs to, each arc knows which polygon (if any) it is related to.

The canal and drain database created for this project was generated by linking a vector based GIS with a raster based system. The raster base analyzed and produced the image layer from which canals were identified. A vector system was used to digitize the canal and system, and put together the tabular database of canal and drain attributes.

1.3.2 Components of a GIS

The definition of a GIS provided by the Environmental Systems Research Institute (ESRI) in the second paragraph of this overview identifies four components
that require discussion. The combination of hardware, software, geographic data, and personnel provide the structure of a GIS. A brief discussion of these is given below.

1.3.3 Hardware and software

Basic GIS hardware and software provides the ability to capture, store, update, manipulate, analyze, display and output geographic information. Since hardware and software form the basic system they will be treated as one in this discussion. The computer hardware needed for a basic GIS can consist of a fast personal computer with substantial memory and storage. We use the term substantial since there is no upper limit to the amount of storage or memory but there is a lower estimated limit of 4 megabytes of random access memory and 100 megabytes of mass storage. Since a GIS is graphic by nature, a high quality color monitor to display maps and images is needed.

Peripheral equipment to the computer can include digitizing tablets, plotters, data printers, and possibly scanners. Geographic data is input to the GIS through the use of tablet digitizers and scanners. Tablet digitizers are basic data input devices and consists of a flat (sometimes back-lit) electronic table underlain with a mesh of wires running horizontally and perpendicular to the table edge. When a map is placed on the surface of the digitizer and the lines traced with a cursor or pen, an electronic current is passed to the computer and the X and Y coordinates of the corresponding to the map features is determined. These X and Y coordinates are reconstructed by the GIS software into the map features.

While digitizers provide the data input portion of the GIS and computers provide the storage and analysis capability, plotters provide a data output function that allows maps to be regenerated onto paper or film material. Plotters come in a variety of sizes and capabilities, which are commensurate with cost. Pen plotters are the most basic form of data output for the GIS. These plotters transfer line work stored in a GIS onto paper or film by using a number of colored pens. Various color pens are used to characterize and therefore separate line features with different attributes. Other plotters include hot wax transfer, ink jet, electrostatic plotters, and film writers. These more
expensive and therefore higher quality plotters are used for production purposes and are necessary for large GIS operations that service a number of users.

Data printers are basic to any computer facility and can consist of laser printers, and/or dot matrix printers. These printers are used to output the tabular information contained in a GIS. They can also, in some cases, be used to output graphical data for inclusion in reports or for general use by field personnel.

The software portion of a GIS can come from a variety of sources and can have a variety of capabilities. The software provided by this project consists of the vector ARC/INFO GIS system. ARC/INFO is currently the industry leader in GIS technology for use in research and land management environments. ARC/INFO is a modular system consisting of data entry, manipulation, and data output modules. The term ARC/INFO needs some clarification. The product called ARC is produced by the Environmental Systems Research Institute (ESRI) located in Redlands, California. The INFO product is generated by HENCO Software located in the state of New York. A proper GIS requires that the cartographic product stored in the computer is linked with a relational database. ESRI, at an early part of its history, linked their ARC product with the INFO product by Henco Software. Thus the name ARC/INFO became an identifiable term used to describe the GIS system produced by ESRI. Since the widespread use of GIS and the rapid explosion in information systems in the computer market other new products called ARC/DBASE and ARC/ORACLE have been generated.

The system provided with this project is the ARC/INFO product. However, we envision that as the GIS database is expanded to the entire Nile delta, that the database needs might be better served by using ARC/DBASE. DBASE is a industry leader in PC based relational information systems. These links with other information systems has allowed ARC to be more flexible and provide users with a geographic system linked with the database used by their employees. Any database generated with INFO for this project would be readily transposed to DBASE in the future.

The basic modules in the ARC portion of ARC/INFO consists of ARC, ARCEdit, ARCPlot, NETWORK, OVERLAY, and DATA CONVERSION. A full explanation of
ARC/INFO utilities and commands is given in the user manuals. We will present a brief explanation of each utility and refer the reader to the manuals for a more in-depth discussion.

The ARC portion functions as the general program from which all other modules are initiated. ARC provides basic data management and analysis functions. Within ARC users can build topology, overlay, copy, and delete geographic coverages. The PC ARC/INFO STARTER KIT manual contains in-depth information on ARC capabilities. A function list and explanations of ARC routines is provided in.

ARCEDIT functions as the database editor and provides complete feature editing capabilities. Users can add, delete, and update cartographic features (points, arcs, polygons) and edit attribute information linked to cartographic features. ARCEDIT accepts commands from the computer keyboard, digitizing tablet, and mouse. Command summaries for ARCEDIT are found in.

ARCPLOT is a cartographic toolkit which provides the user with map generation and editing capabilities. Database coverages can be scaled and combined. Legends can be created as well as titles and scale bars. Maps designed in ARCPLOT can be sent to a plotter to make scaled output or products can be displayed on the computer screen.

NETWORK provides the capability to evaluate and manage transportation networks. This utility works directly with arc features to determine flow of material along pathways. While this module is intended for transportation analysis, it can be used to evaluate flow of water through canal structures. This module has not been incorporated into the database since the Hydraulic Model and the Planning Distribution Model developed for this project will provide a better alternative.

The OVERLAY module allows the user to perform advanced data analysis and manipulation by overlaying, buffering, and dissolving coverage features. The OVERLAY functions maintain the topological relationships within and between coverages allowing users to trace the origin of every point, arc, and polygon.
The DATA CONVERSION module of PC ARC/INFO allows import and export of ARC coverages to other GIS system formats. This module allows the user to integrate data generated by other individuals.

1.3.4 Geographic Data

The term geographic data in this context refers to cartographic information that has been digitized into a GIS system as well as tabular attributes that describe the cartographic features. Geographic data are referenced to a position on the earth by means of a standard coordinate system. In the case of this project all data are referenced to the ground using a Universal Transverse Mercator (UTM) coordinate system. Other than geographic coordinates, geographic data are generated and maintained with a defined accuracy level. Accuracy is determined by the source of the data. The limiting factor in this database is the size of the SPOT pixel (10 meters) and the accuracy of the GPS location on the surface. GPS accuracy on the ground was determined to be approximately 1.5 meters. The accuracy of the SPOT database is set at 10 meters. Even though the accuracy of the GPS was significantly higher than the precision of the SPOT data, we are limited to the accuracy of the SPOT pixel. Therefore characteristics of a geographic data base consists of not only what type of features it contains but also the coordinate system used and the accuracy of spatial position.

1.3.5 Personnel

As with any information system or program of work, a limiting factor is the knowledge of the personnel regarding the technology that is used and the discipline to which it is applied. A properly executed GIS system is staffed by individuals that are competent with the GIS technology and with the discipline. The system itself is limited by the personnel. This is the primary reason a professional engineer familiar with the discipline (irrigation in Egypt) spent nearly 9 months at Utah State University learning how to use the GIS technology.
Use of Global Positioning Systems (GPS)

2.1 Description of GPS

Global Positioning System is a Department of Defense (DoD) operated, satellite-based positioning system which can be used to obtain latitude/longitude coordinates on the surface of the earth. It consists of a constellation of 24 satellites, each broadcasting its orbital position and ground based units consisting of an antenna, receiver and datalogger which processes the broadcasted information and calculates the position of the antenna. The satellites are on 55 degree equatorial plane orbits (10,900 nautical miles high) with an orbital period of 12 hours. The position, speed and altitude of each satellite is frequently tracked to account for any small drifts that might occur. This satellite ephemeris information is constantly broadcasted by the satellite along with accurate time.

The basic principle behind GPS positioning is the use of the satellite positions as reference points for triangulation of a position on the surface of the earth. Thus, with the knowledge of accurate distances between a location on earth and four satellites, a position can be calculated. The satellite must be "visible" to the antenna of the GPS unit on the ground and the datalogger software allows the operator to select elevation angle masks and signal strength thresholds to minimize errors in the estimated positions. Theoretically, the distance to three satellites would be sufficient to obtain a 3-D position through triangulation. This would yield two possible solutions, but only one solution would be compatible with the position of the earth's spherical surface. Distances between the satellite and the receiver antenna are calculated based on the amount of time it takes for the signal to arrive. The satellites have very accurate atomic clocks on board but the GPS receivers do not. To compensate for time errors, the distance to a fourth satellite is used in the calculations. An iterative procedure is used to find the proper solution.

The accuracy of the GPS calculated position is influenced by several factors. These include ionospheric and atmospheric propagation delays, geometric dilution of precision and selective availability. Selective availability is an operational mode used by the DoD in which they introduce errors in the satellite ephemeris in order to degrade
the accuracy of the GPS position calculations. When selective availability is active, it is by far the largest source of error in the calculations of position. Depending on the quality of the receiver, the sum of errors due to ionospheric/atmospheric effects, receiver and ephemeris errors, ranges from 20 to 60 meters. If selective availability is active, the errors in position could be up to 120 meters in the worst case.

