Draft Final Report - 1 [redacted]

FEWS REPORT #5

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PD-AEL-215

USDA-FAS 1985 Sudan Sorghum

Cropped Area Estimate

1.0 Objective. The objective of USDA/Foreign Agricultural Service (FAS) was to make a sorghum/millet cropped area estimate for that portion of Sudan between 11°N and 16°N and the White Nile and the Ethiopian border. This acreage estimate was to be made using Landsat Multispectral Scanner (MSS) data coupled with information about crop spectral characteristics and location--an approximation of ground truth--gathered during extensive travel in the area. Image processing of the Landsat MSS digital data was conducted at the FAS, Foreign Crop Condition Assessment Division (FCCAD) Washington facility with products and reports being delivered to USAID-Khartoum and USAID-Washington.

2.0 Results and Conclusions. FCCAD estimated that approximately 14,824,000 acres were planted to sorghum/millet in the eastern part of Sudan during the 1985 crop year. The acreage estimate was combined with yield estimates from the Sudanese Ministry of Agriculture (MOA) and resulted in a production estimate of 4.57 M metric tons from that portion of Sudan analyzed by FCCAD.

The remote sensing based acreage estimate and resulting production estimate contrast sharply with historical Sudanese production data. Historic production records indicate that the record year was 1981 when the MOA estimated a crop of 3.1 M metric tons for the whole country.

3.0 Background. Sudan and the Sahel in general have recently experienced a multi-year drought which effected large areas. Sudan in 1984 experienced a major crop failure which resulted in the displacement and starvation of many Sudanese. The rainy season was near normal in 1985 some areas and poor in others. By September 1985 there were widely varying estimates of Sudanese grain production. A major concern of the AID mission in Khartoum was that even though the country as a whole might have a grain production surplus indications were that pockets of deficit existed. The problem then became one of identifing the surplus areas from the deficit areas and formulating plans to economically meet the needs in the deficit areas.

Crop production is based on the equation of area multiplied by yield. One of the earliest documented uses of Landsat data is crop area estimation. The Foreign Crop Condition Assessment Division (FCCAD) of Foreign Agricultural Service/USDA agreed to make a sorghum/millet cropped area estimate for eastern Sudan using Landsat Multispectral Scanner Data and digital image processing techniques based on a cost reimbursable basis.

4.0 Project Area Description. The project area covered approximately 51.4 million acres between 11°N and 16°N and from the White Nile to the Ethiopian border (Exhibit 1). The project area ranged from the near desert in the north at Khartoum (16°N) with approximately 200mm of rainfall to tropical savanah/grasslands near Damazin (12°N) with approximately 800mm of rainfall.

The soils in the project area are primarily heavy, black, low relief vertisols in the south grading into sandier, more reflective soils in the north. These vertisols have developed from alluvial material deposited by

the ancient Nile, are very fertile and lend themselves to large scale mechanized farming practices. A major handicap associated with these soils is the very high shrink-swell capacity typical of vertisols. In this instance, Sudan has very few hard surface roads and during a large part of the year the unpaved roads are impassable from either mud or ruts caused by driving in the mud. Ground truthing was both difficult and expensive because of the poor road conditions in both the heavy and sandy soils.

Sorghum/millet cropping practices in eastern Sudan typically fall into one of four categories, discussed in the remainder of this section. In the north near Khartoum there are several large irrigation projects. One of these, the Ghizera, was initiated by the British and currently encompasses approximately 2.2 million acres. Another in the area is the Rhiad project. Both of these projects use fixed crop rotations involving cotton, sorghum or ground nuts, wheat, and fallow. These projects are administered by bureaucratic boards and receive the largest and most modern inputs.

Another type of production is on large dryland parastatal farms. Typically, these farms use modern farm practices and inputs and can be quite extensive. One farm which we visited near Damazin had 220,000 acres under cultivation. Seventy-five percent of the area was cropped to grain sorghum. All land in Sudan is publically owned and rent on these large farms is typically thirty cents (US) per acre. For statistical purposes in this report, acreage for irrigated farms and parastatal farms are called demarcated mechanized.

