SCIENTIFIC VISUALIZATION of MULTI-TEMPORAL REMOTELY-SENSED DATA for MONITORING DROUGHT-RELATED FAMINE CONDITIONS:

NUTRITIONAL, SOCIO-ECONOMIC & CLIMATIC VULNERABILITY in SUDAN'S GEZIRA

by

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ABSTRACT

This study addresses the design and deployment constraints and potential utility of an emerging analytical concept for planning adaptive response and mitigation of the regional impact of global climate change, within the context of a complex region in Sudan, with multiple biogenic and anthropogenic vulnerabilities.

The specific conceptualization is referred to herein as the Temporal Analysis, Reconnaissance, and Decision Integration System (TARDIS). TARDIS is conceived as a composite planning tool, incorporating virtual temporal analysis, virtual spatial analysis, change detection for archival remotely-sensed data, trend extrapolation, generation of alternative future *what-if* scenarios and integration with both quantitative and rule-based decision-support. The rationale for developing the specifications for the TARDIS proof-of-concept is the observation that decisions concerning complex phenomena, involving multiple intractable problems, deserve to be made in an information-rich environment. Moreover, it is contended that such decisions could benefit both from an historical perspective and from the luxury of a comparative visualization of possible future outcomes of past trends, current policies and putative *what-if* constructs.

The broad parameters for multi-variable factors affecting food security and the potentially significant regional impact of global climate change on Sudan's Gezira are presented. Also described are the potential contributions of the TARDIS in supporting planners and decision-makers, whose decisions might benefit from visualization of archival satellite data and from visualization of alternative future scenarios.

I am primarily concerned with a triad of issues, in the order presented, and their interaction with one another:

- FOOD SECURITY, WITH SPECIFIC REFERENCE TO THE SUDAN
- GLOBAL CLIMATE CHANGE AND ITS IMPACT ON FOOD PRODUCING REGIONS, SUCH AS SUDAN'S GEZIRA
- VISUALIZATION TECHNIQUES FOR TIME-SERIES SATELLITE DATA TO SUPPORT DECISION ANALYSIS, UNDER CONDITIONS OF ENVIRONMENTAL COMPLEXITY, TYPIFIED BY THE SUDAN CASE STUDY

Under this broad rubric, I seek to define a discrete area of concentration, namely, the articulation of design specifications for a proof-of-concept composite prototype decision support tool, incorporating scientific visualization of remotely sensed data. Although this tool potentially has generic applicability to decision-making and planning within diverse disciplines and geographic locations, the intended application, herein, is as a tool supporting decisions regarding future food security for Sudan's Gezira agricultural area, with specific reference to food crop, dhurra, *(Sorghum bicolor)* and cash crop, long staple cotton, *(Gossypium Barakatensis)* sustainability, under anticipated hotter and more arid climate conditions.

The objective of applying this tool to the Sudanese context is to facilitate long-term planning and decision-making related to food security issues in the Gezira, given the climatological threat of future increased temperature and decreased precipitation. Accordingly, the first demonstration of the TARDIS proof-of-concept will be a simulated test run (STR) of data pertinent to Sudan's Gezira. The results of this STR will be evaluated in Chapter 4, and, based upon the outcome, recommendations for regional adaptive response are offered and refinements and modifications will be suggested to improve TARDIS utility and functionality.

This research seeks to establish a role for state-of-the-science visualization of remotely-sensed data, as a tool for planning adaptive responses to impending climatic change and to food insecurity. Moreover, the study hypothesizes that informed decision-making and policy formulation can be facilitated, through an analysis of the archival satellite and meteorological data for Sudan's Gezira, combined with an assessment of selected current conditions (e.g. civil war, political instability and international isolation, insect infestation in the irrigated agricultural schemes, prevalence of diseases such as schistosomiasis, malaria and cholera), and with an analysis of alternative future *what-if* scenarios.

Potential vested constituents for such technology include various bi-lateral and multi-lateral entities with trade, aid or oversight relationships with Sudan. For purposes of this study, one such agency has been selected, namely, the Global Terrestrial Observing System (GTOS), a newly established umbrella entity within the United Nations, whose mission is "to provide policy makers, resource managers and researchers with the data they need to detect, quantify, locate and understand changes (especially reductions) in the capacity of terrestrial ecosystems to support sustainable development." Accordingly, GTOS has been identified as a potential TARDIS end-user, under the proposed auspices of the prototypical joint Food and Agricultural Organizattion (FAO)/ World Food Programme (WFP) annual Crop Survey and Nutritional Needs Assessment Mission to Sudan.

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Table of Contents

TABLES

FLOWCHARTS

INTRODUCTION:

Sudan's Gezira region (i.e. herein defined as Lat. 14° 34' 24.5" N to Lat. 13° 33' 49.94" N and Long. 34° 34' 12.56E to Long. 33° 29' 44.68"E) was selected for the study because of its large-scale dependence on both food crops and cash crops, diversity in the mode of production, availability of synoptic seasonally-matched satellite imagery, the relative abundance of rainfall data for the study area, and because of the potentially severe impact of global climate change on such semi-arid agricultural systems.

It has been estimated by Hulme (1989) that the semi-arid zone of central Sudan, wherein the study site is based, has experienced a 20 percent decline in rainfall since 1921, a contraction of its wet season by approximately three weeks, a southward displacement of its rainfall zones by 50km to 100 km, representing 25 percent of the total zonal rainfall fluctuation for the past 20,000 years, according to paleo-climatological analysis (Rognon, 1987; Hulme, 1989; Hulme and Kelly, 1993.)

A proof-of-concept is offered for a planning tool, the full model of which design would facilitate temporal analysis of archival remotely-sensed data and enable trend extrapolation for simulating alternative future scenarios, as a support for decision-makers. The specific decision-makers, for whom TARDIS support is designed, function at three levels: the international, national and regional. At the international level, the intended client or end-user is suggested to be the United Nations Food and Agriculture Organization (UN FAO) / World Food Programme (WFP) Annual Joint Crop Forecasting and Nutritional Needs Assessment Mission to Sudan, in conjunction with the newly-established (i.e. January, 1996), United Nations Global Terrestrial Observing System (GTOS), headquartered at FAO in Rome.

At the national level, the decision-maker for whom TARDIS support would be offered is the UN FAO Resident Representative in Sudan and programming staff. At the regional level, the identified end-users would be the FAO/WFP Annual/Semi-Annual Crop Forecasting and Nutritional Needs Assessment Missions to Sudan, whose number, ideally, would be augmented by a GTOS staff member or GTOS consultant, who would have access to a TARDIS configured laptop computer, throughout the mission. That individual's role would be to monitor the potential impact of global climatic changes upon the region and to assist in developing and updating an annual adaptive response plan and assess local progress in achieving viable mitigation and adaptation activities.

Recommendations for future follow-on research are offered, that would incorporate the more traditional global circulation models (GCMs) and integrated assessment models (IAMs), fusion of large volumes of *in situ* temperature and rain gauge data , *in vitro* crop temperature and CO2 threshold data, archival tabular yield data, and remotely sensed data. However, GCMs and IAMs were viewed as being less critical for the current multi-factorial study. As noted in *Climate Change and Sustainable Development: Toward Dialogue* (Cohen, Demeritt, Robinson & Rothman, 1998, p. 345), "The hegemony of GCMs has served to marginalize other, less reductionist ways of understanding global climate change…" and, "Furthermore, because of their large, often global scale, IAMs rely on a considerable degree of aggregation and abstraction. As a result, many important regional scale environmental and social processes, such as population growth and economic development, can be missed, or worse, assumed to continue on a so-called business-as-usual trajectory." (Cohen, Demeritt, Robinson & Rothman, 1998, p. 347.)

The primary objective for this study is to develop the specifications for a virtual temporal analysis and decision support tool prototype, as a development of concept for facilitating planning for adaptive regional response to mitigate the impact of anticipated climatic changes in temperature, precipitation patterns and CO_2 concentration (Harrison, Butterfield and Downing, 1995; Rosenweig & Parry, 1994), within a militarily, politically, economically, nutritionally and environmentally vulnerable region (Downing, 1991 & 1992) in the Republic of Sudan.

The design specifications are offered for the prototypical Temporal Analysis, Reconnaissance and Decision-Integration System (TARDIS). This study's additional contribution to the development of concept includes analysis of multi-temporal synoptic satellite imagery of the study area particularly, from EOSAT's Landsat Multi-Spectral Scanner (MSS) and NOAA's AVHRR. The experience of other researchers in utlizing data from these sources within the region will be taken into consideration (e.g. Choudhary, 1990; Moussa, Bedford & Smith, 1990; Marsh, Walsh, Beck & Hutchinson, 1992; van Herwaarden, 1993; Ali, 1994).

Subsequent *ex post facto* follow-on research for actual TARDIS Prototype development, documentation, component integration, data fusion, parametric sensitivity analysis, hardening, code parallelization, kerberizing for security code compliance would entail utilization of Delta Data System's (South Africa) Agricultural GIS (AGIS) software for the image analysis, ESRI's (Redlands, CA) ARC/INFO for map rendering, ERDAS (Atlanta, GA) Orthomax Professional for development of digital elevation models, ERDAS Virtual GIS, PCI's FLY! and Autometric's Edge Wings for three dimensional scientific visualisation of the study area, and Alias MAYA/Wavefront for animated sequences of alternative future scenarios.

In Chapter I, the historical background for the Sudan Case Study is presented, together with a discussion of the nutritional, socio-economic and climatic vulnerability in Sudan's Gezira. Chapter II, Adaptive Response to Climate Scenarios, addresses the potential causes and mitigating factors associated with the regional impact of climate change. The detailed description of TARDIS' intended end-users, deployment strategy, system capabilities, utility, proof-of concept prototype design specifications, follow-on development plans, relevance to the Sudan Gezira case study, flow charts and associated commentaries are presented in Chapters III and IV.

The level of detail presented for the case study region is essential to understanding the complex geopolitical arena and the biogenic and anthropogenic context in which the TARDIS would be deployed, the rationale for deploying TARDIS, its *modus operandi* in the field and its human/machine interface, the local data sources that serve as input to the various TARDIS components, the factors which contribute to and are affected by its intended output, its potential contribution to the task performance of its end-users and its overall societal benefit.

It is my intent to define the nature of these relationships as part of the discussions in Chapters III &IV, where TARDIS design and utility issues are specified. As a prelude to this discussion, however, the generic associations are categorized within the introduction, so that readers can more readily observe the connectivity of the first two chapters with the latter chapters. It should be noted that certain variables have multiple interactions with the various TARDIS modules and associated sub-tasks.

The following table summarizes the associations between the TARDIS Modules and the array of variables addressed in Chapters I & II, that will be further elucidated in Chapters III & IV:

Table 1-TARDIS USES

SETTING & CONTEXT	**ARCHIVAL VISUAL.**	**CHANGE DETECTION**	**DECISION SUPPORT**	**FUTURE SCENARIOS**
1.1 History	1.5 Remote Sensing	Landsat MSS & NOAA AVHRR	2.2.4 Drought Resistant Crops	1.6 Climate Change; Crop Forecast: *Sorghum bicolor*
1.2 Poverty & Malnutrition	ERDAS Virtual GIS	Vegetative Cover	Insect Control in Gezira	2.1.1 Global Warming; 2.1.3 Increased CO_2
1.3 Drought & Famine	DEM	MAP-X	Adaptive Response & Mitigation	Nutritional Assessment – Long Term
1.4 War & Famine	Drape Satellite Imagery	Isolate; Multi-Temporal Imagery	GTOS, FAO Res. Rep. &Missions	2.1.4EÑSO; 2.3 Limits of Semi-Arid Agriculture

The Sudan case study is a likely acid test for any new-technology planning tool. Anthropogenic factors contributing to regional vulnerability include:

- A long-standing Civil War, largely waged between the central government of President Lt. General Omar Hasan Ahmad al-Bashir, operating out of the capital city, Khartoum, and the SPLA opposition forces, operating out of Southern Sudan.
- A repressive theocratic fundamentalist government with a track record of major human rights violations.
- International political and economic isolation of Sudan, as a *patria non grata*, resulting from an array of international circumstances, chief among which include the Bashir government's support for Iraq during the Gulf War, Sudan's alledged role in providing travel visas for certain defendants in the World Trade Center bombing, Sudan's alleged collaboration with Ossama bin Laden in establishing a pharmaceutical plant in Khartoum, with potential for manufacturing chemical and/or biological warfare agents.
- Significant regional food shortages resulting from a combination of untimely food exports, refusal to acknowledge famine conditions, resistance to permitting the flow of food relief services, and insecurity associated with armed conflict.

Arguably biogenic factors include:

- Projected increases in surface temperature
- Projected decreases in precipitation
- Observed southward migration of the rain bands
- Projected increases in ambient CO_2

- Projected growth threshold limitations for major crops in the Gezira area, including long staple cotton *Gossypium Barakatensis, "dhurra" Sorghum bicolor,* pearl millet *Pennesetum typhoides* and wheat *Triticum aestivum.*

- Desertification: Recent studies by the National Drought & Desertification Unit-Khartoum together with Hunting Technical Services-Hemel Hempstead,UK (1994) and others challenge the established estimates of Harrison & Jackson in 1958 and Lamprey in 1975 that the vegetational edge of the Sahara was encroaching on Sudan at a rate of 5.5 km. per year (i.e. 90-100 km. over the seventeen year period between 1958 and 1975). No evidence of such a level of encroachment was identified in the more recent investigations; however, the role of soil conservation and reclamation, reforestation, afforestation and desert boundary management and monitoring remains a priority.