To improve the accuracy of GPS positions, a technique called differential GPS can be used. A GPS receiver is placed on a known location such as a previously surveyed benchmark in the vicinity of the working area (within 450 km). A second GPS unit is used to sample the position of the desired locations in the working area. The rationale is that both receivers will be subject to the same error causing influences mentioned above. Special software on the PC computer is then used in post processing to remove the biases from the sampled positions, improving the accuracy significantly (1 to 3 meters in commercial grade GPS units and centimeter accuracy in surveying grade units).

2.2 Acquisition of the GPS Units for the Project - Task 1

The purpose of using GPS in Task 1 was twofold: 1) to obtain ground control points coordinates for rectifying the SPOT satellite imagery and 2) to locate hydraulic control structures and third order canal off-takes not visible in the satellite imagery. Therefore the units would have to be portable and have a significant memory capability in order to be used both as a base station and field sampling unit. The three main grades of portable field GPS units can be characterized as: 1) low cost units with limited memory and sampling frequency and poor post processing software; 2) mid-range units with large datalogger memory, good quality receivers and good post processing software for differential corrections and; 3) high grade units for surveying purpose with the best receivers for centimeter accuracy, large memory availability and good post processing software. The latter were found to be unjustifiably expensive with accuracies far beyond what was necessary for this project. Option 2) was selected as the best suited for the job in hand as accuracies of 1 to 3 meters could be expected after differential corrections. This was more than sufficient
considering the targeted map scale, the 10 meter pixel resolution of the satellite imagery and the requirements of the hydraulic models.

The purchased units were the Trimble Pathfinder Professional Global Positioning System with an Omnidata 600 series datalogger. The unit is capable of flexible sampling frequencies with a maximum sampling and storing frequency of one position every second. It has 440 Kilobytes of memory which allows over 4.5 hours of continuous sampling at every one second. Thus, if a sampling frequency of more than one second were to be used for the base station unit, the memory would be sufficient to log data during a full work day. The field (roaming) unit would be set to log a position every second for a period of 3 to 10 minutes at every location.

Previous experience with these units had been favorable and we knew that the post processing software was excellent and would get the job done. The post processing software supplied with the units is called PFINDER and runs on PC compatible computers. It is menu driven and contains graphics for viewing the data.

2.3 Testing of the GPS Units

The testing of the GPS units was conducted in four phases: 1) The initial testing period after the units arrived to verify if everything was complete and functioning properly; 2) the training of the Egyptian engineers, Eng. Mohammed Alam Eldin from the Sharkiya directorate and Eng. Fayek Amin Farag, from the MPWW; 3) testing of the accuracy of the differential corrections and; 4) testing of the methodology of using the GPS-based ground control point coordinates for image rectification, described in section 2.4 of the report.

The training of the two Egyptian engineers began in the first week of October, immediately after their arrival in Logan, Utah. They were given reading material on GPS concepts and technology and were taught how to operate the units and look for information in the manuals. They proceeded to learn on how to collect data, download the data from the datalogger memory to the PC computer and, operate PFINDER on the PC to process the data and obtain position information.
The test of accuracy of the GPS units was conducted using the following procedures:

1. Two benchmark locations with known coordinates were obtained from the campus planning office. There had been recently surveyed and are used as references for locating all structures on campus. One of these benchmarks was located on the corner of highway 89 and the south entrance to campus, while the second benchmark was located along the pathway between the Spectrum and the cemetery.

2. Test for accuracy of differential corrections: One of the GPS units was placed on the cemetery benchmark and the second unit was placed on the south entrance benchmark. The cemetery GPS unit was set up to sample as a base station at every one second while the second unit was set up to be the roaming GPS, also sampling at every one second. After differential correction, the coordinates obtained for the south entrance benchmark were within five meters of the true coordinates. Longer sampling periods were expected to result in more accurate results.

3. Test for optimal sampling interval of the base station:
   In this test, the base station GPS was set up on the cemetery benchmark sampling at different intervals namely 1, 5, 10 and 15 seconds. The second unit was placed on the south entrance benchmark and set to sample at every one second. This was done in order to study the effect of sampling intervals on the accuracy of estimated positions and obtain an optimal sampling interval for the field work in Egypt. The results of this test are shown in Table 1. and indicate that 10 seconds was the best interval for accuracy among the intervals tested. Therefore 10 seconds was adopted as the sampling interval for the base station GPS during our field work in Sharkiya.
Table 1. Results of the sampling frequency test at USU

<table>
<thead>
<tr>
<th>Sampling Frequency (seconds)</th>
<th>Standard Deviation (meters)</th>
<th>RMS (meters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Lat: 4.228</td>
<td>5.598</td>
</tr>
<tr>
<td></td>
<td>Long: 3.669</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Lat: 8.798</td>
<td>9.415</td>
</tr>
<tr>
<td></td>
<td>Long: 3.351</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Lat: 4.357</td>
<td>5.008</td>
</tr>
<tr>
<td></td>
<td>Long: 2.469</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Lat: 4.695</td>
<td>5.605</td>
</tr>
<tr>
<td></td>
<td>Long: 3.061</td>
<td></td>
</tr>
</tbody>
</table>
2.4 **Test of the Methodology of Using GPS for Satellite Image rectification**

The training of the Egyptian engineers proceeded on a PC workstation with the ERDAS image processing and GIS software. This is the software which was used to process and prepare the satellite images of the pilot area.

An experiment was conducted at USU prior to the planned field campaign, to test all phases of the proposed methodology of using GPS for satellite image rectification. An available LANDSAT Thematic Mapper image of Cache Valley, Utah was used for this purpose. Twelve control points were identified on the three band image (near-infrared, red and green bands) mostly on road crossings and bridges, with easy access. The image was printed on an electrostatic plotter for use by the field crew along with 7.5 minute topographic quadrangle maps of the same area.

On the day of the field data collection, the base station GPS unit was placed on the cemetery benchmark on campus and set to sample every second. The field crew consisted of the two Egyptian engineers and a student technician from USU. They devised a plan to visit each selected control point in such a way to optimize the time spent on the task and minimize driving. At each control point, the best location for placing the GPS antenna was decided based on the image information and what the particular pixel looked like on the ground. The GPS unit was set to sample every second for a period of five minutes, the data being stored in a data file named after the control point. Data for 12 control points were collected in 5 hours.

The data from both GPS units was downloaded to the PC computer and PFINDER was used to run the differential corrections on each data file. The PFINDER software was set to provide the coordinates in the Universal Transverse Mercator (UTM) system automatically. The GCP function in ERDAS was then used to build the coordinate transformation file which relates the pixel row/column file coordinates with the UTM map coordinates. Due to memory overflow problems with the base station GPS units on that day, three of the sampled points were dropped as no base station data was available for differential correction.

The COORDN function was then used to estimate the root mean square (RMS) error for the selected transformation using the control points. A first order linear
transformation was used. After dropping 2 control points which were resulting in a high RMS value, the resulting RMS was 0.2095 pixels, or 6.3 meters. Finally, the image was rectified using a nearest neighbor scheme with the LRECTIFY command and the coordinate transformation file resulting from the COORDN procedure.

The rectified image was tested by comparing pixel coordinates obtained on the image using the CURSES command and the respective coordinates obtained from the 7.5 minute quadrangle maps of the area. The results were accurate and indicated that the methodology would work for the pilot project area in Egypt, with expected higher accuracy as we would be using SPOT satellite imagery at ten meter resolution.
3.1 Summary of Methodology For Map Generation

The generation of base maps for canal and drain structures in the pilot area was accomplished by using SPOT (Le Système Pour l'Observation de la Terre) satellite imagery as the primary base. SPOT was chosen for its high ground resolution (10 meters black and white, and 20 meters color). The SPOT - High Resolution Visible (HRV) sensors are capable of imaging the earth's surface in multispectral (color) and in panchromatic (Black and White) modes. In color mode, the sensor can image a 60x60 km area at 20 meter ground resolution. The sensor is designed to detect reflected light in three distinct areas, or bands, of the spectrum simultaneously. These areas are the reflected green region (0.50 - 0.59 \( \mu m \)), the reflected red region (0.61 - 0.68 \( \mu m \)), and the reflected near infrared (0.79 - 0.86 \( \mu m \)).

These band combinations allow investigators to produce an image that closely approximates a color infrared photograph. Since the color mode of the HRV requires that it segments the spectrum into three distinct zones, the ground resolution of the sensor is degraded. In other words, in order to detect enough light reflected from the surface in each of the above regions of the spectrum to register a signal at the satellite, the HRV must sense a larger area.

This mode allows the SPOT sensor to detect areas of vegetation, and to some degree map variations in vegetation cover. It also provides a means to separate water from vegetation. Actively growing vegetation reflects a great deal of light in the near infrared, and absorbs a great deal of light in the red portion of the spectrum. This reflection/absorption difference contrasts with the absorption of visible and near-infrared light by water. The difference in reflective properties of vegetation and water creates a great deal of contrast. The vegetation normally appears red and water appears black in the image. For the purposes of this study, the color mode of the SPOT sensor is ideal for separating vegetation from water but is not adequate for identifying small canals and drains.