In Sudan a large segment of the agricultural production capacity comes from share crop arrangements between a farm manager who furnishes labor and a village merchant who furnishes capitol and possibly machinery. This production typically occurs without state sanction or the payment of rent for the use of state lands. The production techniques used are mechanically rudimentary with minimal land clearing, no fertilizer, no insecticide, and hand weeding. It is believed that these farms typically produce less per unit area than parastatel farms. The Sudanese nomenclature for this type of production is undemarcated mechanized.

Typically subsistance farming in Sudan occurs on very small acreages with almost no inputs other than seed and hand labor. In many areas the plots may be only five acres. In this report the traditional and undemarcated mechanized have been lumped together as a class.

4.0 Ground Truth. A thorough understanding of the type, nature, and distribution of the crop or vegetation under investigation is necessary in order to accurately accomplish digital image classification. Intensive and extensive ground truth was gathered in the project area. Twelve Landsat scenes cover this part of Sudan (Exhibit 1). An effort was made to transect and gather data from the area covered by each of them. FCCAD personnel (with AID mission support) flew from Khartoum to Damazin and then visited several parastatel farms in the area. Additionally, aerial transects were flown over these same areas and pictures of the crops were taken from both the air and ground. Aerial transects were flown from Damazin to Gedaref, Gadaref to Khartoum, and from Khartoum to Kassala. A ground trip was made to the Ghizira project at Wad Medini. The data gathered about crop type,

spacial distribution, cropping practice, potential yield, general plant vigor, and environmental conditions were used in the classification process.

5.0 Image Processing. USDA/FAS acquired digital images of the twelve scenes covering eastern Sudan during two passes in October and November. Landsat computer compatible tapes (CCT's), high density tapes (HDT's), and 1:1,000,000 false color transparencies were purchased for the 12 Landsat scenes which cover the project area and used in the analysis. Each Landsat scene is comprised of a 3548 x 2400 pixel array of numerical values. This data array is too large to be processed on our system as a single image. A procedure was developed to divide each image in nine equal partitions and then further reduce each subimage by doing a 2 x 2 systematic sampling in order that the data could be efficiently processed (Exhibit 2). For a short discussion of sampling techniques and an overview of the FCCAD remote sensing system please refer to the FAS proposal for this project.

The ground truth gathering process had been designed so that when each subimage was displayed for processing, the information gathered on the ground could be used to identify the spectral signature of grain sorghum in general and certain fields in specific. The spectral signature of identifiable fields was used to build training sets which are composed of values which digitally defined the characteristics of sorghum and other classes of identifiable areas. The outputs from the training set process are a covariance matrix, the minimum and maximum pixel values, and the set mean and standard deviation vectors for each training set. The statistics for each training set class was stored in a disk file. The next step in the analysis uses as inputs the stored statistical results from the training set

step and the original image. The data in these training sets were then utilized by the computer to find, classify, and count all the picture elements (pixels) with similar digital values within a subimage. The results from this procedure are compared with the original image to visually assess the accuracy of the classification. Since a Landsat pixel is 1.1 acre, the acres of crops are directly calculable from the classification output.

Landsat images have a 5% overlap on each end and a side overlap of 11% at this latitude. We could not prevent double and triple counting of area in the scene overlap, therefore we converted from pixel counts into percentages and used a simple average of classified area for all subimages to arrive at total crop area in our portion of the Sudan.

The classification process was repeated for all of the Landsat sub-scenes required to assess the area of responsibility. These subscene statistics were then tabulated and averaged on a province basis (Exhibit 3, pages 1 thru 6). A copy of the digital imagery used in this project is being delivered with the original report.

For example: The area of Landsat scene 173049 which fell in Khartoum province was four sub-scenes:

Orbit	Sub-scene	Mechanized	Traditional
V173049	05	---	---
V173049	06	---	---
V173049	08	.16	---
V173049	09	---	.15
		.16	.15
N=4		.16/4= .04	.15/4= .0375

4.0 is the % of total province area cropped to mechanized sorghum.
3.75 is the % of total province area cropped to traditional sorghum.

Province area was determined by measuring the area of each province on a map and converting that area measurement (sq. in.) into acres. This is a standard cartographic process where 1 square inch is equal to 159,422 acres at 1:1,000,000 scale. A digitizer available in FCCAD was used to determine map area measurements.