CHAPTER I: NUTRITIONAL. SOCIO-ECONOMIC AND CLIMATIC VULNERABILITY IN SUDAN'S GEZIRA

1.1. The Sudan Case Study:

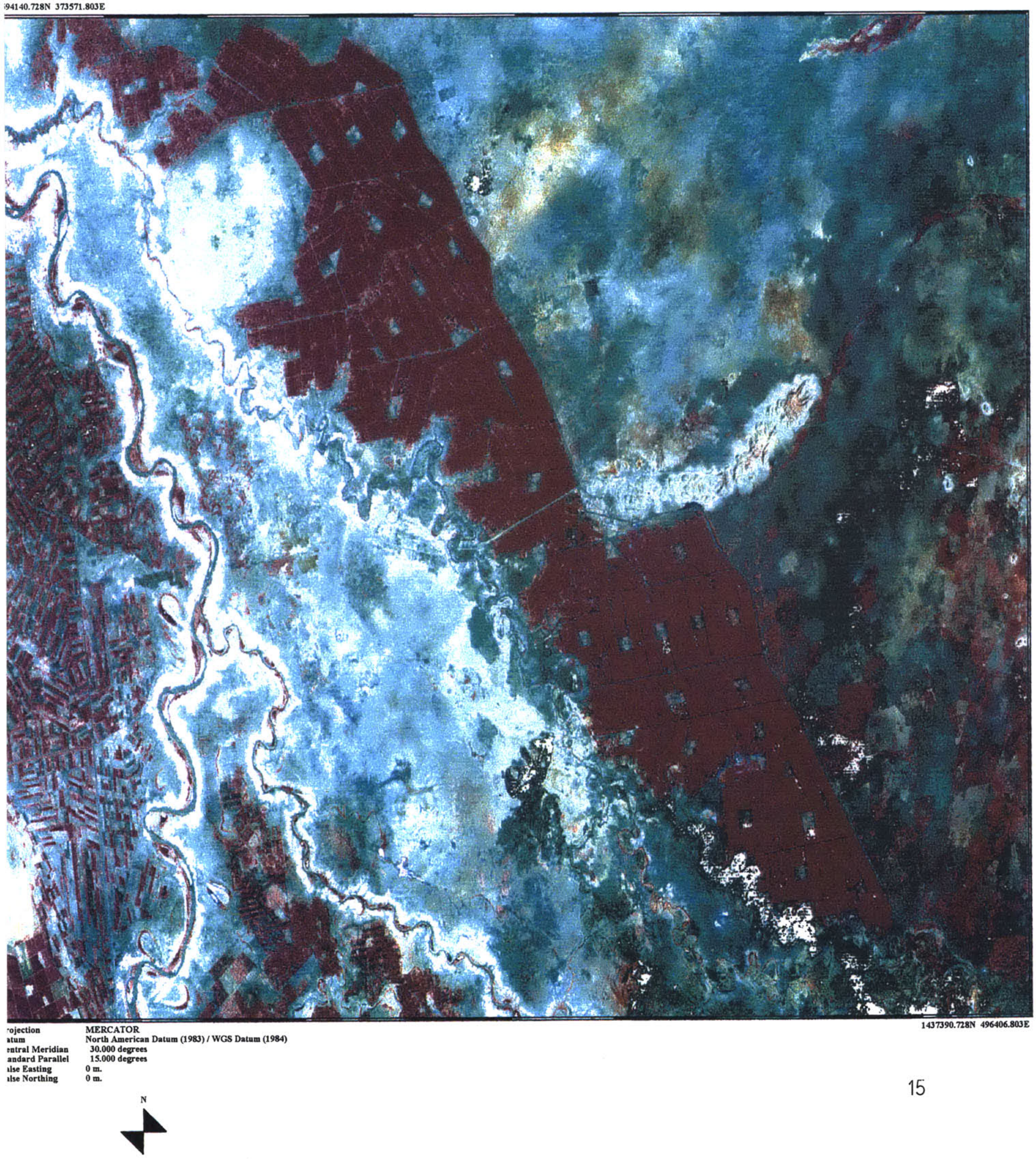
Sudan, the largest country on the African continent, covering an area of 2,505,810-sq. km., utilizes only 6% of its arable land for food production. Many factors contribute to this under-utilization, including the inadequacy of irrigation networks, seasonal labor shortages and out-migration of skilled agricultural technicians, insufficient foreign exchange for purchase of pesticides, fertilizer, mechanization, spare parts, etc.

During the seventies, there was an attempt on the part of Saudi Arabia, Kuwait and the United Arab Emirates to transform Sudan into the "Breadbasket of the Arab World". This was partially in reaction to grain embargoes imposed by the United States in response to Arab oil embargoes. Food security for the Arab world, it was felt, could best be addressed in Sudan, where the combination of a perceived stable government (albeit a military dictatorship), ample land, under-population, average rainfall significantly greater than in the Arabian peninsula, and rich soil offered a promise of long term high productivity.

Sudan's agricultural sector had been the focal point for numerous investors. According to Johnson (1980), "Already six billion dollars have been committed by Arab states to a ten year integrated basic agricultural development program in Sudan." Foreign Direct Investment (FDI) was officially non-existent under Ga'afar Nimeiry, since all foreign investment theoretically required a Sudanese joint venture partner. Several "exceptions" were allowed, however, in deference to

"Arab brotherly investment". Examples of such exceptions included the Kuwaiti Poultry Company in Khartoum and the Prince Mohammed El Faisal Scheme, also known as the Damazine Agricultural and Animal Production Company. Even during periods of documented significant malnutrition and under-nutrition in Sudan, the vast bulk of the local human staple food source, "*dhurra*" or *sorghum bicolor,* harvested from these schemes, were exported to the Middle East. There is little evidence to support the view that foreign exchange generated from these foreign sales "trickled down" to the nutritionally vulnerable population.

Gezira Scheme



In support of Sudan's economic development and putative metamorphosis into the Arabian breadbasket, several multilateral agencies were formed, including the Sudan Development Corporation (SDC) and the Arab Authority for Agricultural Investment and Development (AAAID). Yet another Arab aid organization, BADEA, was headquartered in Khartoum; but directed its largesse to Africa south of the Sahara.

Numerous factors impinged upon the implementation of these plans. First of all, several of the organizations that were established as the implementing arm of the Sudanese "green revolution" (i.e. AAAID & SDC) began to experience delays in the fulfillment of financial pledges from their Arab investors/donors. Moreover, fiscally conservative management found it safer to invest in cotton and sugar production than in grain production.

Sudan has been beset with a rapid succession of drought and regional food shortages in the 1970's, 1980's and 1990's. (Ahmad, 1988; Abdelwahab, 1990; Khattab & Mahgoub, 1987; Harbeson, 1990) The etiology of the current such crisis appears to have both anthropogenic and biogenic dimensions. The human-induced factors include the insecurity and infrastructural disruption associated with the on-going civil war, suspension of virtually all significant foreign investment projects, widespread poverty and unemployment and Sudan's international political isolation, stemming from its support of Iraq in the Gulf War and related foreign policies.

The arguably biogenic factors include evidence of a southward migration of the African rain bands, diminished precipitation in the Gezira, anticipated increase in surface temperature, and elevated levels of CO_2. Controversy with respect to the role of desertification is still unresolved; however, recent findings tend to downplay the degree of encroachment (Csaplovics, 1992; Huntington Technical Services, 1994). Hulme and Kelly (1993) point to evidence of severe desiccation of the Sahel over the past quarter century, resulting in a global increase of 50.7 million hectares in those areas designated as arid or hyperarid and a concomitant decrease in areas designated as humid, dry humid or semi-arid. Balling (1992) argues that the increase in temperature within the hyperarid areas, which has exceeded that of non-desert areas, has possibly contaminated the global mean temperature record. Until further research adequately resolves the degree to which desertification is a significant factor, prudence would dictate continued monitoring and vigilance. The combination of both sets of factors could have a significantly devastating impact on Sudan's self-sufficiency in food production capacity, with catastrophic implications for regional food security.

Tools enabling spatial analysis are well established and continue to play a key role in crop forecasting, famine early warning (Mumford & Eilerts, 1993), and precision agriculture, *inter alia*. One sub-category within this genre can be described as tools for Virtual Spatial Analysis (VSAs). Although typically still deployed more for special effects, training and promotional materials, rather than for regular analytical production, the VSA's offer end-users a bird's eye view of three dimensional satellite imagery, draped over a digital elevation model (DEM). These allow for user-selectable speed, direction and altitude for fly-over, sail-through, dive-under or roll-on, during virtual reconnaissance routines.

In order to better visualize change detection from the study area's archival satellite data record, and to facilitate decision-making among an array of potential future *what-if* scenarios, I propose to develop the specifications for an adaptation of an appropriate commercial off-the-shelf VSA, for use as a Virtual Temporal Analysis (VTA) tool. Once prototyped, the VTA, herein referred to as Temporal Analysis, Reconnaissance and Decision Integration System (TARDIS), could be used as the vehicle to assess and visualize seasonally-matched land cover changes in the Sudanese Gezira, from the Landsat Multi-Spectral Scanner (MSS) archive, and to explore the possible regional impact of global climate change, at selected future periods.

It is expected that such a tool could have utility for planners requiring more evocative visualization, for end-users seeking greater regional self-sufficiency and autonomy in the management of food security data, and for facilitating adaptive regional response to impending climate change.

The etiology of famine in Sudan defies simple explanation. While the literature might evidence disagreement with respect to the dominance of one cause over another, few would deny multi-causality. Major contributory factors certainly include the succession of severe periods of drought in 1972/73 and 1982/84, with only modest respite during the intervening period (Ibrahim, 1988; Deng, 1992; de Wall, 1989). Equally devastating and a major contributor to famine, even during periods of adequate precipitation, as been the prolonged civil war in Sudan (D'Silva, 1992; Prendergast, 1989; Allen, 1991; Deng, 1993).

Not to be dismissed is the conspiracy of silence and denial, through which the Ga'far Nimeiry government and later, the Omer Bashir government, refused to acknowledge famine conditions or to allow relief efforts to towns not controlled by central government forces and suppressed press coverage of widespread hunger (Kilongson,, 1986). This sometimes erupted into reciprocal usage of food deprivation as a weapon of war (Clark, 1987; CNI, 1986).

Another factor to be considered is the significant level of food grain exports to Saudi Arabia, Kuwait, and the Emirates at critical periods during the 1972/73 drought and the 82/84 drought, notwithstanding endemic undernutrition and localized severe malnutrition in Southern Sudan (Shepherd, 1988; Dundas and Futrell, 1986; Ross, et al., 1990; Coulter, Suliman, et al., 1988; Coulter, Omer, at al., 1988; Ali Taha, 1978; Omer, 1975; El Bushra and El Tom, 1988 and 1989). Similar exports to Uganda were recently reported in the midst of the current crisis. The "trickle down" effect of foreign exchange to the affected regions is unlikely, given the current military crisis in Sudan.

Agricultural export policy was but one among many agricultural sector policies deemed in great need of reform. Foreign investment policy in agricultural production, which required no domestic joint venture partner for "Arab brotherly investment", provided generous tax holidays and permitted bulk export of harvest. International Monetary Fund (IMF) pressure on Sudan resulted in displacement of food crops by cotton and other cash crops, skewed exchange rates, lowered producer prices, devalued local currency and removal of consumer subsidies on basic food items. Central government responses to the Southern insurgency resulted in regional inequality with respect to the allocation of inputs and thereby contributed to conditions of food insecurity (Speece, 1987; Spielman,1985; Williams and Karen, 1985; D'Silva, 1985; OICD, 1984).

Coping mechanisms of the malnourished population in resorting to "famine foods" (Salih, Nour and Harper, 1991; Ogilvy, 1981; Salih & Nour, 1992) became inadequate in the face of back-to-back drought years. Food relief efforts were hampered by a host of factors, including armed conflict, inadequate roadway infrastructure, political roadblocks, and lack of coordination (Bickersteth, 1990; Rosen, 1989; Oliver, 1991; Deng and Minear, 1992; Minear, 1991; Watkins, 1985). Even in those circumstances when access to food supplies emerged, the full nutritional benefit was denied due to endemic infections and their synergistic relationship with malnutrition (Dondero, 1985; Woodruff, et al., 1986; Godfrey and Kalache, 1989; El Samani, Willett and Ware, 1987; El Samani, Willett and Ware, 1989).

The direct solution to this recurrent famine problem, regardless of cause, is the development of a functioning system of food security. To some, the key element in food security is the *in situ* storage of grain within drought and famine prone regions, as a hedge against future shortages, cognizant of the delay inherent in food assistance from abroad (Ibrahim, 1987). To others, security should best be achieved by equitable income redistribution coupled with economic growth (Evans and Diab, 1993). Still others favor a comprehensive plan to take into account the multivariate nature of food security issues (Davies, 1987; Holcombe, 1987; Deng, 1992 Lofchie, 1982; Maxwell, 1991). The potential role of remote sensing as a contributor to African food security and early warning for drought and famine is not without its supporters (Gulaid, 1986).

Ground truthing and other collection of surface attribute data in Sudan is constrained by limitations on access to certain southern regions due to the continuation of armed conflict and government imposed travel restrictions. The USAID supported FEWS program recalled its resident data specialist and has opted not to send a replacement. Even in the capital city area, concern for security and for regular access to basic human needs has, understandably, far overshadowed concerns for data availability, accuracy or updates.

Even in the best of times, revenue availability, competing public priorities, inadequate roadway infrastructure, seasonal flooding in some areas and water scarcity in others, and a major outward migration of skilled technicians has severely limited the development and maintenance of a national or localized spatial database for natural resource monitoring and ecosystem management.