The SPOT - HRV in panchromatic mode is designed to detect light throughout the visible portion of the spectrum (0.51 - 0.73 \( \mu m \)). This rather broad area within the
spectrum, relative to the color mode, allows the SPOT - HRV to have a finer spatial resolution of 10 meters on the surface of the earth. The area of coverage is 60x60 km but each cell in the image is one-fourth (1/4) the size of the 20 meter color mode. Since the panchromatic mode is essentially a black and white representation of the earth, there is limited ability to separate surface features that are similar in reflectance. As vegetation absorbs visible light to perform photosynthesis it appears dark in the panchromatic image. Water also absorbs light in the visible region of the spectrum so it also appears black or dark. This similarity in reflectivity reduces, or eliminates, our ability to separate these features. However, the increased spatial resolution of the panchromatic mode allows us to detect relatively small features such as secondary and tertiary canals and drains.

Our objective was to generate a SPOT image base map that had the color capabilities of the multispectral mode, and the spatial characteristics of the panchromatic using a technique that merges the two data types into one product with both characteristics. In this way, we could visually separate canals, and drains from actively growing vegetation, and be able to detect smaller canals not visible in the original color imagery. We therefore purchased both multispectral and black and white (B/W) images for the study area. The technique of combining these images is explained below.

Using this 10 meter color imagery, canals, drains, and the command area were digitized using a vector based GIS system called ARCM/INFOR. Canal digitizing followed field data collection aimed at referencing the SPOT imagery to the surface of the earth. When purchased, the SPOT imagery can be processed at SPOT Image Corp. to one of three levels. The first level consists of basic sensor calibrations and simple geometric correction. The second level includes geometric control using base maps of the area requested. The third level consists of advanced geometric correction to adjust for relief displacement. For the purposes of this study we purchased level one data.

Level two data would not be possible since base maps for the pilot area were not available. Level three data was therefore not possible since it also requires base
maps. Further, if base maps were available, the spatial accuracy of this process would not exceed 15 meters. We felt that a higher degree of accuracy (< 10 m) was necessary to accurately map canal features. Thus we used the process of collecting control points using GPS described in sections 2 and 4.

Once the SPOT image had been geo-referenced to ground coordinates, canal and drain structures were interpreted and digitized into a vector based GIS system using "heads-up" digitizing. The term heads-up refers to the method of digitizing data from a base map. Heads-up infers that the map is on the computer screen and not on a digitizing tablet. Once digitized, the canal and drain networks were attributed with the published name of the canal or drain.

All image processing of SPOT imagery was performed using the ERDAS™ image processing and GIS system. ERDAS™ has the ability to read, enhance, mathematically model, and classify surface features form remotely sensed data. The process of enhancing and merging the 20 meter and 10 meter SPOT data is described below. The GIS database generation was accomplished using the ARC™/INFO™ vector based GIS software. Canals and drains were identified on the processed SPOT imagery and digitized into a database. The database consists of three files including all canals within the command area, all drains within the command area, and the command area boundary. To this point in the project all canals have been attributed with its published name. Other attributes as described in the irrigation delivery model will be entered as the data becomes available.

3.2 Processing of Satellite Imagery

3.2.1 Acquisition of the Imagery

The Zagazig pilot area is covered by two overlapping SPOT satellite images. Image frame coordinates were determined to be K112,J288 and K112,J289. The 'K' coordinate refers to the orbital path number of the SPOT sensor and the 'J' coordinate refers to the frame along that orbital path. One panchromatic (black and white) and one multispectral (color) image were purchased for each K and J. The acquisition date
for the black and white images was 5 July, 1989, while for the color images it was 16 July, 1991.

The image acquisition dates were chosen based on cloud cover conditions, time within the growing season, and the sensor view angle with respect to the surface of the earth. The multispectral image acquisition dates were also selected to be as close as possible to the color infrared photography which occurred in August of that year. Cloud cover was 0% for all images, and sensor angle was 2.6 degrees for the color and 1.6 degrees for the black and white. The low sensor angle was a specified requirement as it reduces the geometric distortion of the image allowing accurate mapping of surface features. All images were ordered during July of 1992, immediately after the pilot area was selected. The images arrived at Utah State in mid-August.

The choice of image dates clearly separated surface features of interest in this study. Water bodies (canals and drains) contrasted with the surrounding actively growing agricultural fields in the color (multispectral) images. The black and white (panchromatic) images provided increased resolution relative to the color. The 20 meter ground resolution of color SPOT imagery was of marginal use for identifying lower order canals. The 10 meter ground resolution black and white images is of little use in separating canals from actively growing fields. By merging the 20 meter color with the 10 meter black and white, a 10 meter color image was produced that allowed separation of agriculture and canals with increased ground resolution.

3.2.2 Image Preparation and Pre-processing

Upon receipt of images from SPOT corporation, each image was read from the computer tape onto a Sun 690 file server computer. All images were previewed by the ERDAS™ image processing system to assure image quality. All images were considered to be of high quality with surface features clearly visible and void of significant sensor error. Agricultural areas were contrasting with urban features, canals, and drains as expected.

Since each image covered a 60 x 60 Km area, and the study area was a subset of each image, they were examined to assure complete coverage of the pilot area.
Using topographic quadrangle 1:25000 maps and other canal layout information provided by the Egyptian engineers, the pilot area was identified and each image was cut, using the SUBSET command, to include only the pilot area and surrounding areas of interest. All processing steps from this point were carried out on the subset images only.

3.2.3 Development of the Base Images

The objective of Task #1 was to generate color maps of surface features at maximum available resolution in order to serve as a map base for canal and drain layout mapping. To accomplish this the color and black and white images were merged to provide a base map of the pilot area capable of identifying canals and drains. The process of merging the images consists of overlaying each color (multispectral) image with its black and white (panchromatic) counterpart and mathematically producing an output file with characteristics of both images.

The steps used to overlay the color and B/W images to produce an output base map were as follows:

1. The two B/W frames were joined in the north south direction to form one image covering the pilot area (Figure 1). The same process was carried out for the color images. Control points were collected along the overlap zone of the adjacent B/W and color images. These points served as "tie" points to stitch the north and south portions of the study area together.

2. Color balance and contrast were enhanced using the ERDAS\textsuperscript{im} image processing system. This improved the image quality and made identification and visual separation of canals and agriculture easier. A simple linear stretch algorithm was employed to increase contrast and improve color. In this process, the brightness range of the spectral data is evaluated and the frequency distribution is stretched to the full color range of the display device (computer screen). The user specifies the
amount of frequency stretching to improve contrast. In our case we
determined that stretching the data from a low of 2 standard deviations
below the mean reflectance value and a high of 2 standard deviations
above the mean reflectance value of each image provided excellent
results. The following formula was used to stretch all images:

\[
( \text{Image}_i - (x_i - (s_i \cdot 2))) / ((x_i + (s_i \cdot 2)) - (x_i - (s_i \cdot 2))) \cdot 255
\]

Where:
\[ \text{Image}_i \] = each pixel of the \( i^{th} \) image (B/W or color).
\[ x_i \] = the mean of reflectance values for the \( i^{th} \) image
\[ s_i \] = the standard deviation of reflectance values for the \( i^{th} \)
    image

Each pixel of the \( i^{th} \) image represented by \( \text{Image}_i \) was subtracted by the
lowest possible brightness value (calculated by subtracting the mean
value \( (x_i) \) by the product of two standard deviations.) This difference was
then divided by the range of possible brightness values (calculated using
the formula making up the denominator). The result was the proportional
positioning of each brightness value within the specified brightness range.
This value (between 0 and 1) was multiplied by the maximum range of
values possible on a display screen (255). This formula effectively
stretched the frequency distribution of the image to fit the possible
frequency distribution (min,max) of the display screen.

3. The B/W (panchromatic) and color (multispectral) images were further
enhanced by using an edge filter to bring out all abrupt brightness
changes within the pilot area. Abrupt changes in ground cover or surface
reflectance resulted in abrupt changes of brightness in the images. These
were due to different cropping patterns, the presence of roads, canals and
Figure 1. Schematic diagram showing the joining of two SPOT images in the north to south direction.
drains which were adjacent to agricultural fields. The result of this edge enhancement was to bring out the high frequency components of the image and therefore make the image appear sharper, improving the visual clarity of the image. This edge enhancement was a necessary step in the image merging process. The high frequency enhancement filter used is shown below.

\[\begin{array}{cccc}
-1 & -1 & -1 & -1 \\
-1 & -2 & -2 & -1 \\
-1 & 60 & -2 & -1 \\
-1 & -2 & -2 & -1 \\
-1 & -1 & -1 & -1 \\
\end{array}\]

This 5 x 5 Sum filter, was systematically applied to all pixels in the image. The cell weights were multiplied by the pixel brightness values that they overlaid and then summed for all cells. The resulting sum of the products replaced the cell in the center of the kernel (weighted by 60).