The results of the Landsat analysis appears as Table 1. The column titled cropped area mechanized was determined by multiplying the percentage mechanized sorghum column by the province area column. This process was repeated to determine acreage throughout both the mechanized and traditional sectors.

6.0 Accuracy Assessment: Automated image classification results are largely dependent upon the quality of the data used to train the classifier and the experience of the analyst. In this instance the analyst has extensive image processing experience and was very familiar with the project area. Digital classification procedures tend to overestimate the area within classes. Typically an accuracy assessment is made to define the amount and nature of the misclassification and the correct image processing results. A formal assessment was not performed during this project due to a lack of systematically collected ground truth and timing constraints. However, significant adjustments were made. The final millet/grain sorghum area data was corrected by subtracting the MOA acreage figures for sesame and further reducing the area by 15% for overclassification (Table 2). While this may appear to be a rough method, the MOA statistics for mechanized demarcated acreage has a GOA measured acreage of 7.180 M and our corrected satellite based estimate was 6.577 M, a difference of 8%. Note

that the acreage based on remote sensing is less than the MOA estimate, a fact that mitigates against the thought that the remotely sensed acreage is overestimated.

7.0 Production Estimate. The total production estimate for the 1985 sorghum and millet crop was made by GOA and USAID personnel in Khartoum. The FAS remote sensing analyst that conducted the analysis participated in the estimation process. The GOA yields multiplied by our area determination for the eastern part of Sudan results in a production of 4,570 MMT (Table 3).

TABLE 1

Province	Area (acres)	Number of Subimages	Sorghum % of Mech.	Sorghum % Undemarcated/Trad.	Cropped Area Mech.	Cropped Area Trad.
Khartoum	2,525,843	4	4.00	3.75	101,033	94,719
Kassala	21,530,026	26	23.84	16.92	5,132,758	3,642,880
Bl. Nile	16,581,908	23	13.30	31.86	2,205,394	5,282,996
Up. Nile	1,544,056	3	17.00	1.00	262,489	1,544
Gezira	6,867,237	7	17.42	7.857	1,196,273	539,559
Wh. Nile	2,005,509	2	02.00	19.50	40,110	391,074
	51,054,578				8,938,056	9,952,772

TABLE 2

Acreage Estimates Corrected for Sesame and Misclassification

Province	Demarcated Mech.	Trad./Und. Mech.
Khartoum	85,878	80,511
Kassala	3,967,594	3,096,448
Bl. Nile	1,249,835	4,278,047
Up. Nile	223,116	1,312
Gezira	1,016,832	458,625
Wh. Nile	34,094	332,413
Total	6,577,000	8,247,000

TABLE 3

Eastern Sudan USDA Sorghum Acreage Estimate - 1985

Mechanized Demarcated	Traditional/Undemarcated Mechanized*	
6,577,000 acres	8,247,000 acres	
x 390 kilos	(30% trad.)	(70% mech.)
2,565,030 MT	2,474,100 ac.	5,772,900 ac.
	x 180 kl.	x 270 kl.
	445,338 MT	1,558,683 MT
Total	2,004,021 MT	