Current conditions for surface data collection for long-term monitoring purposes are exacerbated by Sudan's virtual political and economic isolation from the world community, partly resulting from human rights concerns, but primarily due to the government's support for Iraq during the Gulf War. This tactic estranged the trickle of support from the USA, Europe, Saudi Arabia, Kuwait and the Emirates. Support levels from Russia never recovered from Gen. Ga'far Nimeiry's 180 degree turn away from the then Soviet Union in the early 1980's. Russia's current economic woes and estrangement from the Islamic fundamentalist regime now in Sudan makes future support from Russia highly unlikely.

1.2. Malnutrition and Poverty in Sudan:

Scholars appear to be approaching a consensus, facilitated by the work of Amartya Sen (1981), that famine is more a function of income insufficiency than of food unavailability. This clarification of the relationship between malnutrition and poverty has implications for the formulation of the appropriate mode of intervention policies. On the one hand, the determination that food deficits are primarily implicated, would presumably prompt the appropriate officials to seek bi-lateral and/or multi-lateral food relief shipments, suspend food exports, redirect food surpluses from other regions to the food insecure region or develop a strategy that combines two or more of these responses.

On the other hand, the conclusion that income is the primary constraining factor for the nutritionally-at-risk population presumes that food resources might, in fact, be regionally available, yet unattainable, due to their prohibitive costs or to the lack of "entitlements" on the part of the nutritionally vulnerable groups. Such entitlements, as articulated by Amartya Sen (1988), could include barter rights, shares resulting from prior labor, kinship or a wide variety of commercial and non-market sector rights and associated responsibilities. Interventions based upon the entitlement assessment could include income stabilization, market pricing interventions for agricultural produce and for livestock used for grain bartering.

Locke and Ahmadi-Esfahani (1993) are compelling in using Sudanese data, supporting Sen's food entitlement theory, to "illustrate that a low or declining aggregate food supply does not necessarily imply famine and, conversely, that high or rising food supplies do not indicate the absence of a famine (Locke & Ahmadi-Esfahani, op. cit., p.363)."

The literature offers some analogs to the discussion of Sudan's interplay between hunger and poverty, including the deleterious influence on nutritional and economic status caused by currency devaluation in Rwanda (Minot, 1998), the Philippines' experience with poverty in rural areas (Balisacan, 1993), food insecurity and subsequent coping mechanisms in Mali (Lambert, 1994), and peasantization in the Middle East (Esfahani, 1986).

Most would agree with Ganzin (1985) that while food availability is a function of biogenic factors such as soil fertility, meteorology and longer term climatic issues, and pest prevalence, other anthropogenic constraints are equally crucial. These include, cultivation practices, mechanization, silo or other storage availability, market transport, pricing structures, currency inflation, debt ratio, level of political stability, nutritional awareness and labor availability. To his list, we can add widespread and extreme poverty, effective demand, access to appropriate pesticide, herbicide and fertilizer inputs, and primary health care availability for agricultural workers, especially in schistosomiasis endemic regions, such as the Gezira.

More specifically, the literature does not ignore Sudan or even the Gezira on this issue. Taha and Mirghani (1990) reported the results of their community survey in rural Gezira and reported high rates of illiteracy, poor socio-economic status, unsanitary conditions and unsafe water supplies, with asociated choleral outbreaks, and endemic malaria, schistosomiasis and diarrheal disease. These conditions were subsequent to the drought of 1983-1985. Other studies conducted in Sudan revealed undernutrition among children in rural central Sudan (Eltigani, 1994), poverty in conjunction with malnutrition during the 1988-90 famine in Darfur (Jaspers and Young, 1995) the coping mechanisms in El Fasher, Sudan (Pyle, 1992), and the degree to which the government and its local supernumeraries extracted political, economic and military benefit from creating famine conditions among the Dinka in 1985-89. This resulted in over half a million deaths, forced migration and further impoverishment in Southern Sudan (Keen, 1994).

The exacerbating dual horns of the nutritional and economic vulnerability dilemma in Sudan, namely drought and war, are discussed separately in the following two chapters; although, their combined impact is often experienced by the affected population as an excruciating singularity.

1.3. Drought and Famine in Sudan:

There is a growing consensus among nutritionists and agricultural economists that the complex etiology of famine, notwithstanding biogenic exacerbation, is primarily driven by anthropogenic phenomena. Scrimshaw (1987) observed that "despite the role of natural causes, the conclusion is inescapable that modern famines, like most of those in history, are man-made". Field (1991) echoed this assessment, "…that famine is related to poverty, that it is often triggered by climatic instability, and that it is both an instrument and tragic by-product of political conflict." Mabbs-Zeno (1987) makes it clear that the Nile River Valley region is no stranger to famine, since the first recorded famine occurred there in 4247 B.C. He further cites the research of Buchinskiy (Mabbs-Zeno, op. cit., p. 5) who determined that sixty major droughts occurred in or near Russia during the period 994 A.D. to 1954 and that only 16% of these droughts were major contributors to famine. He concludes that "Most of the recent cases where famine was associated with major aggregate declines in food availability cannot be explained on the basis of variation in natural factors."

Continuing in this vain, Gibbons (1991) entitled his article in ***Science*** quite bluntly, "Famine: Blame Policy, Not Nature." Anderson and Woodrow (1991) arrived at he same conclusion, "Famine in today's world results from human misuse of natural resources and from ill-designed human systems for producing, marketing and distributing food rather than from overall production shortages, climatic failures or fixed resource constraints." Ending on a more positive note, the same authors confidently maintain that "famine in the late twentieth century can be overcome through human actions." (Anderson & Woodrow, 1991, p. 43).

The human capability, although not yet the demonstrated human political will, to prevent famine is directed not only to those aspects of famine that are caused by humans, but to the biogenic factors, as well. Although the control of drought is beyond current human technology, some mitigation of the impact of drought can be attempted. These activities include improved water management in the irrigated sector, *hafir* (traditional water collection and storage basin) rectification, expanded bore wells and pump schemes, use of drought resistant plant varieties, and afforestation and reforestation for land stabilization and reclamation purposes.

Moreover, I have earlier in this study applied the delimiter "arguably biogenic" when referring to so-called natural occurrences impacting the study area. The justification for so doing is the well-documented human contribution to global change, including the production and proliferation of greenhouse gases. Sudan and the rest of Africa could make only minimal contributions to greenhouse gas mitigation since the level of industrial emissions and effluent, as compared with Europe, the United States and parts of Asia, have been minimal. In this instance, Africa is victimized by secondary smoke, without having benefited from the exogenous industrial prosperity. Nonetheless, some congressional leaders are insisting that Africa and the third world contribute their "fair share" to greenhouse gas mitigation. A presumably unintended consequence of an otherwise laudable environmental objective would be the maintenance of the status quo with respect to the North/South industrialization and development disparity and subsequent global continuity of distributional inequities.

Famine emerges as the result of a continuous economic, political and climatic process (Currey, 1988), rather than as a discretized event. Its role as a potentially major cause of human suffering and death is linked to the demonstrated synergistic relationship between malnutrition and infection (Scrimshaw, Taylor and Gordon, 1968). The specific associations between famine, morbidity and mortality are discussed in Young and Jaspars (1995#2), and in *Famine and Disease: Annual Conference of the Society for the Social History of Medicine* (1991). Hay (1986) expounds on the political economy of famine and links the claims of "risk vulnerable households" to their larger communities, countries and the global economy. Export prices paid for basic commodities from the developing countries of Africa are hostage to the General Agreement on Tariffs and Trade (GATT) and, in effect, if not by design, maintain and widen the gap between the primary product economies and the tertiary wealth economies.

The specific lessons learned from drought and famine in other countries may be of some relevance to the Sudan case study. Some famines are unique to the socio-political and temporal milieu in which they occur. This appears to be the case with respect to the Chinese famine of 1958-1961, resulting in over thirty million deaths (Chang and Wen, 1997), wherein communal dining and revolutionary fervor in denying the existence of food shortages were implicated in the disaster. The denial aspect, although originating from ideologically divergent sources (i.e. Mao's Cultural Revolution, Ga'afar Nimieri's military dictatorship and, subsequently, Omer el Bashir's fundamentalist theocracy) was a common thematic characteristic.

In the case of China, famine denial served to perpetuate the myth of already-attained self-sufficiency amongst the peasantry. This was directed both to the domestic audience, too dispersed, propagandized and media-deprived to be aware of the actuality, and to the international audience, to whom China was eager to tout the success of the revolution. The feigned tolerance of critique and even of opposition, as typified by the Hundred Flowers Campaign, was soon discovered to be a device to identify revisionists and subject them to Thought Reform.

Nimieri's Sudan had endured his metamorphosis from being an initially left-wing pro-Soviet military icon, reminiscent of the left wing military *coup d'etat* in Portugal, into an apparent pro-Western, ultra-right military dictator. His mode of famine denial appeared to be motivated by dual interest in thwarting the Southern Sudanese liberation movement at any human cost and in internationally characterizing the Southern Civil War as a Libyan supported terrorist movement that required foreign aid for arms and militia training, in order to suppress it.

Bashir has continued the tradition of denying famine in Sudan, also for ostensible use of food deprivation as a weapon of war and to bolster the illusion that Sudan was self sufficient in agricultural produce, despite international isolation resulting from Bashir's support for Iraq during the Gulf War. Both Nimeiry and Bashir, except for the past two years, permitted the export of food from the Sudan during periods of widespread undernutrition and regional malnutrition.

"Food deprivation as a weapon" is the terminology used here to characterize a range of activities associated with the government of Sudan's actions, including forced population relocation from agricultural areas, tacit allowance of crop destruction, confiscation of farm equipment and animals, refusal to acknowledge food deficits in the South, despite warning by international experts, export of food surpluses in the North while malnutrition was rampant in the South, and refusal to allow food shipments from donors to regions not controlled by the central government.

Countries neighboring Sudan have not been spared famine. As in the Sudan, both drought, war and local politics were implicated. Included in this group are Uganda, Ethiopia, with special reference to the Ogaden (Hogg, 1991), Eritrea and Tigray, Chad and Mali (Autier, et al., 1989), Kenya (Kennedy, 1992), Tanzania (Seavoy, 1989) and Botswana (Teklu, 1994). Sudan's own sequential famines have been analysed by Curtis, et al. (1988), de Waal, (1989), Buchanan-Smith, et al. (1991), Patel (1994), and Teklu (1994), *inter alia.* What emerges from the discussion is the centrality of political stability, humanitarian focus and economic inclusivity in famine prevention and mitigation. Sudan, lacking in all three of these elements, is less likely to withstand biogenic externalities like drought, with substantial human suffering and dislocation.

While acknowledging the primacy of politics and associated human interventions' aggravation of conditions that give rise to famine, it is important to note the effects of drought on the Sudan, irrespective of such externalities. In Torry's (pp. 93-115) account of the 1984-85 drought in South Darfur, Sudan, the far reaching nature of the disaster is unfolded. Sorghum and millet production were greatly curtailed due to insufficient rainfall, over a quarter of million people were forced to migrate to South Darfur, seed stocks for future planting were decimated, surface water resources for human and animal consumption were depleted and bore well resources were greatly strained, gum arabic (*Acacia senegal*) trees were killed resulting in a substantive decrease in cash crop revenues, and nomadic groups were forced to sell off livestock and terminate their trek due to dramatic increases in wateryard fees.

1.4. Famine Relief:

The literature on famine relief in the Sudan is replete with accusations of insouciance and/or incompetence on the part of the Sudanese government and on the part of some international donors. So overwhelming is the criticism that some of the humanitarian relief efforts could be characterized as iatrogenic, in that they are credited with unnecessarily increasing the level of displacement, mortality and morbidity among the vulnerable population in Sudan.

The specific critiques address the lack of foresight on the part of donor agencies and Sudan's government in planning the logistics of relief (Watkins, 1985), the famine "creation" and subsequent "benefits" on the part of the Sudanese government and the naivete of donors in failing to curtail such activity (Keen, 1995), the virtual collaboration between the government's ethnic cleansing of the Dinka and the Nuba from their homelands and the international donors policy of supporting relocation camps for such displaced persons (Bradbury, 1998), and the use of "sovereignty" and "consent of government" as excuses for U.N. delays and inaction in responding to humanitarian crises (Minear, 1991). Deng and Minear (1992, p. 16) assert that "the politics of regionalism and ethnicity manifests itself in the vacuum of moral responsibility implicit in the negative responses of the central government to both famines and the need for international intervention."

Donors are also challenged for being over-reliant on kill rates in determining the need for intervention and failure to make good on the level of donations pledged (Kelly and Buchanan-Smith, 1994). They are admonished to emphasize long-term social security, rather than short-term responses to emergencies (Duffield, 1990) and to broaden the base of food security, diminishing the need for aid and imports (Bickersteth, 1990). The most damning criticism is offered by de Waal (1997), who advocates the dismantling of the present day variant of humanitarian aid in Sudan, in that, in his view, it undermines local initiative and curtails more appropriate domestic resolution to crises.

Other critics reserve their vituperation for famine early warning activities (Cutler, 1987; Buchanan-Smith and Davies, 1995), prompting the assessment, "Let them eat information!" The major critique is less directed towards the systems managers of early warning systems (e.g. the USAID supported Famine Early Warning System (FEWS) and the UN FAO Global Information and Early Warning System (GIEWS)) than toward the national governments and donor agencies who fail to heed the warnings and deny acknowledgement of the crisis and delay responding to the crisis, respectively. Herman, Kumar, Arkin and Kousky (1997) describe the method for estimating rainfall for Africa in support of FEWS, utilizing cold cloud duration (CCD) as observed by the European Space Agency (ESA) METEOSAT 5, as a surrogate for *in situ* rain gauge data. Khan, Mock and Bertrand (1992) provide a detailed delineation of the composite indicators for FEWS.