4. An averaging filter was then used on the B/W image to reduce (smooth) the high frequency component of the image. This filter was applied in a similar way as the one described above. However, the cell weights and size of the kernel was changed to produce an image that was smoother (blurry) relative to the original B/W data. This process reduced the resolution of the B/W image to approximately the resolution of the color imagery. A "round" 7 x 7 averaging filter was used to smooth the B/W image:

\[
\begin{array}{cccccc}
0 & 0 & 1 & 1 & 1 & 0 \\
0 & 1 & 1 & 1 & 1 & 0 \\
1 & 1 & 1 & 1 & 1 & 1 \\
1 & 1 & 1 & 1 & 1 & 1 \\
0 & 1 & 1 & 1 & 1 & 0 \\
0 & 0 & 1 & 1 & 1 & 0 \\
\end{array}
\]

As explained above, each cell weight was multiplied by the underlying brightness value and summed. The sum of the products replaced the value in the center of the filter kernel.
5. The high frequency enhanced color (multispectral) image was geometrically referenced to the enhanced B/W image. Since the B/W and color images were collected at different times, the sensor ground angles were slightly different. Control points were selected between the two images along the four edges and within the center of the images so as to reference the color coordinate system to the B/W image coordinate system. The color image was rectified to the B/W using a 2nd - order polynomial (non-linear) algorithm. A non-linear rectification was needed to properly register the two images due to the different incidence (view) angle of the sensors. Accuracy of the pixel-to-pixel overlay was estimated to be within 2.5 meters. During the rectification process, the color image was re-sampled to a 10 x 10 meter pixel size to match the coordinate system of the 10 meter B/W image. This re-sampling of the 20 meter color to 10 meters did not increase the resolution of the color image but simply segmented each of the 20 meter pixels into four 10 meter pixels. The apparent resolution of the color imagery was still 20 meters.

6. In order to increase the resolution of the color image to an apparent 10 meters, the last processing step was carried out. This step involved an algebraic formula designed to add the high frequency component of the B/W image to the color and subtract the low frequency component of the B/W from the color. Since the multispectral (color) images were composed of three bands of information, the algorithm was applied to each layer separately:

\[
10\text{metercolor}_i = 20\text{metercolor}_i + \text{Highfreq}_{(bw)} - \text{Lowfreq}_{(bw)}
\]

Where:

- \(10\text{metercolor}_i\) = 10 meter output for band 'i' of the color image.
- \(20\text{metercolor}_i\) = 20 meter input for band 'i' of the color image.
The result of this algorithm was to increase the apparent resolution of the 20 meter color SPOT image to 10 meters. This increased our ability to define smaller canals not visible in the color, and to separate actively growing crops from the irrigation canals and drains.

The final base image consisted of a 10 meter resolution color image covering the pilot area north of Zagazig. This image was segmented into three equal parts representing the north, central and southern portion of the study area. All three maps were output onto a color electrostatic plotter and laminated with plastic for use in the field. The digital version of these maps were then used by the Egyptian engineers stationed at USU to select control points to be visited in the field by USU personnel.

### 3.2.4 Selection of Ground Control Points.

The purpose of selecting ground control points was to properly reference the ten meter color imagery to a geographic coordinate system. Control points were preselected at USU, and each point was visited on the ground during the field trip in November of 1992. Global Positioning Systems (GPS) were used in the field to record geographic coordinates of the ground control points.

Ground control points were selected by the Egyptian engineers at USU by studying the final base image, comparing it to existing maps, and relying on their personal knowledge of the area. Accessibility by vehicle, visibility on the image and a well distributed spacing within the image were criteria used for the selection of the GCP’s, in order to result in an effective use of the time allocated for the field campaign in the pilot area. This resulted in points being generally located at intersections of roads, bridges, canals and drains. A total of 43 ground control points were identified. A detailed description of the field campaign and ground control point data collection using GPS is presented in section 4.0.
3.2.5 Rectification of the Imagery and Preparation of the Base Image Maps

Following the field campaign and the collection of geographic coordinates using differential GPS, all GCP points were entered into the ERDAS™ image processing system to properly rectify the 10 meter color image. The corresponding image file coordinates were entered into the system to produce a linear transformation algorithm. All 43 control points are shown in Table 2 along with the coordinates of the wall base station (#44).

These control points were used to generate a linear transformation matrix that is used to calculate a geographic coordinate for any given image coordinate. The error tolerance (RMS) of the transformation matrix was set to 7.5 meters, specifying that on average no pixel was more than 7.5 meters from its actual location on the surface of the earth. The transformation matrix was iteratively calculated for all points. If the average error was greater than the specified 7.5 meters, the point with the highest error was removed from the analysis and the transformation matrix is recalculated. This was repeated until the specified acceptable RMS error was reached or exceeded. Of the 44 points collected, only 8 points were removed from the analysis. All but one point was within an average of 10 meters from the estimated location.

3.4.6 Test of Accuracy

In order to test the accuracy of the image rectification, digitized canal lengths were compared with the published canal length (obtained from the Sharkiya directorate). If the rectification procedure had been inaccurate, all GIS products derived from the imagery would have grossly incorrect distance and area measurements.

We conducted some preliminary comparisons between the lengths of canals obtained from the GIS database with the lengths of some of the canals provided by the Sharkiya directorate. In some cases, such as for the El Quftaniya, Bahr El-Dakar and Bahr Iweis canals, the lengths were within 50 to 300 meters of the provided value. The Bahr Mashtoul canal which forms the main artery for the command area has a provided length of 27.35 km. Our estimate of the length of Bahr Mashtoul from the digital imagery came to 27.9 km. This is a .55 km error over a 27.35 km distance. If we
assume that the provided length is accurate, the error per kilometer of canal is approximately 20.11 meters on the average, or two pixels. This represents adequate accuracy for this method as it is probable that some of the error originated in the digitization process itself. In other cases however, such as for Bahr Ads, the provided values did not match the values obtained from the database. We presume that one of the problems could be the interpretation of where a canal ends. Locally, a canal could change name at a certain intersection or branch, while our interpretation of the image does not consider these local particularities. This is specially the case when canals cross major drains and water is shared from two different main canals.

The error in digitization can be minimized by carefully reviewing the arcs displayed over the satellite imagery and correcting for any visible discrepancies caused by the ARC/INFO cleaning and building process. Careful consideration of the canal beginning and ending points should also improve the estimates. However, if we are going to use the Sharkaia data provided to us as "ground truth" for comparison purposes, it is imperative to determine how it was gathered and at what point in time, as it became evident by comparing existing 1:25000 scale topographical maps with the satellite imagery, that the canal and drain system within the Bahr Mashtoul command area have undergone extensive changes in layout over the last 40 years. These topographical quadrangle maps were obtained from the Surveying and Mapping authority and were produced between 1934 and 1953. The quadrangle sheets used were namely the Zagazig, Hihya, Kafr Saqr, El Huquq and Tel Rak quadrangles.

The solution to many of these issues will be obtained as the data from the field becomes available and more information is gathered about the system operation at the Sharkiya directorate.
Table 2. Listing of ground control points used to geometrically reference SPOT color imagery.

<table>
<thead>
<tr>
<th>Geographic Easting (UTM)</th>
<th>Geographic Northing (UTM)</th>
<th>Image Coordinates</th>
<th>Image Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>361829.5620</td>
<td>3381962.0000</td>
<td>4015.8750</td>
<td>7160.8750</td>
</tr>
<tr>
<td>363099.4060</td>
<td>3383688.2500</td>
<td>4106.1250</td>
<td>6967.8750</td>
</tr>
<tr>
<td>361667.2810</td>
<td>3387628.0000</td>
<td>3889.3750</td>
<td>6609.8750</td>
</tr>
<tr>
<td>359828.8750</td>
<td>3381928.5000</td>
<td>3819.8750</td>
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<tr>
<td>356838.0000</td>
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<td>357918.7810</td>
<td>3381400.0000</td>
<td>3642.6250</td>
<td>7292.3750</td>
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<td>356723.1870</td>
<td>3385384.0000</td>
<td>3447.6250</td>
<td>6924.6250</td>
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<td>357257.2810</td>
<td>3387161.7500</td>
<td>3465.6250</td>
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<tr>
<td>357684.0060</td>
<td>3390260.2500</td>
<td>3446.6250</td>
<td>6426.3750</td>
</tr>
<tr>
<td>358052.3120</td>
<td>3388251.0000</td>
<td>3523.1250</td>
<td>6617.8750</td>
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<td>358656.0310</td>
<td>3392268.7500</td>
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<td>357188.6250</td>
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<td>364716.2190</td>
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<td>4760.1250</td>
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</tbody>
</table>
Ground Truthing Field Campaign

4.1 Planning of the Field Campaign

The main task to be accomplished during the field campaign was to obtain coordinates for the selected ground control points on the satellite image covering the pilot project area. As a secondary task, some locations along canals and drains that indicated discrepancies between the imagery and the 1:25000 quadrangle maps were selected to be visited during the field work in order to verify the actual situation. Finally, the field campaign would serve as an additional training exercise for Eng. Mohammed Alam Eldin and on-site training for other engineers from the Sharkiya directorate and the MPWWR. The process of systematic location of all the hydraulic structures, pumping locations, turnouts along the main canals etc. using the GPS system would be initiated and later completed by the trained engineers.