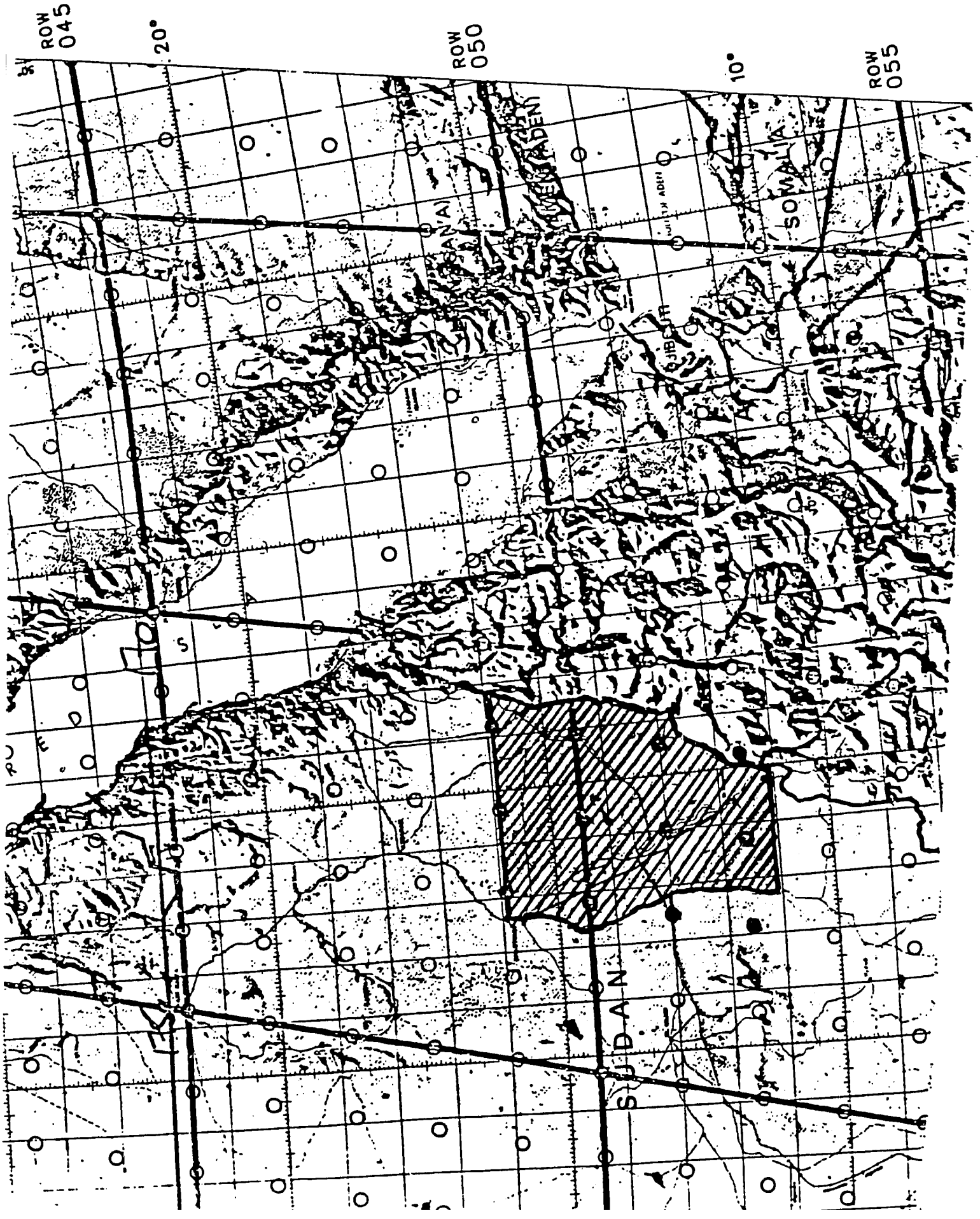
Estimated total Eastern production