1.5. War and Famine in Sudan:

April 25, 1999 marks the end of the current humanitarian cease-fire between the Government of Sudan and the Sudan People's Liberation Movement/Army (SPLM/A). Its extension beyond that date is uncertain, according to the United States Committee for Refugees (USCR) Weekly News from Sudan, dated April 22, 1999, (http://www.refugees.org/news/crisis/sudan.htm). The Inter-governmental Authority on Development (IGAD) is hosting another round of peace talks in Nairobi, Kenya, that was to start the week of April 26, 1999. The Government of Sudan failed to arrive for the talks. As of this writing, the government spokesperson insists that the talks are being delayed for undisclosed reasons, not cancelled. So far, this is just the latest in a series of, heretofore, unproductive peace initiatives, in which Nairobi has played an historic role (Chand, 1991).

The civil war in Sudan represents the longest running armed conflict within Africa. The central government cast of characters has changed from a military dictatorship to a fundamentalist theocracy; yet, governmental opposition to the demands of the Southern insurgency has remained. For its part, the SPLM/A has apparently resolved major internal divisions and has extended its reach. The objectives of the struggle have oscillated between the bipolar quest for regional autonomy and the struggle for national liberation of Sudan, under a democratic secular government. The antecedent objective, namely national liberation under scientific socialism, has given way to post cold war political realities and to the pragmatic urge to develop economic and political support from more conservative Western and Middle Eastern opponents of the Khartoum government, which had allied itself with Iraq during the Gulf War.

The origins of the struggle have their roots in the disruptive manipulations of the colonial British condominium government and in the all-too-familiar tale of ethnic, religious, cultural and linguistic differentiation and concomitant exploitation of the Southern periphery by the Northern oligarchy. The discovery of oil in the South, the most impoverished and underdeveloped region of the country, and the decision by the central government to build a pipeline to siphon the resources to the North for refinement, export and concentration of revenues, was the proximate impetus for galvanization of the Southern rebellion.

This present study, as its title suggests, is overtly concentrating on the scientific visualization of multi-temporal remotely sensed data for monitoring

drought-related famine conditions in Sudan. That task is, of itself, a non-trivial undertaking. It remains for subsequent investigations to define the parameters for replicating such a feat for the significantly more complex phenomenon of **conflict-related famine**. Nonetheless, it is not possible to engage in any meaningful discussion of famine conditions and related sequellae in Sudan, without taking such a major externality into consideration. Indeed, although each mode of famine may theoretically exist independently of the other, the singularity of their manifestation to the vulnerable population in Sudan dramatizes the need for differentiation, as may be required for the design of appropriately engineered preventative measures, adaptive responses and humanitarian interventions.

The use of food as a weapon of war in Sudan has been effectively chronicled (Macrae and Zwi, 1992). The use of government-backed militias for large-scale cattle rustling (Mawson, 1991), for human enslavement (Keen, 1991; Hutchinson, 1991) and regional depopulation (Allen, 1991; Hamid, 1992) has prompted international outcries against the el Bashir regime for human rights violations. Chand (1987) provides some insight into coup d'etat that presaged the current crisis as well as the prelude to the current peace initiatives in Nairobi (Chand, 1990).

1.6. Application of Remote Sensing to Support Food Security in Africa, and Sudan in Particular:

The Sudan scenario dramatizes the need for remotely sensed data, since conditions within the country impinge so heavily upon surface data collection. Certain *in situ* data requirements are, nonetheless, ineluctable. These requirements include, for example, anthropometric measurements for nutritional status assessment and agricultural health status for crop forecasting .

Satellite data can be viewed as an equal opportunity technology, in that less developed countries like Sudan enjoy the same frequency of overpasses and same level of resolution as do the highly industrialized countries. Even without its own satellite development and launch capability, a country, like Sudan, can still cost effectively download satellite data, perform analyses and incorporate the data into a multi-layered spatial database, all within a PC environment.

Table 2 -SATELLITE SENSOR IMAGERY AND SPECIFICATIONS

RES.	NAME	AGENCY	TYPE	# CHAN	SWATH	Re-Visit	Launch
7.6km	ARTEMIS	UNFAO	AVHRR NDVI	1	Africa Hamar-Aitoff	10 days*	Composite For 15 yrs.
4 km.	AVHRR	NOAA	GAC	5	Hemispheric	daily	1974
1.15km	SPOT-4	CNES-France	VI Multi	4	60 km.	26 days	March, 1998
1.13km	OrbView	US & Orbimage	SeaWIFS	8	2,800km	1 day	Aug., 1997
1.1 km.	AVHRR	NOAA 12,14&K	LAC HRPT	5	Continental	daily	1974
1km.	ERS-1&2	ESA	ASTR Radar/Multi	4	99 km.	35 days	1991
600m.	RESURS 01-3	RUSSIA	THERMAL	1	600 km.	21 days	1994
189m.	IRS-1C	INDIA	WiFS Multi - Spectral	2	810km	24-25 days	1995
170m.	RESURS0 1-3	RUSSIA	Multi-Spectral	4	600km.	21 days	1994
120m. 30m	Landsat-5	US EOSAT	THERMAL TM	1 7	185km.	16 days	1972
82m.	MSS-Landsat	USA NOAA	Multi-Spectral	4	185 km.	16 days	1972
72 .5m	IRS-1A, 1-B	INDIA	LISS-I Multi-Spectral	4	148 km.	24/25 days	1988
70.8m	IRS-1C	INDIA	LISS-III Multi SWIR	1	148km.	24/25 days	1995
70	IRS-1D	INDIA	LISS-III Multi SWIR	1	148km	24/25 days	8/1997
30	EO 1	USA	ALI Multi-Spectral	9		16 days	12/15/99
30	EO1	USA	Hyperion Hyper-Spectral	220	7. 5 km x 100 km	16 days	12/15/99
20	SPOT-1-4	CNES-FRANCE	HRV	4	60 km.	26 days	1986
18	JERS-1	Japan NASDA	SAR Radar L-	1	75 km.	44 days	2/1992
10	SPOT-1-4	CNES-FRANCE	HRV Panchromatic	1	60 km.	26 days	1986
4	QuickBird	Earth Watch	Multi-Spectral	4	40km 20	5 days	1999 4thQ
1	QuickBird	EarthWatch	Panchromatic	1	22 km.	5 days	1999

Sources: NASA, EOSAT, NASDA, UN FAO, NOAA, Brown U. Planetary Sci., GLAVCOSMOS, JPL

The full utility of the remotely sensed data for long-term monitoring purposes, however, is constrained by factors such as the need for periodic correlation with surface realities, (notwithstanding the present difficult conditions), cost, required levels of resolution, availability of cloud-free and haze-free imagery, continued availability of trained personnel, and both the duration and integrity of the archival data sets.

Ground truth continues to be obtained, albeit unevenly, throughout the current long-term conflict in Sudan, with notable exceptions, particularly in Southern Sudan . Increasingly, Sudanese nationals have participated directly in these activities. The UN FAO's Forest Resource Assessment Project is a case in point. Both Sudanese geographers and researchers from Lund University in Sweden conducted extensive ground truthing to verify classifications based upon Landsat TM data.

As conditions continue to destabilize, however, it may no longer be possible to conduct on-site inspections. A possible alternative to be explored is the use of higher resolution satellite data, such as the Indian Government's IRS, SPOT, TM, and even MSS, as a form of "surrogate ground truth" for courser imagery, such as that from NOAA AVHRR Global Area Coverage (GAC) and Local Area Coverage (LAC). Systems for analysis and visualization of remotely sensed data are only as good as the quality of the data itself. Periodic ground truth, whether actual or virtual is essential for verifying and improving the accuracy of image classifications.

Although pricing for Landsat TM skyrocketed after the privatization of the Landsat program, price reductions for MSS have made it affordable for large area coverage. At 80 meters resolution, it offers significantly higher resolution than AVHRR, yet lacks the continental coverage and coherent twelve year, decadal, virtually cloud free, AVHRR data archive, now available for Africa and for global long-term monitoring.

On the one hand, monitoring a vast land area like Sudan necessitates the availability of wide area coverage. On the other hand, the small size agricultural holdings (with notable exceptions such as the Gezira, Managil, Rahad and the Prince Mohammed El Faisal Schemes) requires higher resolution satellite data. In either circumstance, the data must be available and affordable. MSS data is in this study as an adjunct to the AVHRR data set for the archival visualization component of TARDIS.

The study site selected in Sudan is Wad Medani, the focal point for the mechanized farming activity, dating prior to the British/Egyptian Condominium government of Sudan. Satellite imagery at hierarchically registered or synoptic resolution were prepared, so as to qualify and quantify the relative benefit of utilizing higher resolution than the prevailing 7.6 km., 4 km. or even 1 km. resolution AVHRR twelve year decadal data set for future projections, such as crop forecasting or climate change scenario impact assessment on a regional scale.

Let me hasten to insist that I am not recommending the abandonment of the AVHRR data set at any of its three levels of resolution. The frequency of coverage, band distribution, inexpensive accessibility, twenty year long archive, "industry standard" format and widespread installed user sites clearly argue for its continuance. Landsat, in particular the Multispectral Scanner, long spurned in deference to its higher resolution sibling TM, emerged as a useful adjunct to the established data set, until its abandonment. JERS-1, the NASDA (Japanese Space Agency) offered promise, with combined multi-spectral and radar bands. Unfortunately, JERS-1 lost its on-board storage capability early on and is now dysfunctional. Its archive, however, still has utility for major projects, such as the Global Rainforest Mapping Project and the Global Boreal Forest Mapping Project.

The MSS archive's current disadvantage, an incomplete archive and need for comparatively greater storage capacity, may be offset by its now lowered access cost, the age of its archive for change detection (now over twenty years), less expensive and longer-life storage media and, at 80 meters resolution, a significantly more powerful tool for studying local heterogenous areas.

The imagery presented in the accompanying map was archived, corrected, and geoencoded at JPL. Temporal overlays were registered and developed at Delta Data Systems in Picayune, Mississippi, using AGIS (Agricultural GIS) and MAP-X software, image analysis and GIS packages that support both raster and vector data. ERDAS IMAGINE Virtual GIS was used for image fly through visualizations on Sun SPARCstations on a Gateway Pentium II.

Normalized Difference Vegetation Index (NDVI) data for Sudan during August and September of 1994 (FEWS Bulletin, August 30 & Sept. 10, 1994- SH-9) indicates attainment of three times the average level of vegetation, as compared with both the comparable period during 1993 and the 1982-90 average NDVI.

Given this minimization of biogenic contributory factors to famine during the 1993/94 and the 98/99 periods and the persistence of regional food insecurity in Sudan, it would appear that further research in needed to ascertain the influence of anthropogenic factors on food security. Suspect factors include extreme poverty among large segments of the populations, the effective demand for available food resources, agricultural investment and export policies (Lofchie, '82), level, focus and degree of coordination of foreign support, efficiency of production capacities, adequacy of distribution channels and the impact of armed conflict.

It is clear from FAO's own ARTEMIS slides that both 5 km. Meteosat data and 7.6 km. ARTEMIS NDVI data show significant differentiation among the decadal (ten day composite) periods within a single month. Hence, MSS would be no substitute for this data, given the irregularity of the Landsat archive. However, the comparison between seasonally matched drought periods, one in 1972, ten years before the launch of AVHRR, and the other in 1987 after significant agricultural investment accompanied by deforestation and adjacent grassland burning dramatically displays the potential utility of MSS as an adjunct to the current AVHRR data archive for selected interest areas (Arets, 1984; Pickup & Chewings, 1991; Babiker, 1988; Alchrona, 1986; Hutchinson, 1991; Mohammed, 1986).

A comparison of the same seasonally matched irrigated area near Wad Medani as observed by AVHRR GAC, by AVHRR LAC (Fig. 8) vividly illustrates the superior utility of the higher resolution MSS data for applications requiring greater detail and for local area planning. A listing of the satellite imagery acquired for this study site is appended.

1.7. Anticipated Regional Impact of Climate Change in Sudan:

Unlike the relatively benign prognosis with respect to climate change impact in the Northern Hemisphere (Buol, Sanchez ,Weed and Kimble, 1990), Sudan and most of the Third World face a potentially daunting challenge, if global change scenarios prove reasonably accurate. Europe, Canada, the United States and Russia, Greenland, and Iceland, on the other hand, although confronted with some major loss in botanical and animal biodiversity, may, nevertheless, experience an increased growing season, expanded areas of agricultural productivity, forest extension, temperate weather, and increased tourism. Sudan is likely to experience, for its part, decreased rainfall, increased temperature and diminished capacity for agricultural production.

Rognon (1987) in "Aridification and Abrupt Climatic Events on the Sharan Northern and Southern Margins, 20,000 Y BP to Present," cites paleoclimatological evidence to demonstrate that two earlier abrupt periods of aridity occurred within the past 20,000 years along the southern Saharan boundary, according to the pluviometric record, and notes the fast acceleration of the longterm tendency toward repeated droughts lasting five to fifteen years each (i.e. 1910-16; 1944-48; 1968-84). "The Sahel," according to Rognon, "for instance, seems to be a region where the risks of climate catastrophes are very heavy because the rapidity of these abrupt events often exceed the capacity for adjustment of natural system parameters." Other historical abrupt climate changes within the region are noted, as applied to the Nile River flood levels for the period 622 A.D. to 1470 by Fraedrich, at al. (1996).