Thus the field campaign activities were planned to accomplish the above listed tasks in a short period of time. Full work days, beyond the usual 2:00 pm Egyptian quitting time were necessary for optimal use of time and resources. The field crew was divided into two groups, each with a vehicle. At the beginning of each work day, a short meeting was conducted to discuss and plan the activities for the day (Figure 1).

The first activity was to set up the base station GPS unit on a benchmark. Once the unit was sampling, the collection of data with the second unit could begin. The crew in the leading vehicle had the task of finding the desired control point marked on the quadrangle maps of the area. At each site, the crew in the chaser vehicle would set up the GPS unit and collect the necessary data. At the end of the day, the base station GPS unit would be retrieved and the data from both units downloaded to the PC computer and analyzed.

4.2 Test of the Benchmark Locations with GPS

Latitude, longitude and altitude coordinates for three benchmarks in the Zagazig area were obtained from the Egyptian Surveying and Mapping Authority and provided by Mr. Leo Busch. During the first day of the field campaign, two of these benchmarks were visited namely the benchmark on the roof of the post office building in Zagazig
and the benchmark by the wall in the northwest part of the pilot project area. A third benchmark atop a water tower in a neighboring town was not considered as it was out of the way and would require extra driving. The base station GPS unit was placed on post office benchmark (Figure 2) sampling at every one second while the roaming GPS unit was placed on the wall benchmark and also set to sample as base station every one second for about forty minutes. These data were analyzed during the evening of the first day to determine how accurate were the coordinates provided for each benchmark and to decide which benchmark would be used for the GPS base station for the remainder of the field work.

The analysis consisted of trying to obtain differentially corrected coordinates for each benchmark while using the other as a base station. Both units had been set on manual 2D mode as the altitude of both benchmarks was known. The results of this test are shown in Table 3. They indicate that for long term averages (30 minutes or greater) we could estimate the latitude/longitude position of the benchmarks to within 0.5 meters of latitude and longitude with an RMS of 2.57 meters. The uncorrected long term position averages also indicate a longitudinal bias, which is probably due to the fact that they could have been surveyed using a different reference surface than the one we adopted for our field calculations (WGS84). The analysis also indicated that either benchmark could be adopted for our field work, thus the wall benchmark was selected at first as the post office location was not accessible after 2:00 pm.
Figure 2. Coordination meeting for planning of the day field activities

Figure 3. Setting up the base station GPS unit on the roof of the post office building
Table 3. Results of the test of benchmark locations in the Sharkiya region, Egypt

<table>
<thead>
<tr>
<th>Benchmark</th>
<th>Post office building</th>
<th>Corner of Wall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surveyed Coordinates</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lat:</td>
<td>30° 35' 17.085&quot; N</td>
<td>30° 45' 0.32711&quot; N</td>
</tr>
<tr>
<td>Long:</td>
<td>31° 30' 10.540&quot; E</td>
<td>31° 29' 59.8107&quot; E</td>
</tr>
<tr>
<td>Altitude: 63.98 m</td>
<td>5.5609 m</td>
<td></td>
</tr>
<tr>
<td>Uncorrected Mean</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lat:</td>
<td>30° 35' 17.708&quot; N</td>
<td>30° 45' 1.058&quot; N</td>
</tr>
<tr>
<td>Long:</td>
<td>31° 30' 16.367&quot; E</td>
<td>31° 30' 5.158&quot; E</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lat:</td>
<td>28.86 m</td>
<td>17.646 m</td>
</tr>
<tr>
<td>Long:</td>
<td>24.132 m</td>
<td>23.667 m</td>
</tr>
<tr>
<td>Differential GPS mean</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lat:</td>
<td>30° 35' 17.101&quot; N</td>
<td>30° 45' 0.341&quot; N</td>
</tr>
<tr>
<td>Long:</td>
<td>31° 30' 10.514&quot; E</td>
<td>31° 29' 59.751&quot; E</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lat:</td>
<td>1.7540 m</td>
<td>1.8242 m</td>
</tr>
<tr>
<td>Long:</td>
<td>1.8481 m</td>
<td>1.8289 m</td>
</tr>
<tr>
<td>GPS Coord. minus true Coordinates</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lat:</td>
<td>0.01612&quot; or 0.50 m</td>
<td>0.01354&quot; or 0.41 m</td>
</tr>
<tr>
<td>Long:</td>
<td>-0.02565 or 0.51 m</td>
<td>-0.06009&quot; or 1.20 m</td>
</tr>
</tbody>
</table>

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4.3 Obtaining GPS Based Coordinates for the Ground Control Points (GCP)

This task consisted in finding the selected GCP points on the ground and sampling their location with the roaming GPS unit. Forty three GCP had been selected from the satellite imagery and had been marked both on the field image maps as well as on the 1:25000 topographic quadrangles that covered the Bahr Mashtoul pilot project area, namely the Zagazig, Hihya, Kafr Sakr and Abu El-Shuquq quadrangles.

On the first day, the wall benchmark was used and a technician from the Sharkiya Directorate guarded the base station GPS unit during the day. The setup parameters for this unit are shown in Table 4.

The first GCP’s to be sampled were in the vicinity of the wall benchmark. The roaming GPS unit was set up with the same parameters shown in Table 4, except the sampling interval was every one second and the altitude was set at each location by interpolating of the topographic quadrangle maps. Manual 2D mode was used for both units as it is the most accurate mode if the true altitude of the location being sampled is known.

The GCP’s had purposely been spread out over the entire region covering the satellite imagery in order to improve the rectification process by minimizing errors. On the second day, it became obvious that too much time was being lost on the drive from Zagazig to the wall benchmark so arrangements were made with the post office guard for him to stay overtime so the post office benchmark could be used throughout the rest of the field campaign. This improved the efficiency of the entire field operation as, everyday, Zagazig was the starting and ending point.

All forty three GCP’s were sampled in three full days of field work. At each location, the selected pixel on the satellite imagery was identified and the tripod for the antenna was set up within the pixel in a convenient location (Figure 4 and 5). Many GCP’s were on bridges crossing large canals, in which case the GPS antenna was set up on the bridge railing on either the upstream or downstream side (Figure 6). Field sketches were made of antenna position and the surroundings in the area. Photographs and video footage were taken at each location for use in the laboratory at USU if any
Table 4. Setup parameters for the base station GPS during the field work

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
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<tbody>
<tr>
<td>Sampling Intervals:</td>
<td>Position every 10 seconds</td>
</tr>
<tr>
<td></td>
<td>Raw data every 15 seconds</td>
</tr>
<tr>
<td>Antenna Altitude:</td>
<td>7.6809 meters for wall base station</td>
</tr>
<tr>
<td></td>
<td>63.98 meters for the post office base station</td>
</tr>
<tr>
<td>Sampling Mode:</td>
<td>Manual 2D</td>
</tr>
<tr>
<td>Reference Altitude:</td>
<td>WGS84</td>
</tr>
<tr>
<td>Units of Measure:</td>
<td>Metric</td>
</tr>
<tr>
<td>North Reference:</td>
<td>True north</td>
</tr>
<tr>
<td>Time Zone:</td>
<td>+2 Hours east of Greenwich</td>
</tr>
<tr>
<td>GPS Parameters:</td>
<td>Elevation Mask=15°</td>
</tr>
<tr>
<td></td>
<td>Signal Level Mask=6</td>
</tr>
<tr>
<td></td>
<td>PDOP Mask=10</td>
</tr>
<tr>
<td></td>
<td>PDOP Switch=6</td>
</tr>
<tr>
<td>Beeper:</td>
<td>off</td>
</tr>
</tbody>
</table>
doubt existed on the position of the GPS antenna. This information was important as
ERDAS allows sub-pixel coordinate extraction for improved accuracy. In addition, video
footage was used to record structures, canals and drains to document the position of
gates and syphons for management purposes (Figure 7).

4.4 Differential Correction of Ground Control Points

At the end of each field work day, data from the GPS dataloggers were
downloaded to a portable PC computer and the differential correction calculations were
conducted. The PFINDER software on the PC was set up to automatically supply the
positions in UTM coordinates, as this would be the coordinate system adopted for
rectification of the satellite imagery. This was done using the Config/Coordinate
System option of PFINDER. The Config/Geodetic Datum
option was used to select the same reference surface that was used to collect the data
in the field i.e. WGS84 in this case. The Config/Units option was used to select the
information shown in Table 5.