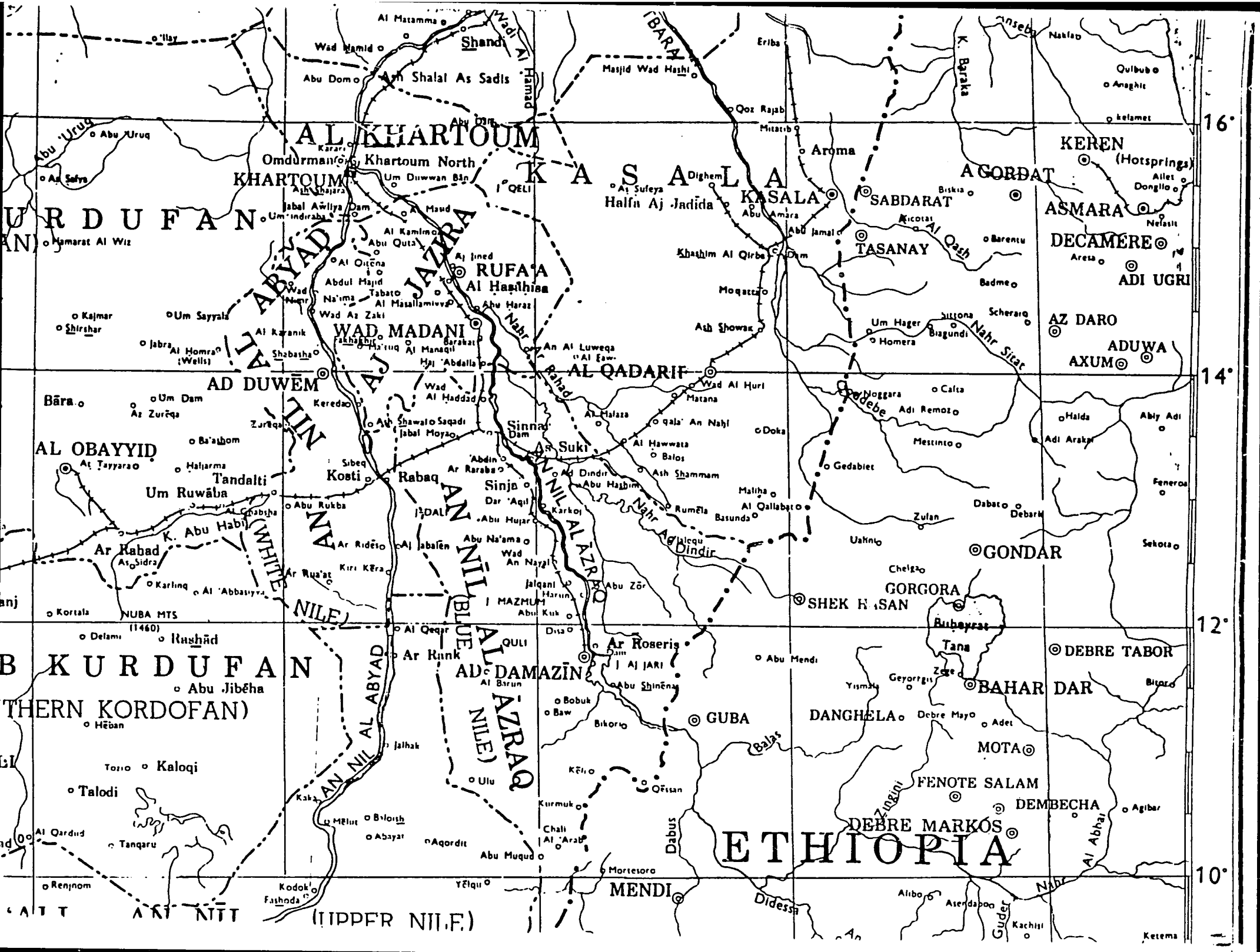
2,004,021 MT + 2,565,030 MT = 4,569,051 MT