Xue (1997) concludes that degradation of the land surface can have significant impact on the Sahelian regional climate. "It increases the surface air temperature and reduces precipitation, runoff and soil moisture over the Sahel region..." (op. cit., p. 1483). He faults human degradation of vegetative cover as a contributing factor to the climate anomalies of the past forty years. There is not unanimity, however, in ascribing to man the responsibility for climatic perturbations within the region. Ahlcrona (1988), while acknowledging some man-made qualitative deterioration of vegetation in central Sudan, concludes that climatic factors rather than human intervention are primarily responsible for reduction in the land's biological productivity.

The potential immanence of abrupt, and possibly catastrophic, climate change within the region, in my judgement, warrants the construction and/or adaptation of new tools to assess regional-scale impact, so that appropriate adaptive responses can be formulated and implemented at the regional level. Global change assessments are necessary but insufficient for developing regional scale responses, given the heterogeneity of human settlement patterns, landforms, ecosystem distributions, political and economic complexity and microclimate phenomena.

This is but one attempt to address the perceived need for regional specificity for a unique region that, from a food security perspective, is worthy of designation as a long term ecological research (LTER) site. Obviously, the risk of error is compounded exponentially when one attempts to prognosticate decadally rather than just annually, let alone for nearly a half century into the future. It is not hubris that motivates one to be offer such grandiose time horizons. Rather, it is the fate of the planner to identify hazards to the biosphere as dimly as they can be perceived in the distance and, thereby, offer constituents as much advanced warning and lead time as possible to mount an adequate defensive perimeter and pre-emptive strike force.

The literature evidences a well-defined linkage between malnutrition and poverty and associated entitlements (Amartya Sen, 1988). There is potential merit in extending Sen's entitlement approach to climatic entitlements, as well. Clearly the poor are far more vulnerable to the vicissitudes of climatic perturbations than are those who have the economic freedom to choose less vulnerable habitat and to recuperate more readily after natural disasters. The degree to which this issue requires further study is evidenced by the very few articles that address linkages between global climate change and food insecurity and between global climate change and income insecurity (Ribot, Magalhaes & Panagides, 1998; Watts, 1987; Wang'ati, 1998).

An important discussion of the existing dichotomy, and subsequent need for dialogue between the Climate Change scientific community and the advocates of Sustainable Development, was recently articulated in a paper by Stewart Cohen, David Demeritt, John Robinson ad Dale Rothman *in Global Environmental Change* (1998).

As a follow-up to Newby (1993), Cohen, et al. argue that the Inter-governmental Panel on Climate Change (IPCC), deals "with the human or social dimensions of global change by attaching some social science analysis, virtually as an appendage, to a body of work that defines the problem in terms of natural science approaches. From this perspective, the social science contribution (the humanities are rarely invoked) is to analyze the ‘driving forces’, ‘impacts’, and ‘adaptive capabilities’ relative to the biophysical phenomenon of global climate change, largely divorced from their social context.”

It is hypothesized, herein, that there is a closer interrelation among the three identified dimensions of vulnerability than is generally acknowledged within traditional analyses of either climate change, sustainable development, poverty or food insecurity, particularly for semi-arid agricultural zones, such as Sudan’s Gezira.

It is argued that an integrative regional planning approach is essential to address the multi-dimentionality of vulnerability within the study region. Moreover, the potential utility of a long-term regional-scale crop forecast and nutritional assessment approach to planning regional adaptive response is described.

Chapter II: ADAPTIVE RESPONSE TO CLIMATE SCENARIOS:

This chapter is divided into four sub-sections. The first addresses the manifestations of climate change and its potential impact on the study area, including warming, rainfall and greenhouse gasses. The second sub-section addresses possible responses to these global events at the regional level, including improvements in cultivation techniques, management of inputs (i.e. water, fertilizers, pesticides and crop varieties). The third and fourth sub-sections address the major constraints faced by semi-arid agriculture and the role of the United Nations agencies, with special reference to the Global Terrestrial Observing System (GTOS).

2.1. POTENTIAL CAUSES OF REGIONAL CLIMATE IMPACT

The etiology of climate change is complex and extends beyond the proximate causation. The following discussion confines itself to the immediate manifestations of climate change as is presented to the Gezira, rather than to the ultimate causes that are rooted in a matrix of paleometeorology, emissions and effluent from industrial processes, indiscriminate utilization of propellant-enhanced consumer products, ocean/atmosphere circulation phenomena, volcanic eruptions, ozone layer depletion and release of previously sequestered carbon and associated greenhouse gases, accruing from deforestation, methane discharges from wetlands and animal herds, slash and burn agriculture, and ignition of fossil fuels. Accordingly, the following four segments cover global warming, diminished precipitation associated with the southward migration of monsoon rain bands, the buildup of ambient $CO_{2,}$ and the role of EÑSO.

2.1.1. Global Warming

In discussing the triad of contributory factors (i.e. temperature, rainfall and greenhouse gases) as individuated phenomena, it is acknowledged that their interdependent relationships may become obscured. Hulme and Kelly (1993) address this issue in "Exploring the Links Between Desertification and Climate Change," **Environment**, Vol. 35, No. 6, July/August, 1993. In the subsection entitled "The Future of the Sahel," the authors composite the results of seven Global Circulation Model (GCM) experiments, resulting in "an estimate of mean annual rainfall that may accompany each 1° C rise in global-mean temperature induced by greenhouse-gas forcing." (Hulme and Kelly, p. 43). They found that precipitation actually would increase in most areas, particularly in the Northern Hemisphere mid-to-high latitudes. Rainfall decreases for North Africa, the Mediterranean and the Sahel. Infact, for parts of the Sahel, the decrease in precipitation is estimated to be more than 6% for every 1° C of global mean warming. Since estimates by the Intergovernmental Panel on Climate Change (IPCC) for temperature increase for the region range from 1° C to 5° C, that would equate to a decrease in rainfall in the range of 6% to 30% by 2100 A.D (Hulme and Kelly, op. cit.).

2.1.2. Precipitation Bands Southward Migration

Sudan, North Africa and West Asia have endured abrupt changes in rainfall patterns in the distant past, according to Gasse and Van Campo (1994), paleoclimatologists who report on post-glacial climate events. Hulme (1993) makes it clear that such events are not entirely natural occurrences, since the escalation in the pace of rainband southward migration coincides with the past two hundred years, i.e. the industrial revolution onwards, in contrast with the previously slow migration over the previous 20,000 years.

Yamamoto (1978) reinforces the realization that Sudan is not alone in this impact, but experiences impacts in conjunction with the entire Asian, Australian and East African extended meteorological region. As stated earlier, in this study, however, increased temperature, CO_2 and aridity is viewed by some in Canada, Northern Europe, Russia, the USA, Greenland and Iceland as a potential benefit to northern latitude agriculture, forestry and tourism; however, at the probable high cost of reductions in botanical and animal biodiversity. Sudan's further aridification and warming pose serious challenges for agriculturists and policy makers.

2.1.3. Increased CO_2

Africa's emergence from being a continental net sink for carbon to that of a net source of carbon, is linked by Branchu, Faure, Ambrosi, van Zinderen Bakker and Faure-Denard (1993) to a combination of biogenic factors (i.e. aridification of the Sahara Desert) and anthropogenic factors (e.g. agricultural practices and deforestation and denudation of natural vegetation). While increased ambient CO_2 may under some circumstances serve as a "fertilizer" for plants, which tend to utilize excess CO_2 for additional foliation, studies at the Mississippi State University and the University of Arizona indicate that although additional foliation does occur, with CO_2 enrichment, the concomitant reduction in moisture and temperature elevation (both accompanying events under global change scenarios) does not result in additional fructification. Instead, the new foliage dries out and falls off, merely becoming additional detritus.

2.1.4. El Niño Southern Oscillation (EÑSO)

Unganai (1996), of the Drought Monitoring Centre in Belvedere, Harare, Zimbabwe, in his discussion of the 'Historic and Future Climate Change in Zimbabwe," raises the issue that EÑSO, itself, may not be immune to climate change and that the current state of scientific knowledge leave one uncertain as to whether or not EÑSO's strength, duration and/or periodicity could be affected by climate change. He recommends further research and development of coupled ocean/atmosphere circulation models, in order to elucidate the concatenation of the relationship between EÑSO and the associated elements of global change, i.e. warming, precipitation and greenhouse gas forcing. It is conceivable that a phenomenon associated with anomalously high sea surface temperatures (SST) might behave differently under conditions wherein the SST is routinely higher due to exogenous global warming trends.

2.2. POTENTIAL MITIGATION OF REGIONAL CLIMATE IMPACT

In adaptively responding to the threat of a hotter, drier Gezira, in addition to the array of other natural and man-made problems faced by the region, one can only hope that serendipitous benefits, such as moisture and temperature survival thresholds being reached by the insect pest population, will occur before being reached by the food crops. Such hope appears to be in vain; however, based upon the resilience shown by crop pests during previous periods of drought in Sudan.

More proactive measures may be warranted to safeguard food security within the region. Several categories of such measures (i.e. improved cultivation techniques, water management strategies, fertilizer and pesticide strategies and drought resistant crops are discussed in the following sections.

2.2.1. Improved Cultivation Techniques

There are yet technological advances that have not been introduced into the Gezira; that may yet delay or totally forestall the need for agricultural relocation to the South and subsequent mass migration, with accompanying nutritional vulnerability, political and economic dislocation. Sharif Elmusa, for example, in his book entitled, A Harvest of Technology: The Super-Green Revolution in the Jordan Valley, (1994), cites the successes as well as the social costs of the implementation of drip irrigation equipment and "plasticulture," in Jordan.

This technique utilizes plastic sheeting as protective covering and greenhouse construction, dramatically increasing yield, in this case, of fruits and vegetables for export. Elmusa's caveats with respect to the heightened regional income disparities associated with this agricultural scheme can be taken as a blueprint for avoidance of the negative social effects, while still benefiting from the emerging technology.

Terra Corporation's (South Africa) recently acquired subsidiary Delta Data Systems (Picayune, Mississippi) has developed the Agricultural Geographic Information System (AGIS) and the VISION System, components of a Precision Agriculture Array that, in combination with satellite data and a Global Positioning System (GPS) can titrate the exact combination of seed, moisture, fertilizer, pesticide, nematocide, herbicide and other inputs in accordance with past productivity data, soil type, slope, aspect, elevation, biogenic pest control, interstitial cropping, and other objectives, in order to maximize yield. The centrally planned, contiguous Gezira area, with its wealth of historical cropping data is ideally positioned to benefit from such technological advances.

The emphasis on continued sorghum production for future scenarios is based upon several assumptions, (a) having significantly displaced cotton within the Gezira, it would be difficult to revert to a system of inedible export cash crop production, given the level and frequency of food insecurity episodes, (b) despite earlier findings that Gezira has a comparative disadvantage in sorghum production (Laki, 1992), the expectation is that while this may hold for sorghum export, the primary use for the near-term will be for domestic consumption, ideally moving toward self-sufficiency.

Other schemes in Gedaref, Damazin, Dilling, Kadugli, and Radhad may in future assume a greater export role. (c) Based on a twenty year *in situ* (Nebraska) study by Yamoah, Clegg and Francis (1997) *Sorghum bicolor* performed well under a wide variety of drought, nitrogen fertilization and both pre-seasonal and seasonal wetness/dryness scenarios, and particularly so when rotated with soybean. If fact, with soybean rotation, nitrogen fertilization becomes obviated, thereby reducing production costs. The study thresholds did not, however, approach the degree of drought and temperature conditions associated with anticipated regional climate change in central Sudan.

2.2.2. Management of Fertilizers and Pesticides

Nitrogen and Phosphorus are the two fertilizers that are applied with *Sorghum bicolor*, when fertilizers are used at all. In some smaller scale rainfed production units, fertilization is not practiced, due to cost considerations. Even in the Gezira, the UN FAO Crop Forecasting Missions found variations in the degree of application, based on availability, cost and/or labor considerations. Certain soils, such as those that have a feldspar component in the parent material, are considered to be sufficient in potassium (Yamoah, et al., 1997). When sorghum is rotated with certain legumes (e.g. soybeans and, potentially, the Sudanese and Egyptian favorite, *Ful Masri*), nitrogen fertilization becomes unnecessary (Yamoah, op. cit.). In the absence of crop rotation, nitrogen serves to significantly increase yield.