The procedure for differential correction of GPS coordinates was done in the
following manner:

1. First the raw data files from the base station GPS unit and the rover GPS unit
were downloaded to the PC using the Comm/Data Files to PC
(communications) option in PFINDER.

2. The next step is to process the base station files using the Utils/Reference
Position command. The appropriate filename is selected and the true
latitude/longitude/altitude coordinates of the benchmark being used as a base
station are entered.
Table 5. Setup units used for differential correction of ground control points using the PFINDER software.

<table>
<thead>
<tr>
<th>Angle: seconds</th>
<th>Height: ellipsoid</th>
<th>Distance: meters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decimal Accuracy: 6</td>
<td>Velocity: Meters/second</td>
<td>Quadrant: NS/EW</td>
</tr>
</tbody>
</table>
3. The differential correction of each sampled location in the field is conducted using the **Utils/Differential Correction** option entering the appropriate base station and rover filenames. The output of this procedure will be written to a file with the same name as the entered rover filename however the extension will be `.cor` instead of `.ssf`.

4. The option **Utils/Calculate Statistics** is used to with the `*.cor` file to obtain the UTM coordinates of the ground control point or any other rover file.

The UTM coordinates obtained with this procedure are shown in Table 2, section 3.4.5. The standard deviations for the coordinates obtained (all 43 control points) varied from 1.8 to 6.9 meters, the average being around 3.0 meters. These were higher than those shown in Table 3 for the base stations due to the fact that the sampling period was allot smaller: most GCP's were sampled for a four minute period using a sampling interval of one second. If we assume that the ratio between the mean and the standard deviation is the same for the GCP’s as it was for the base station data shown in Table 3, we can expect the positions to be within 2 meters of the true position. This is more than enough accuracy for the map scale we are working with.

### 4.5 Systematic Location of Hydraulic Structures and Pumping Locations

The third part of the field activities consisted of the systematic sampling and surveying of turnout locations, pumping locations and control structures along the Bahr Mashtoul canal and main branch canals. At this point in time, Eng. Fatouh and Eng. Neder from the MPWWR as well as Eng. Amro from the Sharkiya directorate had also been trained on how to use the GPS in the field to collect position data.
Figure 4. Roaming GPS unit set up on one of the ground control points.

Figure 5. Close up of the GPS unit datalogger and receiver
Figure 6. Roaming GPS unit set up on a ground control point on a bridge crossing a drain

Figure 7. Filming of canal end structure with video camera
On the fifth day of the field activities, the surveying along the Bahr Mashtoul canal was initiated. The field crew drove along the canal to identify pumping locations, turnout structures and in-stream control structures (Figures 8 and 9). At approximately every 300 meters, when a turnout gate or pumping location was identified, the GPS would be set up to locate such a structure. While the sampling was underway, part of the field crew would measure the distance to other structures and pumping locations (including buffalo wheels) upstream and downstream from the sampled structure. A surveyor's measuring tape was used for this purpose and extensive notes were entered into the field book regarding the measurements and the nature of the structures.

At the end of the day, the training continued with the downloading of data to the PC and the differential correction procedures using the PFINDER software. On the sixth day, the field crew continued the surveying job without the supervision of the PI's and are presently continuing this work.

4.6 Ground truthing activities

During the field activities, several stretches of canals and drains were visited on the ground to verify the preliminary interpretation of the satellite imagery. There were several locations where lateral canals would cross major drains through aqueducts, expanding the command area of Bahr Mashtoul. Some of these areas were not clear even by examining the higher resolution color IR photographs at the surveying and mapping project. For example, a canal that arrives from Mashtoul at El Ibrahimiyah drain close to the town of Ibrahimiyah has a small aqueduct carrying water to a small 20 feddan area on the other side. This was only discovered by visiting the site and interviewing the local farmers.

These issues were solved by visiting the sites and interviewing the local irrigators as well as interviewing the Sharkiya Directorate management personnel.
Figure 8. A buffalo wheel pumping location converted to motor pumping.

Figure 9. Control gates on Bahr Mashtoul at El-Hagarsa.
Development of the Canal and Drainage System Maps

5.1 On-Screen Digitization of the Canal and Drain System.

Digitizing of canals and drains within the pilot area was accomplished using ARClm/INFOtm vector GIS software linked to the ERDASlm image processing system. The geo-referenced 10 meter color image was used as a map base from which to digitize. The image was displayed onto the computer screen and the canal and drain network interpreted with the help of data collected during the field campaign in November 1992.

While visiting the Office of Surveying and Mapping in Cairo, color infrared aerial photographs of the pilot area were interpreted onto non-geo-referenced satellite hard-copy images, this identified the command area, separated drains from canals, and identified canal and drain intersections. These interpretations were used by the visiting Egyptian engineer and USU students as a guide to digitize the canal and drain structure onto the digital version of the color image.

The ERDASlm - ARClm/INFOtm "Live-link" was used to digitize canals, drains and the command area. The Live-link allows the ARClm/INFOtm, ARCEdittm program to use images displayed by ERDASlm image processing system. Since the 10 meter color SPOT image was geo-referenced to a Universal Transverse Mercator (UTM) coordinate system, the digitizing process automatically referenced the resulting canal and drain network to the same UTM system. By displaying the image on the screen and then digitizing canals and drains over it, the technician was able to follow canal and drain networks visually by using the image. The interpretation of the color IR aerial photos from the Mapping and Surveying Office was used as a guide to help the technician decide which was canal and which was drain. It also helped in defining the extent of the canal and drain system and defined which canals intersected and which canals did not. Canals, drains, and command areas were digitized into separate GIS layers.
5.2 Building of the GIS overlays

Once all canals and drains were digitized, the task of correcting digitizing mistakes, and building topology began. The process of digitizing in ARC\textsuperscript{tm}/INFO\textsuperscript{tm} consists of entering line segments (arcs) which may or may not form closed polygons. The basic building block of a vector based GIS are single vertices (x and y coordinate). A chain of vertices form an arc. The vertices at each end of the arc are termed nodes. Nodes can be found at the end of arcs or at the intersections of three arcs. Therefore, the canal and drain network is composed of vertices linked together to form arcs. The arcs are linked to form a network of arcs. Each arc begins and ends with a node. Where two arcs join, the result is three arcs joined by one node.

The term topology is defined as the spatial relationships between connecting or adjacent coverage arcs, nodes, polygons and/or points. The process of linking arcs and forming topology is termed cleaning and building in ARC\textsuperscript{tm}/INFO\textsuperscript{tm}. The cleaning process joins intersecting arcs, forming a node at the intersection, and builds the topologic relationship between arcs and nodes. The topology is built from the simplest feature (vertices) to the most complex (adjoining arcs.) Therefore, each vertices belongs to a certain arc, each node belongs to a certain arc, or arcs in the case of intersections. Each arc is connected to another arc and the node is the linking point.

To this point in the project, all canals and drains have been entered into ARC\textsuperscript{tm}/INFO\textsuperscript{tm} databases. All arcs have been cleaned and topology has been generated. Names of each canal and drain have been entered as attributes. The database is now in a presentable form to define reaches and enter data relevant to each reach for hydrologic modeling. This will be accomplished in Task #7 as field data becomes available.

5.3 Preparation of Preliminary Maps

Preliminary field maps were generated from the 10 meter color SPOT imagery prior to the field campaign. Since the SPOT imagery was not geo-referenced at this time, the maps were not scaled. However, comparison between published maps at
1:25,000 showed that the SPOT image maps to be similar in scale. In addition to the image maps, overlays of preselected control points were made to guide us in locating control points in the field. Figures 2 - 7 show a reduced version of preliminary maps. Black and white images are shown in figures 2 - 4. Field maps used were color in addition to the black and white shown here. All maps were generated using the ARCPLOT utility of ARC/INFO.

Ground control points were identified by the Egyptian engineers as stated above. The image coordinates of each point was recorded in an ASCII computer file. Using the generate command, the points in the ASCII file were imported to ARC/INFO. The point coverage generated from the ASCII file of ground control points was plotted into a map composition made to match the image files.

The text below shows the general methodology used to generate a map composition, the commands appear in bold. It is important to read the users manual of the ARC/INFO software to properly understand the meaning of each command. These commands may change depending on the revision number of the software.