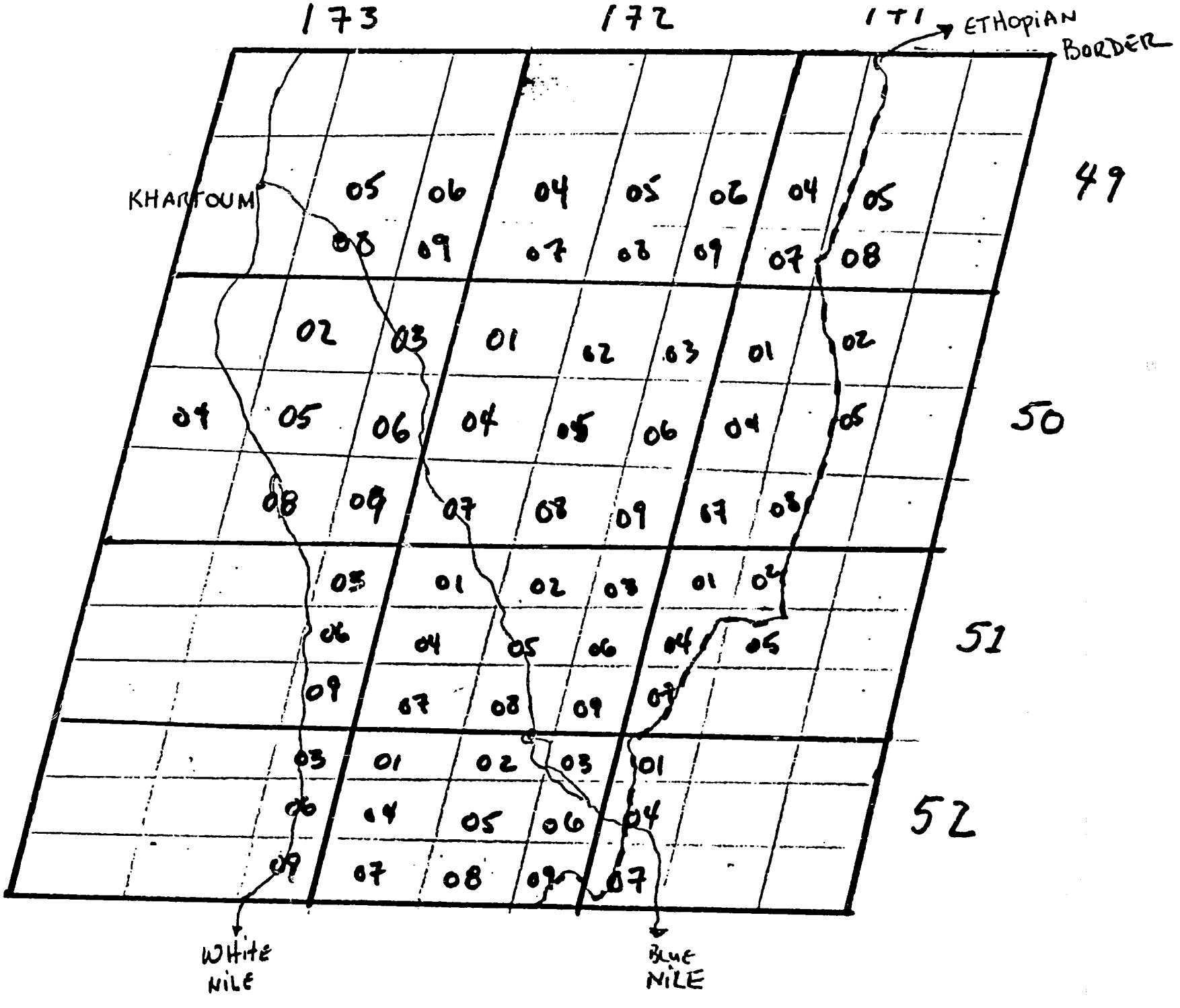
*According to our Sudanese agronomic consultants, the split in this sector is approximately as shown.

8.0 Observations and Outlook. It should be noted that the application of Landsat MSS remote sensing technology was almost ideal on this project. The results and accuracy could have been better quantified had more lead time been available. The large fields, almost single crop agriculture and uniform growth stage made this a relatively easy task. Even with these conditions the task could not have been done without the on-site ground observations by the FCCAD image analyst. A more thorough job could have been performed if additional data acquisitions had been acquired earlier in the growing season and ground observation data could have been registered and correlated to the satellite data. The information derived from satellite data is another source of information that can be used by informed crop production forecasters and policy makers.