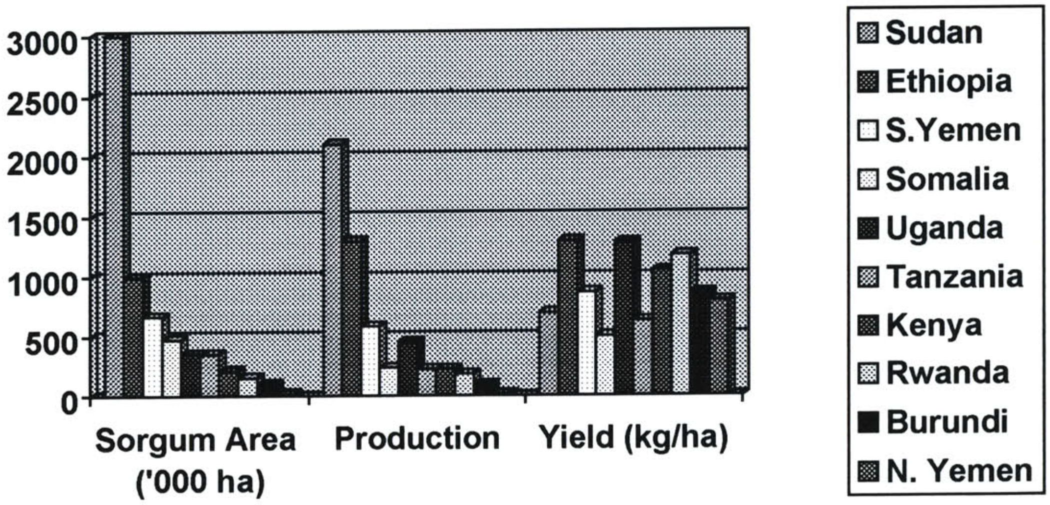
The Gezira's sorghum crop (*Sorghum bicolor* L. Moench.) faces its share of pests from many quarters, including pests that attack the panicle (i.e. grain head), namely the sorghum midge *Stenodiplosis (=Contarinia) sorghicola* Coquillett (*Diptera: Cecidomyiidae*) (Kausalya, Nwanze, Reddy & Nwilene, 1997), plant foliage, such as the desert locust (*Schistocerca gregaria* Forskål) and grasshoppers (*Orthoptera: Acrididae*) (Stonehouse, et al, 1997), and plant stem borers (*Busseola fusca* Fuller*)* (Nwanze, 1984) and plant root fungi, such as *Fusarium oxysporum* and *Macrophomina phaseolina*, which can thrive in hot and arid conditions (Hillocks, et al., 1996 #1). Witch weed varieties, which compete for soil nutrients, sunlight and water resources, particularly *Striga hermonthica* (Carsky, Singh & Ndikawa), and rust infections caused by *Puccinia purpurea* Cooke (Karunakar, Pande and Thakur) also, take their toll.

In a paper presented in the International Sorghum Entomology Workshop, Reddy and Omolo (1984) describe a wide range of pests afflicting sorghum in the field and in storage within Burundi, Ethiopia, Kenya, Rwanda, Somalia, Tanzania, Uganda, People's Democratic Republic of Yemen, the Yemen Arab Republic and Sudan. Moreover, they cite data on production and yields. Reviewing the data on Sudan, it is obvious that while Sudan dominates in the area planted with Sorghum (3,000,000 hectares in 1983) followed by 1,000,000 hectares in Ethiopia and 2, 322,000 hectares for the remaining 8 East African countries combined, its sorghum production for 1983 was only 2,100,000 m.t.

This represents a grain yield of only 700 kg/ha, one of the lowest yields within the region, only barely surpassing Tanzania and Somalia.

Sorghum yields in Ethiopia and Uganda at 1330 kg/ha and 1286 kg/ha, respectively, for 1983 were almost double that in Sudan.

Table 3 -Sorghum Production by Country



(Sources: Reddy & Omolo, 1984; FAO (1983)

The Following Listing Summarizes The Categories Of Pests Affecting *Sorghum Bicolor* In Sudan:

Weeds:

- *Striga hermonthica*
- *Striga gesnerioides*
- *Commelina forskalaei*
- *Cenchrus biflorus*
- *Cyperus rotundus*
- *Digitaria spp.*
- *Pennisetum spp.* wild ***'shibra'** millet*

Soil-Borne Diseases:

- *Pythium spp.*
- *Macrophomina phaseolina*

Root and Lower Stalk Eaters:

- Termites*: (Isoptera:Macrotermes; Microtermes; Odontotermes; Amitermes; Psammotermes; Trinervitermes; Hodotermes)*
- Beetles*: (Heteronychus arator)*
- Plant Bug: *(Homoptera: Hilda patruellis)*

Leaf/Shoot Eaters:

- Locusts: *(Schistocerca gregaria); (Locusta migratoria)*

- Grasshoppers: *(Acrotylus patruelis); (Chrotogonus hemipterus); (Homorocoryphus nitidulus); (Gastrimargus africanus)*
- Aphids: *(Melanaphis sacchari); (Rhopalosiphum maidis)*
- Armyworms: *(Spoptera Exigua); (Spodeptera Exempta)*

Shoot/Stem Borers:

- Stem borers *(Busseola fusca); (Chilio partellus)*
- Shoot Fly *(Atherigona soccata)*

Panicle Eaters:

- Sorghum Midge *(Stenodiplosis (= Contarinia) sorgicola* Coquillett) **(***Diptera: Cecidomyiidae***)**
- Head Bugs *(Agnonoscelis versicolor); (Dysdercus superstitiosus)*
- Head caterpillar *(Heliothis armigera)*

Post-Harvest Storage Pests:

- Nile Rat *(Arvicanthus Niloticus)*
- *Rhyzopertha dominica*
- *Sitotroga castaneum*
- *Tribolium castaneum*
- *Tribolium confusum*

(Sources: Hillocks, et al.1996 #1; Reddy & Omolo, 1985)

Other food crops like pearl millet (*Pennisetum typhoides*) (Hillocks, et al., 1996 #1) and cash crops such as long staple cotton *(Gossypium Barakatensis)* are subject to some of the same pests as those that afflict sorghum, as well as more specialized species.

In the case of commercial cotton in the Sudan, which was initiated in 1867, there is a complex strategy for integrated cotton pest control in Sudan, developed by El Tigani, El Amin and Ahmed (1991) which is flow-charted in the Appendix. Other control measures have been described for grasshoppers (Stonehouse, et al,, 1997), deploying chemical pesticides, kerosene, fire and smoke, hand catching, eggpod digging, trenches and beating techniques. Kooyman, et al. (1997) report on the application of *Metarhizium flavoviride* , a "biopesticide version of a naturally occurring entomopathogenic fungus" for controlling locusts and grasshoppers. Similarly, Delgado, et al. (1997) describe both laboratory and field testing of the fungus, *Beauveria bassiana* (Balsamo) Vuillemin, GHA & BF, as a biogenic control mechanism for locusts and grasshoppers in Africa. Hillocks, et al. (1996 #2) offer, in their discussion, a comprehensive array of strategies including the use of pheromones, predator species, antibiotics, herbicides, baiting, insecticides, fungicides, nematicides, interstitial cropping, crop rotation and a variety of cultural practices.

2.2.3. Drought-Resistant Crops

For Southern Africa, the literature describes potential introduction of more drought resistant crops, such as cassava *(Manihot esculenta)* in anticipation of the warmer and drier conditions foretold by the General Circulation Models (GCMs) and increased ambient Carbon dioxide (Kamukondiwa, 1996; Rosenzweig & Parry, 1994). For the Sudan, the options are more limited. The Gezira already has a hot and semi-arid climate of the type that may be descending upon Zimbabwe in

2050 A.D. The crops currently planted and harvested within the Gezira are already drought-resistant and are being eyed for potential cultivation in more Southern latitudes, based upon projected diminution of precipitation and increased temperature. There are certainly hybridized variants that may withstand the new climatological order; however, these frequently require additional research, insect resistance, more expensive inputs (e.g. irrigation, fertilizers, pesticides and the improved seed itself). War-ravaged and diplomatically-isolated Sudan is hardly positioned to optimize agricultural practices and green revolutionary strategies for the near term.

The Revised Sorghum Descriptors (1984), published in Rome by the International Board for Plant Genetic Resources (IBPGR) and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), lists 19 Sorghum "race" variants and 28 'group names", not counting "Anomalous" and "Other" categories or breeders' pedigree/cultivar names. *Sorghum bicolor* is the general designation for the Sorghum variety commonly cultivated in Sudan's Gezira.

2.3. THE LIMITS OF SEMI-ARID AGRICULTURE

Whether or not Sudan is able to achieve a peaceful and equitable settlement to the current civil war in the near future, recognizes and accepts the potentially dramatic impact of climate change, establishes adaptive response as a national priority and succeeds in attracting external funding sufficient to implement a reasonable plan, despite competing fiscal priorities, it is conceivable that the severity of the climatic impact, particularly in combination with cyclical drought and El Niño Southern Oscillation (EÑSO) events in the Indian Ocean and its Red

Sea tributary, could force the southward relocation of the major food production areas. Unlike most countries in Africa, such an event for Sudan, while catastrophic, could still be accomplished within the present day borders of Sudan, given its equatorial tropical climate in the South. It remains to be seen, however, whether or not a peace accord can be accomplished without partitioning the country.

Moreover, the tentative partitioning plans from the opposing sides draw markedly divergent separation lines. Omir el Bashir, for example, includes the Southern oil fields in the Northern half of the country, an interpretation unlikely to achieve peaceful consensus. Hence, near-term viable solutions to both the military crisis and the climatic crisis seem quite difficult to achieve.

Yet, it must be admitted that the limits of man's endeavors, as may appear to us in the light of today's technology, may be vastly transformed by technological innovations and breakthroughs as well as political and economic events that may emerge within the time frame of this long-term planning exercise. We are anticipating climatic changes that may occur over the next fifty to one hundred years, assuming continuity of the trajectory of past and current trends. Exogenous or unanticipated biogenic and/or anthropogenic factors could either alter the severity, or lack thereof, for these climate events.

Alternatively, human capacity to respond to the crisis could be dramatically enhanced or substantively diminished, as a result of those same or another set of future technological and/or political externalities. These realizations should not be interpreted as a recipe for paralysis or stoic indifference. Rather, one is, perforce, committed to developing the best possible array of strategies in the service of humanity and of the biosphere, albeit with the requisite humility that comes from recognizing that the integration of archival databases, satellite imagery, trend extrapolation, decision support and future scenario generation neither equate to prescience or omniscience.

2.4. UNITED NATIONS ROLE IN ADAPTIVE RESPONSE: THE GLOBAL TERRESTRIAL OBSERVING SYSTEM (GTOS)

Certain U.N. agencies have played and continue to play formidable roles in addressing famine relief and human displacement caused by drought, war and both natural and economic catastrophes in Africa and in compiling databases in support of their activities. These include the World Food Program (WFP), the United Nations High Commission on Refugees (UNHCR) and the United Nations Office of Emergency Operations in Africa (UNOEOA).

Still others provide significant support services to populations at risk, such as the United Nations Childrens Fund (UNICEF), coordinate the flow of U.N. involvement with the host countries, namely the United Nations Development Program (UNDP), develop training and employment strategies for coping with the aftermath of famine and drought, particularly the U.N. International Labor Organization (ILO) or provide support for implementing primary health care programs (i.e. the World Health Organization (WHO)). So as to facilitate its planning for integrating spatial database development and satellite data into its array of structured programs, the WHO sponsored an international conference at the Louisiana State University on the contributions of Remote Sensing to Epidemiology and Parasitology.

An early U.N. entrant into the application of remotely sensed data and GIS to environmental monitoring in Africa, and elsewhere in the third world is the Global Resource Information Database (GRID). Established in 1985, GRID is the spatial database product of the United Nations Environmental Program (UNEP). Earlier in GRID's history, NASA's Stennis Space Center was involved in user interface development, modeling, and updating. GRID incorporates satellite data with aerial photos and attribute data derived from ground surveillance. UNEP's collaborators on the GRID project include the World Meteorological Organization (WMO), the World Health Organization (WHO), the United Nations Educational Scientific and Cultural Organization (UNESCO) and UN FAO. (UNEP, 1987).

The United Nations Food and Agriculture Organization (UN FAO) Remote Sensing Centre in Rome, established the Africa Real Time Environmental Monitoring Information System (ARTEMIS) in 1988 (Hielkema and Snijders, 1993). Data from ARTEMIS supports the FAO's Global Information and Early Warning System (GIEWS) and the Desert Locust Plague Prevention Programme. Communication with end-user nodes for ARTEMIS digital data products is achieved via the Direct Information Access Network for Africa (DIANA). Cooperators with FAO at various stages of the ARTEMIS data collection, manipulation and distribution process include NASA's Goddard Space Flight Center, the National Aerospace Laboratory of the Netherlands, the University of Reading in England and the European Space Agency. (Hielkema and Snijders, 1993).

As a result of the success of ARTEMIS, as a tool for environmental monitoring in Africa, the FAO is now in the process of planning its expansion into a global monitoring and spatial database system, with proposed iterations in Asia and in South America. The prototype for Asia, the Operational Low-Cost Integrated Vital Information Access (OLIVIA) has found initial encouragement from the State Science and Technology Commission of the Government of China. Other FAO spatial databases of relevance to Africa, include the digital Eco-Floristic Zone Map of Africa (Sharma, 1988), the newly digitized African Soils Map, and the digital vegetation Map of Africa (Lavenu, 1987).

ANDREX, the database developed by the World Bank, contains over three hundred variables for each of the countries supported by the Bank's mandate. In addition to the expected array of economic and trade variables, ANDREX includes multi-temporal data on social variables like infant mortality, food consumption, etc. Accordingly, this database would represent a unique and extremely valuable source of attribute data to link with the remotely sensed data. Unfortunately, the data is aggregated at the country level and the constituent regional subsets are not available on the system.

The contributions of the United States Geological Survey (USGS) in archiving, processing and distributing AVHRR imagery for use by the USAID FEWS program and Landsat Thematic Mapper (TM) archival data for the UN FAO Forest Resource Assessment 1990 Project for Sudan and for other Sahelian countries should be acknowledged. More recently, the USGS manages the web-based African Data Dissemination Service (ADDS: See:

http://edcintl.cr.usgs.gov/adds/data.html). ADDS offers full year downloads of AVHRR NDVI for the African Continent, representing cloud-free merged imagery every ten days or three per month, equalling 36 “dekads” per annum. Also available through ADDS are tabular statistics on agricultural production, rainfall estimates and an array of digital feature maps, which are searchable by geographical region, including Sudan data sets.