General methodology to plot image files in ARCPLOT.

```
arc> arcplot
arcplot> display 400
arcplot> map <enter name of map composition>
arcplot> mapextent image <enter the file name here>
arcplot> pagesize 30 20
arcplot> mapposition cen cen
arcplot> image <enter the file name here> composite 3 2 1
arcplot> textsize .25
arcplot> move *
arcplot> textfont 9
arcplot> text '<enter whatever text you want>'
arcplot> display 1040
arcplot> plot <enter name of plot composition here>
```
General methodology to plot point files in ARCPLOT.

arc>  arcplot
arcplot>  display 400
arcplot>  map <enter name of map composition>
arcplot>  mapextent image <enter the file name here>
arcplot>  pagesize 30 20
arcplot>  mapposition cen cen
arcplot>  points <enter the name of the point coverage here>
arcplot>  labelpoint <enter the name of the point coverage here>
arcplot>  textsize .25
arcplot>  move *
arcplot>  textfont 9
arcplot>  text 'enter whatever text you want'
arcplot>  display 1040
arcplot>  plot <enter name of plot composition here>
Figure 10. Reduced field map used to locate GCP and points of interest (circles) on the southernmost portion of the study area.
ZAGAZIG STUDY AREA 3 OF 3

GCP POINTS AND AREAS OF CHANGE
Figure 11. Reduced field map used to locate GCP and points of interest (circles) on the central portion of the study area.
ZAGAZIG STUDY AREA 2 OF 3

GCP POINTS AND AREAS OF CHANGE
Figure 12. Reduced field map used to locate GCP and points of interest (circles) on the northernmost portion of the study area.
ZAGAZIG STUDY AREA 1 OF 3

GCP POINTS AND AREAS OF CHANGE
**Figure 13.** Reduced black and white version of the preliminary field map used to locate GCP points, points of interest, and navigate on the southernmost portion of the study area.
**Figure 14.** Reduced black and white version of the preliminary field map used to locate GCP points, points of interest, and navigate on the central portion of the study area.
Figure 15. Reduced black and white version of the preliminary field map used to locate GCP points, points of interest, and navigate on the northernmost portion of the study area.
While these commands are relatively simple, final maps have to potential to be very complicated based on the amount of material entered into the map composition. Field image maps were plotted onto white paper and laminated with plastic to protect them against the weather. Point maps were plotted onto transparent mylar to allow overlay onto field maps. Two copies of all maps were made for the field excursion.

5.4 Preparation of Final Maps

Maps produced from the spatial GIS database can be found in Appendix 1. Four maps are presented:

1. A base image map from which the canal and drain system were digitized
2. A map of the canal system and corresponding command areas
3. A map of the drain system and corresponding command areas
4. A map of the canal and drain system

The final maps were prepared at the end of Task 7 after all existing field data had been incorporated and the location of structures, turnouts and pumping points along the main canal and large laterals has been completed. Reduced versions of non-image canal and drain maps are presented in Figures 16 -18.

5.5 Extraction of physical system data from the GIS database

The GIS database can be queried to obtain useful information and some basic parameters. The present spatial GIS overlays consist of:

1. Boundary of the pilot project area
2. Main canals and laterals
3. Main drains
4. Command areas of main canals and laterals
5. Command areas of drains

Using the command TABLES in ARC, and then the SELECT command to choose the arc attribute table (.aat) of the coverage, we can SORT the item for example "NAME" and use the LIST "NAME" length to give the canal names and
lengths for example. The same procedure can be done to obtain areas, by selecting polygon attribute tables (.pat) instead.

Data resulting from querying the database are shown below in Table 6 and Table 7 for the canal lengths and command areas respectively. Drain lengths and command areas are shown in Tables 8 and 9. Other information will be added to the database as part of Task 7, which comprises the attribute database development. This information will include data being gathered by the Egyptian consultants and engineers presently working in the field. The data consists of carrying capacity of canals and drains, cross section of the canals, slope of the canals, roughness coefficient for the canals, operating criteria for the canals, organization responsible for water releases, canal lining, delivery points and control points.

The delivery and control points are being systematically sampled along the Bahr Mashtoul canal and main lateral canals by the Egyptian engineers from the MPWWR and Sharkiya directorate. It is our understanding that Mr. Fawzy Helwa, the Egyptian consultant, is collecting the canal hydraulic data necessary for the hydraulic models. This includes, canal cross sections, slopes, roughness etc., thus carrying capacity will be obtained. We will incorporate whatever data is collected into the GIS database as it becomes available.
Figure 16. Interpreted canals and command area map generated from "heads-up" digitizing from the SPOT imagery.
Figure 17. Interpreted drain and command area map generated from "heads-up" digitizing from the SPOT imagery.
Figure 18. Interpreted drains and canals map generated from "heads-up" digitizing from the SPOT imagery.
Table 6. Lengths of canals obtained from GIS database.

<table>
<thead>
<tr>
<th>CANAL NAME</th>
<th>LENGTH (in km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bahr Mashtoul</td>
<td>27.988</td>
</tr>
<tr>
<td>Genn. Kafr El-Hamam</td>
<td>7.884</td>
</tr>
<tr>
<td>Bahr Iweis</td>
<td>7.815</td>
</tr>
<tr>
<td>El-Fegla Canal</td>
<td>3.666</td>
</tr>
<tr>
<td>Bahr El-Dakar</td>
<td>4.380</td>
</tr>
<tr>
<td>Bahr Ads</td>
<td>2.142</td>
</tr>
<tr>
<td>Bahr El Hager</td>
<td>8.870</td>
</tr>
<tr>
<td>El-Quftaniya Canal</td>
<td>16.949</td>
</tr>
<tr>
<td>El-Nizam Canal</td>
<td>2.778</td>
</tr>
<tr>
<td>Mes. El-Shanaita</td>
<td>3.446</td>
</tr>
<tr>
<td>El-Hagarza Canal</td>
<td>7.542</td>
</tr>
<tr>
<td>El-Gedida Canal</td>
<td>4.215</td>
</tr>
<tr>
<td>El-Dakik Canal</td>
<td>2.320</td>
</tr>
<tr>
<td>Genn. Manzil Haiyan</td>
<td>3.278</td>
</tr>
<tr>
<td>Umm Shusha Branch</td>
<td>1.454</td>
</tr>
<tr>
<td>Umm Shusha Canal</td>
<td>2.800</td>
</tr>
<tr>
<td>El-Gimmeiza Canal</td>
<td>5.879</td>
</tr>
<tr>
<td>El-SIDS Canal</td>
<td>4.294</td>
</tr>
<tr>
<td>El-Mostagada Canal</td>
<td>5.139</td>
</tr>
<tr>
<td>El-Santa Canal</td>
<td>0.770</td>
</tr>
<tr>
<td>Mes. Qurwa</td>
<td>2.442</td>
</tr>
<tr>
<td>El-Seru</td>
<td>1.243</td>
</tr>
<tr>
<td>Mes. Diyan</td>
<td>1.178</td>
</tr>
<tr>
<td>Mes. Muharram</td>
<td>0.829</td>
</tr>
<tr>
<td>Mes. Dabbus</td>
<td>1.306</td>
</tr>
<tr>
<td>L. Mahdyia Canal</td>
<td>4.751</td>
</tr>
<tr>
<td>El-Naker Canal</td>
<td>1.643</td>
</tr>
<tr>
<td>Mes. El-Soltan Hosin</td>
<td>1.424</td>
</tr>
<tr>
<td>El-Shawarshy Canal</td>
<td>2.226</td>
</tr>
</tbody>
</table>
Table 7. Canal command areas for main canals and laterals of the Bahr Mashtoul pilot project area, Sharkiya directorate.

<table>
<thead>
<tr>
<th>Name of command area</th>
<th>Area (m²)</th>
<th>Area (fedd.)</th>
<th>Area (Ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EL-Hagarsa</td>
<td>16472711.00</td>
<td>3922.07</td>
<td>1647.27</td>
</tr>
<tr>
<td>EL-Quftaniya</td>
<td>32604812.00</td>
<td>7763.05</td>
<td>3260.48</td>
</tr>
<tr>
<td>Bahr Mashtoul (D.I)</td>
<td>31720062.63</td>
<td>7552.40</td>
<td>3172.01</td>
</tr>
<tr>
<td>Bahr El-Hager</td>
<td>18765472.00</td>
<td>4467.97</td>
<td>1876.55</td>
</tr>
<tr>
<td>Gen. Kafr El-Hamam</td>
<td>7388354.50</td>
<td>1759.13</td>
<td>738.84</td>
</tr>
<tr>
<td>Bahr Iweis</td>
<td>5085089.50</td>
<td>1210.74</td>
<td>508.51</td>
</tr>
<tr>
<td>Bahr Ads</td>
<td>2307751.50</td>
<td>549.46</td>
<td>230.78</td>
</tr>
<tr>
<td>Bahr El-Daker</td>
<td>4097816.75</td>
<td>975.67</td>
<td>409.78</td>
</tr>
<tr>
<td>ElFegla canal</td>
<td>1902586.50</td>
<td>453.00</td>
<td>190.26</td>
</tr>
</tbody>
</table>

Total command area of Bahr Mashtoul

<table>
<thead>
<tr>
<th>Area (m²)</th>
<th>Area (fedd.)</th>
<th>Area (Ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>120344656.38</td>
<td>28653.49</td>
<td>12034.4</td>
</tr>
</tbody>
</table>

* D.I : Direct Irrigation from Bahr Mashtoul

*1 Fedd. = 4250 m²

* 1 Hectare = 10000 m²
Table 8. Lengths of the drains in the pilot area obtained from the GIS database