Exhibit 1
East Sudanese Coverage




AL KHARTOUM
KHARTOUM
Omdurman
Khartoum North
KASALA
KASALA
KEREN
(Hotsprings)
AGORDAT
ASMARA
DECAMERE
ADI UGRI
AZ DARO
ADUWA
AXUM
SABDARAT
TASANAY
RUFA'A
Al Hasāhisa
WAD MADANI
AL QADARIF
AD DUWĒM
AL OBAYYID
Tandalti
Um Ruwāba
Kosti
Rabaq
Sinja
As Suki
Sinnar
Ar Rabad
Ar Roseris
AD DAMAZĪN
GUBA
GONDAR
GORGORA
SHEK HASAN
BAHAR DAR
DEBRE TABOR
DANGHELA
MOTA
FENOTE SALAM
DEMBECHA
DEBRE MARKOS
ETHIOPIA
MENDI
NUBA MTS
(1460)
Rashād
Kaloqi
Talodi
Tana
Aroma
Halfa Aj Jadīda
Khashim Al Qirba
Ash Shawak
Qoz Rajab
Masjid Wad Hashi
Shandi
Ash Shalal As Sadis
Abu Dom
Wad Hamid
Al Matamma
Omdurman
Um Dubwan Bān
Jabal Awliya Dam
Al Kamlin
Abu Quta
Al Qitena
Abdul Majid
Wad Nimr
Na'ima
Tabat
Al Masallamiyya
Wad Az Zaki
Al Karanik
Shabasha
Al Homra (Wells)
Um Sayyala
Kajmar
Shirshar
Jabra
Bāra
Um Dam
Az Zurēqa
Ba'ashom
Hajarma
Ar Ridēs
Al Jabalēn
Kirī Kēra
Ar Rua'at
Karlinq
Al 'Abbasiyya
Kortala
Delami
Abu Jibēha
Hēban
Tozio
Al Qardud
Tanqaru
Renjnom
Kodok
Fashoda
Al Qeqr
Ar Rank
Jalhak
Kaka
Mēlut
Balosh
Abayat
Aqordit
Abu Muqud
Ulu
Kurmuk
Chali Al 'Arab
Mortesoro
Bobuk
Baw
Bikorio
Qēssan
Kēli
Al JARI
Abu Shinēna
Abu Mendi
Yismala
Geyorrgis
Zege
Debre Mayo
Adet
Bitore
Agibar
Alibo
Asendabo
Kachisi
Ketema
Didessa
Dabus
Baḷas
Zingini
Guder
Nahr Al Abbai
Nahr Sitat
Nahr Rahad
Nahr Ad Dindir
Wadi Al Hamad
K. Baraka
K. Abu Habl
Abu 'Uruq
Al Safya
Eriba
Naklab
Qulbub
Anaghit
Kelamet
Aiket
Donglio
Nefasit
Barentu
Areta
Badme
Scherarq
Um Hager
Biagundi
Homera
Qoggara
Calta
Adi Remoz
Halda
Ably Adi
Adi Arakai
Mestinto
Doka
Gedabiet
Feneros
Dabat
Debark
Sekota
Zulan
Uahni
Chelga
Bubayeat
Maliha
Al Qallabat
Basunda
Rumēla
Al Hawwata
Balos
Ash Shammam
Abu Hashim
Dar 'Aqil
Abu Hujar
Karkoj
Abu Na'ama
Wad An Nayal
Jalqani
Harun
Abu Zōr
Abu Kuk
Disa
Al Barun
Al Hafaza
Qala' An Nahl
Wad Al Huri
Matana
Wad Al Haddad
Al Qawz
Jabal Moya
Saqadi
Keredo
Zurēqa
Sibeq
Al Qabasha
Abu Rukba
Al Ghabisha
Al Qaqr
Al Ḥaqq
Al Manaqil
Hai 'Abdalla
Barakat
Fakhashir
Abu Haraz
Al Ined
Al Qitena
Al Kamlin
Abu Quta
Al Maud
Ash Shajara
Karari
Um Indiraba
Qeli
Dighem
Abu Amara
Abu Jamal
Dim
Moqatta
Kicotai
Biskia
Al Qash
Nefasit
Aresa
Ad Dindir
Abu Hujar
Abu Na'ama
Wad An Nayal
Jalqani
Harun
Abu Zōr
Abu Kuk
Disa
Al Barun
Bobuk
Baw
Bikorio
Qēssan
Kēli
Kurmuk
Chali Al 'Arab
Mortesoro
Abu Muqud
Ulu
Al Qardud
Tanqaru
Renjnom
Kodok
Fashoda
Al Qeqr
Ar Rank
Jalhak
Kaka
Mēlut
Balosh
Abayat
Aqordit
Abu Muqud
Al Jari
Abu Shinēna
Ar Roseris
Dam
Al Barun
Bobuk
Baw
Bikorio
Qēssan
Kēli
Kurmuk
Chali Al 'Arab
Mortesoro
Abu Mendi
Yismala
Geyorrgis
Zege
Debre Mayo
Adet
Bitore
Agibar
Alibo
Asendabo
Kachisi
Ketema
Didessa
Dabus
Baḷas
Zingini
Guder
Nahr Al Abbai
Nahr Sitat
Nahr Rahad
Nahr Ad Dindir
Wadi Al Hamad
K. Baraka
K. Abu Habl
Abu 'Uruq
Al Safya
Eriba
Naklab
Qulbub
Anaghit
Kelamet
Aiket
Donglio
Nefasit
Barentu
Areta
Badme
Scherarq
Um Hager
Biagundi
Homera
Qoggara
Calta
Adi Remoz
Halda
Ably Adi
Adi Arakai
Mestinto
Doka
Gedabiet
Feneros
Dabat
Debark
Sekota
Zulan
Uahni
Chelga
Bubayeat
Maliha
Al Qallabat
Basunda
Rumēla
Al Hawwata
Balos
Ash Shammam
Abu Hashim
Dar 'Aqil
Abu Hujar
Karkoj