US AID’s FEWS project (See: http://www.fews.org/imagery/imagery.html) also offers regional climate forecasts, satellite imagery for Africa and associated commentaries, updated every ten days, rainfall data and the monitoring of El Niño and La Niña. The Fews Project, previously managed by Tulane University’s School of Public Health and Tropical Medicine, is currently managed by ARD, Inc. of Arlington, VA. (info@fews.org). NOAA's role in managing the AVHRR satellite system and its historic role in developing the Landsat system, both crucial to this discussion, should also be acknowledged.

Moreover, several U.S. agencies are engaged in forest, rangeland and agricultural land cover classification and crop monitoring activities in Africa, utilizing remote sensing technologies. These include the Environmental Protection Agency (EPA), US AID, USGS, NOAA and the USDA Foreign Agricultural Service (FAS).

Other efforts, because of their inter-agency coalition structure, offer promise of a new era of resource pooling and multi-disciplinary cooperation in addressing the complexity of resource management and environmental monitoring in Africa. These include the African Inventory and Comprehensive Observation of

Vegetation/Land Cover and Environmental Resources (AFRICOVER), a primary effort of the UN FAO, with consultation support from the USDA Forest Service, among others.

AFRICOVER's objectives are "to produce a vegetation cover/land cover map, digital databases and a geographic reference at scales of 1:250,000/1:200,000 and 1:1,000,000, for the entire African continent, with some specific areas and a few small countries (below 30,000 square km.) at 1:100,000, based mainly on data captured by remote sensing," with GIS manipulation. (Lund, 1994).

Another inter-agency activity, more global in nature, but directly related to the issues raised herein concerning Africa, is the EOSDIS Version 0, Global Land 1km AVHRR Data Set. This activity represents a coalition of agencies (i.e. the U.S. Dept. of the Interior's U.S. Geological Survey, the U.S. Commerce Dept.'s National Oceanic and Atmospheric Administration (NOAA), NASA, the European Space Agency and the IGBP). It seeks to achieve global daily coverage of 1 km AVHRR/HRPT (High Resolution Picture Transmission) LAC data for an eighteen month period, beginning April 1, 1992, as a precursor to the Earth Observation System (EOS) MODIS. As of the project start date, central Africa, including the entirety of Sudan is covered by HRPT receiving stations, together with northern South America, most of Europe and parts of Asia and the former Soviet Union.

A number of joint congressional hearings were carried out under the aegis of the House of Representatives (One Hundredth Congress) Select Committee on Hunger, the Subcommittee on Africa and the Committee on Foreign Affairs, with specific reference to "Response to Relief Efforts in Sudan, Ethiopia, Angola and

Mozambique", (U.S. House of Representatives, 1988). On the Senate side, in hearings before the United States Senate, Subcommittee on African Affairs, 101st Congress, entitled, **War and Famine in Sudan,** (U.S. Senate, 1989).

Several organizations within the USDA are also involved in environmental surveillance programs for Africa. These include the Foreign Agricultural Service (FAS), which assigns consultants to African agricultural ministries to assist with a wide array of activities, including crop forecasting, input management (e.g. pesticides, fertilizers, irrigation and mechanization) and agricultural research. Other USDA resources include the FAS Foreign Crop Assessment Division (FCCAD) database (Hutchinson, 1991), which maintains a country-specific database of agricultural production statistics, for each major crop. In the case of Sudan, these included dhurra (*Sorghum bicolor*), pearl millet *(Pennisetum typhoides)*, wheat (*Triticum aestivum*) and cotton (*Gossypium Barakatensis*).

The USDA Forest Service, in cooperation with the USGS, USAID and the Government of Sudan, were technical contributors to development of the Sudan Reforestation and Anti-desertification Project (SRAAD). The project's objectives included a resource inventory component, utilizing satellite imagery, and a resource rehabilitation component (Lund, El Deen, Allison and Jasumback, 1990). USDA and NOAA also cooperate on the Joint Agricultural Weather Facility (JAWF).

CHAPTER III: TARDIS DEPLOYMENT & CAPABILITY ISSUES:

In the previous chapter, we introduced the framework for a hypothetical case study, based upon actual data from the study area, wherein the interdisciplinary United Nations (UN) Food and Agriculture Organization (FAO)/ World Food Program (WFP) Assessment Mission to Sudan, as part of its preparation in Rome for the annual Crop Forecasting and Nutritional Needs Assessment function, opts to enlarge the array of expertise on the Team for the Year 2000 visitation, based upon credible reports that the region is potentially undergoing accelerated climatic perturbations, with possibly grave implications for agricultural sustainability and food security.

Moreover, the World Health Organization (WHO) Resident Representative in conjunction with the Sudan's Ministry of Health, have issued a joint advisory that anomalously high incidence of malaria (*Plasmodium falciparum*), cholera (*Vibrio cholerae*) and schistosomiasis (*Schistosoma haematobium and S. mansoni*) has apparently occasioned significant agricultural labor shortages within the Gezira-Managil Irrigation Scheme. Accordingly, the Mission for the upcoming season will be augmented by representatives from the WHO and from a relatively new UN agency, the Global Terrestrial Observing System (GTOS). To assist them in what purports to be a complex set of tasks, the team members have been provided with a prototype laptop-based planning and decision support tool, dubbed the Temporal Analysis, Reconnaissance and Decision Integration System (TARDIS).

In order to assure the appropriateness of the technology for the designated functions and context and its utility to the UN Mission Team, the following meta-objectives should ideally guide the systems development and deployment:

- The technology is relevant to the problems and needs faced by the population-at-risk
- The cost of the technology is within reach of the intended end-users
- The level of technical sophistication required of the operators is commensurate with the skills of the primary end-users and is ultimately suited for technology transfer to locally available manpower
- The necessary learning curve for staff training is of a reasonable duration
- The hardware, software, data and satellite imagery required to operate the system is potentially available and maintainable
- The funding is potentially in place to sustain such an enterprise over a long term period

With respect to the direct applicability of these guiding principles for TARDIS, the relevance of the tool to the problems described in the case study region, affecting the population at risk, is believed to be on target, inasmuch as the tool is specifically designed with the case study immediately in mind, as the sole initial proof-of-concept application. The costs associated with TARDIS deployment are three tiered, international, national and regional, since the particular array of software packages, computational facilities and display devices represent gradations in size, capability and cost, with the most expensive and fully featured parallelized configuration based in Rome, the moderately priced work station-based at the FAO Resident Representative's headquarters in Sudan and the inexpensive PC-based version to be deployed with the FAO/WFP/WHO/GTOS Expert Missions' Crop Forecasting & Nutritional Needs Assessment periodic visitation to Sudan and to Southern Sudan..

There is a learning curve for skill acquisition that, it is proposed, could be addressed through a one to two day TARDIS training program based at FAO/GTOS offices in Rome, both for the FAO/GTOS on-site staff , as well as for international consultants prior to their assignments within the host country. The length of the training (one to two days) would depend upon the prior computational/visualization background of the specific mission experts.

3.1. INTENDED END-USERS REGIONAL, NATIONAL AND INTERNATIONAL:

For the Sudan Case Study, I have identified three levels of likely deployment (i.e. multi-lateral/international, national and regional), each of which must be tailored to fit the prevailing conditions and special constraints imposed by each level. The first level is that of the multi-lateral/international agencies who have purview over foreign assistance to the key sectors associated with food security, environmental protection and climatic adaptation (e.g. UN FAO, WFP, UNICEF, UNHCR, WHO, UNEP, IMF, WORLD BANK, etc.). This is, clearly, too unwieldy a group to consider accomodating within the confines of one host country or one case study.

Fortunately, several of the entities identified above, along with others, have collaborated to form an umbrella agency of United Nations, whose explicit *raison d'être* is to monitor the impact of global climate change on regional land masses in the third world, and to develop strategies for facilitating adaptive response and mitigation of such impacts on the human population, on agriculture, forests, rangeland, inland waterways and associated plant and animal ecosystems. This relatively new UN agency is the Global Terrestrial Observing System (GTOS). This agency has counterparts devoted to observing the oceans, hydrology, etc

At the National level in Sudan, one would be hard pressed to identify a regime since the time of the Mahdhi, which demonstrated a primary commitment to the development and wellbeing of the Sudanese people, both in the North and the South. This would certainly include the British-Egyptian Condominium Government, the dictatorship of Ga'afar Nimeiri and the current theocratic fundamentalist rule of Omer el Bashir. Inasmuch as the country is in the throes of a protracted civil war, prudence dictates the logical locus for TARDIS deployment at the national level would be with the offices of the Resident Representative of the UN FAO in Khartoum. Should the system be determined to be reliable after extensive beta-testing, potential dissemination to other FAO Missions would be considered, with the ultimate objective of technology transfer to host country Ministries of Agriculture. To assist the FAO Resident Representative (Res Rep) in Khartoum in on-going technical management of the facilities, consideration will be given to contracting thesse functions to an appropriate NGO/PVO.

At some point, the FAO Res Rep might consider collaborative utilization with his/her counterparts at the other UN agency headquarters in Sudan, such as the United Nations Development Program (UNDP), United Nations Children's Fund (UNICEF), the World Health Organization (WHO) or the World Bank. This would serve to enrich the comprehensiveness of the database availasble for multi-sectoral planning. Similar shared databases might at length be established with bi-lateral aid agencies of UN member states, which have offices in Khartoum, such as the British Overseas Development Agency (ODA), the German Aid Mission *Gesselschaft für Technische Zussamenarbeit* (GTZ), the French Aid Mission (SARDEC) or, when reinstated in Sudan, the U.S. Agency for International Development (AID) and the Arab Authority for Agricultural Investment and Development (AAAID). For far too long, such databases have been consideered proprietary and competitively safeguarded, to the detriment of inter-agency collaboration and coordinative services to the developing countries. This is now rapidly changing, as agencies, such as the FAO, are posting their data sets on the World Wide Web.

After successful debugging, hardening, documentation and besta testing, it is conceivable that a TARDIS unit configuration in the form of a PC Pentium II based with real-time AVHRR and Meteosat receiving stations (available to applicants from developing countries from the University of Reading, UK, funded by the ODA), could be extended as a form of technology transfer to appropriate host country agencies, such as the Sudan Gezira Board in Barakat, the University of Wad Medani, the Blue Nile Health Project, or the Agricultural Research Station (ARS) in Wad Medani.

The most propitious immediate deployment, however, would appear to be the UN FAO/WFP annual missions to Sudan and to Southern Sudan. The mission team currently has responsibility for annual crop forecasting combined with nutritional needs assessments for the population. The mission team could possibly be augmented by a staff member or consultant, designated by GTOS, with access, through TARDIS, to archival tabular and imagery data, change detection, future scenario generation and decision support, the potential contributions could conceivably extend to support on behalf of the regular mission in addition to supporting longer term forecasts and assessments, taking changing climatic conditions into consideration.

3.2. POTENTIAL CONTRIBUTIONS AND UTILITY:

Pioneering software packages that make significant contributions to underscoring the utility of remotely sensed data for food security in Africa included IDA_VIEW, commissioned by Dr. William Bertrand of Tulane University's School of Public Health & Tropical Medicine, under its initial Famine Early Warning System (FEWS) Project contract with the United States Agency for International Development (US AID), and developed by Eric Pfirman, and the Global Information Management and Monitoring System (GIMMS) developed by J. Compton Tucker, Steve Price and Chris Justice at NASA's Goddard Space Flight Center. An expanded version of that concept was later designed for the FAO's Africa Real Time Emergency Management Information System (ARTEMIS) and for the FAO's Global Information and Early Warning System (GIEWS) (Marsh, Hutchinson, Pfirman, Des Rosiers and Van Der Harten, 1994). These systems represented a welcomed major structural departure from the mainframe databases maintained by several multi-lateral agencies, with field data aggregated at the national level, thereby precluding regional-scale analyses.

The need for even greater functionality at the field level, including GIS and scientific visualization capabilities, was recognized early on as being potentially beneficial (ten Velden and van Lingen, 1990). Related technological developments included facilitation of the management of scientific information in support of environmental reseach (Stafford, Brunt and Michener, 1994) and for monitoring soil moisture (Heimovaara and Bouten, 1990), of great significanse to agricultural sustainability under conditions of increasing aridification.

The ultimate beneficiaries of TARDIS are planned to be the Gezira tenant farmers. By having an equipped TARDIS facility, potentially wedded with Precision Agriculture technology (e.g. Terra Corporation's Precision in Agriculture System with mounted GPS), in the Gezira and Managil Extension, whether at the Board Office itself in Barakat, University of Wad Medani, ARS, or at a local NGO/PVO office, the Gezira farmers can witness changes over time within their fields visually, without the burden of computer statistical readouts. They can see the extent to which increases or decreases in fertilizer, pesticides and other inputs contributed or failed to contribute to crop yield. They can also view expected changes in rainfall and temperature and, thereby, arrive at conclusions with respect to appropriate responses to climatic perturbations.

This represents an opportunity for potential regional empowerment at the grass roots level, and self-sufficiency with respect to remotely sensed data and analytical capacity. Replication in other regions in Western and Southern Sudan, after hostility cessation and stabilization, could yield comparable benefits. This assessment is supported by the findings of Hunting Technical Services (1994) "In the mid 1980's there were valid technical reasons for centralizing the processing of NOAA data for Africa, this also served the objectives of FAO. However, as we approach the mid 1990's the technical impediments to the local processing of NOAA imagery 'in country' have now largely been overcome." (Hunting Technical Services, op. cit.)

Post-war Sudan, with the national installation, could increase its accuracy with respect to anticipated crop yield and thereby be better positioned to negotiate with the IMF and other multi-lateral and bi-lateral partners. It could better anticipate food shortages in regions-at-risk and initiate anticipatory relief, effectively utilizing TARDIS in support of FEWS. For the long term, a national strategy for adapting and mitigating the effects of climate change can be developed and facilitated.