<table>
<thead>
<tr>
<th>DRAINS</th>
<th>LENGTH (Km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EL-IBRAHIMIYA DRAIN</td>
<td>31.279</td>
</tr>
<tr>
<td>B.SAFT EL-QIBLI DR.</td>
<td>24.541</td>
</tr>
<tr>
<td>EL SIDS DRAIN</td>
<td>17.445</td>
</tr>
<tr>
<td>EL-MAHMUDIYA DRAIN</td>
<td>16.639</td>
</tr>
<tr>
<td>MUBASHIR DRAIN</td>
<td>8.389</td>
</tr>
<tr>
<td>MUHSIN DRAIN</td>
<td>6.152</td>
</tr>
<tr>
<td>IKRASH DRAIN</td>
<td>7.704</td>
</tr>
<tr>
<td>MIGAHID DRAIN</td>
<td>7.145</td>
</tr>
<tr>
<td>IKWA DRAIN</td>
<td>9.648</td>
</tr>
<tr>
<td>MANZIL HAIYAN DRAIN</td>
<td>4.667</td>
</tr>
<tr>
<td>UMM EL-RISH DRAIN</td>
<td>4.74</td>
</tr>
<tr>
<td>EL-HUDUDA DRAIN</td>
<td>3.74</td>
</tr>
</tbody>
</table>
Table 9. Drain command areas for the Bahr Mashtoul pilot project area obtained from the GIS database.

<table>
<thead>
<tr>
<th>Drain Command Area</th>
<th>AREA(m²)</th>
<th>AREA(fedd)</th>
<th>AREA(Ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B. SAFT EL-QIBLI DR.</td>
<td>11428100</td>
<td>2720.98</td>
<td>1142.81</td>
</tr>
<tr>
<td>EL-HUDUDA DRAIN</td>
<td>2335051</td>
<td>555.96</td>
<td>233.51</td>
</tr>
<tr>
<td>EL-IBRAHIMIYA DRAIN</td>
<td>31466070</td>
<td>7491.92</td>
<td>3146.61</td>
</tr>
<tr>
<td>EL-MAHMUDIYA DR.</td>
<td>11702353</td>
<td>2786.27</td>
<td>1170.24</td>
</tr>
<tr>
<td>EL-PRINCE DRAIN</td>
<td>1309426</td>
<td>311.77</td>
<td>130.94</td>
</tr>
<tr>
<td>EL-SIDS DRAIN</td>
<td>28329090</td>
<td>6745.02</td>
<td>2832.91</td>
</tr>
<tr>
<td>MANZIL HAIYAN DR.</td>
<td>6078456</td>
<td>1447.25</td>
<td>607.85</td>
</tr>
<tr>
<td>MUBASHIR DRAIN</td>
<td>4307785</td>
<td>1025.66</td>
<td>430.78</td>
</tr>
<tr>
<td>MUHSIN DRAIN</td>
<td>10237280</td>
<td>2437.45</td>
<td>1023.73</td>
</tr>
</tbody>
</table>
5.6 Linkages with the Hydraulic and Planning Distribution Models (PDM)

The main purpose for the development of the GIS database was to map the spatial layout of the canal and drain system as well as to store physical information on the irrigation and drainage structures to be used by the Hydraulic and Planning Distribution Models.

The Hydraulic models being developed in other tasks to aid in the operation of the canal system require input data such as length of canals, reach number, feeding canal, cross-section dimensions, slope, hydraulic roughness, hydraulic control structures etc. The GIS has been developed so that this information is stored as attributes by reach of the canal and can be easily retrieved.

The PDM model is a high-level simulation software which will be used for water resources planning and aid in the decision making process of water distribution and allocation under different operating conditions (Task 4, final report).

The model represents the canal and drain system using a network of connected nodes. Nine different types of nodes are used: source, measurement, bifurcation, inflow, command area, municipal and industrial, return flow, drainage re-use and terminus. The GIS spatial database developed for the pilot area also represents the system using arcs and nodes. The nodes in the GIS database were placed at the sources of water, in-line structures defining reaches, and lateral off-takes (bifurcations). In addition, a new GIS coverage consisting of turnouts and pumping locations along the main canal and laterals was developed in Task 7 to identify command area nodes for smaller canals and mesqas. Other data to be shared with the PDM model are the extent of the command areas for demand calculations, pumping and re-use of water from drains, and crop classification. In Task 7, a macro language interface has been developed to allow for the easy entering and modification of attribute values. In addition, the macro language routines allow for the query and/or writing of the data per canal reach, to ASCII files which are accessed by the hydraulic and PDM models. The users' manual and technical documentation describing the macro language interface is included in the Task 7 report.
Other information

6.1 Delineation of Canal Command Areas

The delineation of the major lateral canal command areas has been done and presented in section 5.4 of the report. The command areas for some of the smaller canals and mesqas can be obtained in the future and added to the existing GIS database by interpretation and digitizing of the 1:10000 orthophotos soon to be completed by the Surveying and Mapping project. Training of Egyptian engineers will be conducted during the final workshop in Cairo on the use of the digitizing tablet and interpretation of Orthophotos.

6.2 Classification of Major Crop Types

During our second trip to Egypt, we identified and selected different crop types on the 10 meter color imagery based on visual interpretation of the color infrared photos. These areas were marked on the mylar overlays and were used to study the spectral signatures of the three major summer crops i.e. corn, rice and cotton on the 20 meter multispectral imagery. Training sets were then developed on the multispectral imagery and maximum likelihood supervised classification techniques were used to obtain the cultivated areas for each crop. These results can eventually be compared to the cultivated areas obtained from the ongoing effort at the surveying and mapping project.

Other crops are also planted during the summer, but amount to small areas when compared to the three main crops. These fields are usually small which did not allow their identification in the 20 meter imagery. The 10 meter imagery could have potentially been used for classification if the Panchromatic image had been acquired during the same season as the multispectral, which was not the case for our project.

The surveying and mapping project is presently conducting a complete crop inventory for the Nile delta region. This information is being mapped in ARC/INFO and could be merged with the GIS database being developed for this project. This information could then be transferred to the PDM model for estimates of crop water demand.
6.3 Expansion of the spatial database to other areas of the Sharkiya Directorate

The spatial and attribute GIS database has been developed for the pilot area to be general enough so that the same framework can be used to expand and map other areas of the Sharkiya Directorate or even the Nile Delta. The expansion of the database should be conducted on tertiary canals on the same order of size as Bahr Mashtoul, on a command area to command area basis, using the 1:10000 orthophotos from the surveying and mapping project as the base map for digitization of the canal and drain system. These maps will provide considerably greater spatial resolution than the 10 meter satellite imagery being used for the pilot area. An upper limit in size for a command area can be estimated based on software and hardware limitations i.e. disk space.

The methodology of database development will be similar. The main difference will be the use and interpretation of 1:10000 orthophotos as a map base instead of rectified satellite imagery. The canal and drain system layout will be digitized on the maps by placing them on digitizing tablets interfaced with PC ARC/INFO. The coverages should be placed in hard disk sub-directories named after the command area of the tertiary canal being digitized. This technique will be covered in the final training workshop.

The attribute GIS database will be a shell with empty slots for the different parameters of interest associated with the new spatial layout i.e. canal hydraulic data, turnouts and controls etc. A "friendly" interface has been developed and described in the Task 7 final report to allow the input of data into this database as it is obtained from map interpretations and field measurements. For example, the systematic sampling of turnouts and pumping locations along the canals using GPS might not be necessary as it is probable that the buffalo wheels and smaller canals will be visible on the orthophotos.
6.4 Hardware and Software Requirements for the Expansion of the Database

The hardware and software required for this project was PC based as per project specifications. The following hardware and software configurations are recommended for the MPWRR to be self sufficient:

**Computer:** (supplied by USU)
PC Microcomputer 486 33 MHz
8 MB of ram memory
500 MB of hard disk space (at least)
Disk drives: one 3.5" and one 5 1/4" floppy disk drives
Monitor: high resolution VGA or Super VGA

**Mouse**

**Peripherals:**
- Text printer: High quality text
- Tablet Digitizer: A 48"x36" tablet, preferably CALCOMP 9500 series. (tablet digitizer to be supplied by USU)
- Plotter: 'E' size pen plotter preferably CALCOMP 1025 series, with draft and final map quality paper, color and black pens of different tip sizes

**Software:**
PC ARC/INFO with manuals (supplied by USU)
ARC/VIEW (supplied by USU)
Windows 3.2 (supplied by USU)
DBASE III+ (supplied by USU)

**Hardware and Software for processing satellite images:**
- Imagraph board or other PC graphics board supported by ERDAS
- High resolution monitor 1024x1024, MITSUBISHI Diamond Scan or similar
- PC ERDAS Image Processing and GIS software
Bibliography


APPENDIX 1

MAPS OF THE CANAL AND DRAIN SYSTEM