173
172
171
ETHOPIAN BORDER
KHARTOUM
49
50
51
52
WHITE NILE
BLUE NILE

EL GEZIRA

SCENE	MECHANIZED	TRADITIONAL/NONDEMARCATED
17305002	.22	---
17305003	.18	.11
17205005	.29	.01
17305006	.30	---
17305008	.22	---
17205001	---	.16
17205004	.04	.27
N=7	1.22 (.1742)	.55 (.07857)

14

BLUE NILE

SCENE	MECHANIZED	TRADITIONAL/UNDEMARCATED
17305009	---	.26
17205007	.04	---
17305103	.26	.31
17205101	---	.16
17205102	---	.08
17205104	.01	.27
17205105	---	.32
17205106	---	.38
17205107	.04	---
17205108	.17	.73
17205109	---	---
17205201	.13	.05
17205202	.03	.17
17205203	.24	.27
17205205	.39	.52
17205206	.10	.80
17205208	.02	.75
17205209	---	.71
17105201	.34	.42
17105204	.52	.16
17105207	---	.21
17105104	.60	.19
17105107	.17	.57
N=23	3.06	7.33
	(.1330)	(.3186)

KHARTOUM

SCENE	MECHANIZED	TRADITONAL/NONDEMARCATED
17304905	---	---
17304906	---	---
17304908	.16	---
17304909	---	.15
N=4	.16	.15
	(.04)	(.375)

WHITE NILE

SCENE	MECHANIZED	TRADITIONAL/NONDEMARCATED
17305004	.02	.13
17305109	---	.26
N=2	.02 (.01)	.39 (.195)

UPPER NILE

SCENE	MECHANIZED	TRADITIONAL/UNDEMARCATED
17305203	.24	---
17305206	.27	---
17305209	---	---
N=3	.51	---
	(.17)	

KASSALA PROVENCE

SCENE	MECHANIZED	TRADITIONAL/UNDEMARCATED
17204904	.06	.09
17204905	.02	---
17204906	.03	---
17204907	---	.22
17204908	.74	.27
17204909	.08	.46
17205002	---	.08
17205003	.17	---
17205005	.01	.27
17205006	---	.32
17205008	---	---
17205009	.17	.73
17205103	.24	.27
17104904	.04	---
17104905	.09	---
17104907	.43	---
17104908	.49	---
17105001	.33	---
17105002	.21	---
17105004	.26	---
17105005	.30	---
17105007	.59	.43
17105008	.44	.34
17105101	.29	.49
17105102	.60	.19
17105105	.61	.24
N=26	6.2 (.2384)	4.4 (.1692)

Actual vs Estimated Costs

Eastern Sudan Project

1. Actual Costs

a. Personnel

2 personnel full time for 17 weeks each		$ 32,995.67
1 person (technical support) for 2 weeks		2,283.08
	Sub-Total	$ 35,278.75

b. Travel

• 2 trips by Messrs. K. Haley & W. Boyd		
	Sub-Total	$ 17,749.25
• Local travel	Sub-Total	64.85
	Total Travel	$ 17,814.10

c. Miscellaneous	Sub-Total	1,403.97
d. Imagery		
Includes acquisition costs, CCT's & color composites.	Sub-Total	32,880.00
	Total Actual Costs	$ 87,376.82

2. Estimated Costs

a. Personnel	Sub-Total	29,078.53
b. Travel	Sub-Total	28,200.00
c. Supplies	Sub-Total	1,500.00
d. Imagery Costs	Sub-Total	57,500.00
	Total Estimated Costs	$116,278.53