The Gezira is best positioned for adaptive response as the largest single planned agricultural scheme within Africa. The pre-existing network of irrigation canals, roadways, market access, history of utilizing drought-resistant strains, and pre-war control mechanisms for infectious diseases (e.g. *schitosoma mansoni*) best position the Gezira, with all its problems, as the most-likely-to-succeed among large scale agricultural schemes in semi-arid Africa. This assessment is contingent, of course, on a felicitous resolution of the current conflict.

At the International level, GTOS will have another planning tool available to support its global mission and to supply country-specific or even region-specific data to countries and regions that lack their own TARDIS installations.

CHAPTER IV: DESIGN and DEVELOPMENT ISSUES:

Chapter IV presents the history, rationale and component nodes of the TARDIS system, itself, describes each of the TARDIS modules and places the system within the context of the initially designated target end-users.

4.1 TARDIS DESIGN SPECIFICATIONS AND FLOWCHART: FORESIGHT WITH THE BENEFIT OF HINDSIGHT:

The preliminary concept for TARDIS was first articulated in an interview I gave to Cathy L. Willis, editor of the **Naval Meteorological & Oceanography Command News** (Vol. 17, No. 2, pp. 8-10), published in February/March, 1997 issue, under the title, "NAVOCEANO's Scientific Visualization Center: Creating a Virtual Environment for DoD," while I was serving as a Physical Scientist with the Naval Oceanographic Office (NAVOCEANO), under an Intergovernmental Personnel Agreement (IPA), between the Navy and Dillard University (See Appendix). The concept grew from an observation that critical antecedent events did not appear to be taken into consideration by decision-makers in a wide variety of settings. It was not immediately apparent whether this was the case due to inaccessibility or complexity of the data, insufficient time to access such data, ignorance of history or insouciance on the part of the individual decision-maker, or loss of institutional memory in the case of group decisions.

In certain instances, the "official histories" may be inaccurate or biased, as they may be written under the auspices of the dominant social or political group. This would certainly be the case for the study region in Sudan, where wartime propaganda masquerades as official history. It would also be the case for various minority groups who have yet to exert their own historical voice with sufficient fervor against the backdrop of post-colonial or post-modern mainstream historical scholarship. Johnson (1975) in his critique of multi-lateral and bi-lateral policies towards Africa, quotes W.E.B. DuBois on this point, to the effect that until the lions have their own historians, the tales will continue to glorify the hunters.

A related observation to the phenomenon of decision-making, devoid of historical context, is that decision-makers, again in multiple settings, appear to blithely make decisions which impact the future without a real sense of what ramifications their decisions will have or even whether or not such decisions were consistent with the realization of their intended objectives.

These dual observations eventually emerged into a conviction that hindsight or at least a narrowly focused historical perspective on the task at hand was crucial to making informed decisions. Furthermore, an understanding of the future consequences of one's decisions would also be important in that, armed with such foresight, one might thereby attempt to avoid negative consequences and embrace positive consequences, through the framing and implementation of decisions most likely to achieve the desired results and eschew unintended outcomes, as much as possible.

I soon discovered that arriving at such convictions was a far simpler task than designing systems in order to facilitate informed decision-making. The initial constraint was the straightforward realization that the traditional modes of communicating past events, through books, journal articles, computer printouts, annual reports or even through griots, the African historical storytellers, would be too daunting a task for decision-makers who are frequently required to render their services under conditions of stress, immediate hazard, and limited time constraints.

One possible solution which presented itself, at least for landscape scale decisions involving the recent past, was the use of remotely sensed satellite data. The qualifiers were necessary because the multi-spectral sensor record only extends back for approximately the past twenty years and even then in relatively course resolution, by today's standards.

This potential solution to the historical archive aspect of the problem had several immediately apparent difficulties. First of all, many decisions were rooted in events that occurred long before the meager satellite record. Secondly, there were expenses to be incurred for the satellite imagery itself, the software needed to analyze it and the trained personnel required to operate it. Thirdly, the existing software packages for data exploration were primarily structured for spatial analysis, rather than for temporal analysis.

An even more complex set of constraints faced the potential exploration of future scenarios. While some decision-makers might be unaware of important historical realities concerning the context of their decision task (e.g. the geomorphology of the region, demographic changes, and meteorological perturbations), at least there is somewhere some historical record in some format, whether manual or digital. This is not the case for future scenarios. By definition, these events have not yet occurred and, therefore, any "records" must perforce be in a putative mode (e.g. extrapolation of past and current trends; yet unrealized strategic plans, goals and objectives; fictional representations).

Hence, the relevance of satellite data for the future scenarios seemed initially unproductive. Galison's (1997) celebration of the contributions of imagery to the history of physics, as an adjunct to traditional numerical counter devices, in his **Image and Logic,** gave ample examples of how visualization had revolutionized the field by making mundane tabulations both evocative and accessible to multidisciplinary analysis and disparate audiences.

Inspired by this logic of the image, it seemed plausible that if it were possible to "daisy-chain" commercial-off the-shelf (COTS) software and value-added enhancements, with an appropriate graphical user interface (GUI), and access to a global virtual data warehouse, it might yet be possible to offer decision-makers and planners the tools needed to make complex multiple criteria decisions and recommendations in an information-rich environment, while still retaining some semblance of simplicity, cost effectiveness and verisimilitude.

To this end, the major components of the TARDIS prototype's design specifications are addressed in the following sub-sections (i.e. scientific visualization of the archival data, change detection, future scenario generation and decision support, along with the design parameters for the GUI and a commentary on the system flowcharts).

The principal components of and prerequisites for TARDIS would ideally include the following:

- Geo-referenced, corrected, rectified, seasonally-matched satellite imagery for, at a minimum, T_1 and T_2, with optional iterations through T_n.
- Digital Elevation Model (DEM), Digital Line Graph (DLG), GPS Elevation Coordinates, or alternative terrain model
- Virtual Spatial Analysis Software (e.g. ERDAS IMAGINE's Virtual GIS, PCI's FLY!, Autometrics EDGE)
- Hardware suitable to run the above software (e.g. SUN Ultra 60 SparcStation, IBM RISC, or SGI Onyx for the ERDAS product, SGI Onyx or Sun Ultra 60 or 450 for Autometric's EDGE and Pentium II for the PCI product).
- Display Options: (CAVE, Immersidesk, Powerwall, Crystal Eyes, or, at minimum, large high resolution color graphics monitor or digital video projector.
- Inter-layer transitioning and sequencing both for the archival data and for the future scenarios.
- Virtual Time Travel Vehicle selection (e.g. H.G. Wells' Time Machine, Dr. Who's Tardis, Back to the Future's DeLorean, Star Trek's Enterprise)
- Spatial Analysis Capability, including Change Detection, Within Each Temporal Data Layer, and mobility within each data layer.
- Attribute Data Handling Protocols, to include heterogeneity of attributes among temporal data layers, so as to accommodate phenomena present during one time period but not in another.
- Future Scenario Generation: End-User flexibility should be safeguarded, so as to accommodate user choice for Global Circulation Models (GCMs), Global Environmental Mathematical Models (GEMMs - such as Vladimir Krapivin, Bui ta Long, et al.), Integrated Assessment Models (IAMs), Regional Impact

Models (RIMs -e.g. Butterfield, Harrison & Downing) or Simple Trend Extrapolations (STEs).

- Decision Integration (Ideally, supporting both quantitative approaches and rule-based approaches)

Beyond articulating the configuration of TARDIS, there are some fundamental questions that ideally should be addressed in the course of the study, namely:

How does visualization of the past assist the planning process?

How does visualization of alternative futures assist the planning process?

How is the transition made from past to present to future scenarios, not only technically, but, from the planners' psychological perspective? Is there a basis upon which one simultaneously makes a temporal leap and a normative leap, from what simply "existed" in the past to what "ought" to exist in the future? Feigning objectivity and innocence, one might argue that the end-user makes the decision from an array of possible futures. In reality, one must acknowledge that the framing of the future array of choices may be partially dictated by default settings, which can truncate outliers, thereby depriving the end-user from initially considering choices that are predetermined, for example, to be too radical or too ultra-conservative.

Also to be addressed is the question as to why this particular planning tool is an appropriate match for the Sudan Gezira data. Are we simply superimposing a new technology on age-old problems in a cavalier manner? On the other hand, are we unfairly dooming a potentially useful planning tool by choosing to beta test it with an overly complex case study, that could well be the undoing of any technological tool candidate?

4.1.1. Scientific Visualization of Archival Data:

In his book, "Image and Logic," Peter Galison (1997), the Mallinckrodt Professor of the History of Science and of Physics at Harvard, elucidates the dichotomy between research based on imagery and that based upon numerical counting devices and reports on his 1985 interview with Louis Leprince-Ringuet, the noted cosmic ray researcher:

> " 'I always wanted to see things – I am a painter. One never knew what was going on with the counters. I always loved photography – since I was eight or nine years old. I always loved to have tracks.' Images presented a fullness, a completed form of knowledge about the world—no gaps, no processes hidden behind the discrete data points provided by counters. More than just an aesthetic, his commitment to images was a system of belief; like many of his colleagues in pictures, Leprince-Ringuet himself suggested the existence of a new kind of particle based on a handful of cloud chamber photographs."
> (Galison, 1997, p. 433.)

It might be argued that scientific visualization represents an interstice between the logicians' tradition and the imagery tradition, in that it combines the ability to quantitatively measure objects and events and tabulate results, as well as, to portray both processes and results in three or four dimensional coloured and textured splendour. The evocative nature of visual representations of reality or of virtual reality of times passed, times yet to come and times phantasmagorical, is difficult to deny in this age of hypermedia. It is only logical that an attempt be made to provide decision-makers and planners with tools that transcend coded numerical print outs, particularly when decisions are carried out within a complex milieu, with multiple variables and at high stakes for errors in judgement, or, as is commonplace today, rendered by decision-makers unschooled in the art of quickly and accurately deciphering abstruse quantitative representations.

As with any interstitial phenomenon, however, carving out a niche betwixt already established entities is a monumental task, requiring aggressive positioning. Virtual time travel associated with the archival data can be simulated through user selectable blackouts, transition momentum sequences, morphing or instantaneous arrival.

Once within any temporal layer, one would have the same mobility options as would be the case with any of the virtual spatial analysis packages and, concomitantly, the user would have access to the usual array of spatial analysis routines (e.g. classification, principal component analysis, maximum likelihood, nearest neighbor, feature extraction, histogramming, etc.). When exiting from one "time zone" to another, one automatically "arrives" at the same latitude/longitude or universal transverse mercator (UTM) that one's vehicle occupied when "departing" from the previous time zone, whether travelling forward or backward in time.

TERRA's Agricultural Geographic Information System (AGIS) software will be utilized to catalog inter-layer change detection. Vegetation and surface water changes would be the default, given the nature of this investigation;

however, end-users could alter the features identified for change detection, with C++ or JAVA programming languages.

4.1.2. Change Detection:

Consistent with the goal of developing a support tool that makes minimal demands on the end-user for specific hardware and software purchases and is supportive of the a wide array of packages that might be on hand, TARDIS is conceived as a plug and play modular system that end-users may elect to use either *in toto* or eclectically, based upon the perceived need of the project at hand, the available ancillary software packages and the sophistication of the systems operative.

To this end, Users may elect to deploy any major methodology available to them for change detection. The result would be transmitted to the receptor TARDIS module and while the particular change detection software and method would be readily apparent to the end-user, it would be transparent to TARDIS. Lest this level of liberality be misunderstood, one would be required to have some capability for specialized change detection already on hand, opt to perform the change detection optically/manually, or select from a menu of available methods embedded within TARDIS

Among the array of potential change detection options inherent to TARDIS would be the set articulated by J. F. Mas (1999), in "Monitoring Land Cover Changes: A Comparison of Change Detection Techniques," published in the International Journal of Remote Sensing, Vol. 20, No. 1, 1999, pp. 139-152. These include image differencing, vegetation index differencing, selective principal components analysis, direct multi-date classification, post-classification analysis and a hybridized image enhancement/post-classification analysis. Should the user/operator elect to select from among these options, macro-enhanced calculations would provide the results in the form of a difference image, histogram and/or tabular representation, as requested.

Mas (1999, op. cit.) establishes a typology for change detection techniques, dividing them into (a) Image enhancement (b) multi-date data classification and (c) comparison of two independent land cover classifications. He then offers the following descriptions for the change detection methods identified:

Image Differencing- georeferenced and co-registered images acquired on different dates are subtracted. The change between T_1 and T_2 is symbolized by a "difference image".

Vegetation Index Imaging- A vegetation index is calculated for two or more different images of the same area. This might be the apparent standard, the Normalized Difference Vegetation Index (NDVI), the Modified Soil Adjusted Vegetation Index (MSAVI) or other vegetation indices. The indexed images are subtracted form one another and the resulting image represents the change in vegetative land cover between T_1 and $T_{2.}$

Selective Principal Components Analysis: Two bands only are selected from the time series image. Commonalties to T_1 and T_2 are mapped to one component and the changes, representing that which is unique to either band, are mapped to the other component.

Direct Multi-Date Classification: The imagery from T_1 and T_2 are combined and then analyzed jointly, using the ISODATA method within the ERDAS IMAGINE software.

Post-Classification Analysis: Spectral classifications for T_1 and T_2 are independently conducted and comparatively analyzed. A change map is generated from the two images.

Hybrid Image Enhancement/Post-Classification Analysis: A mask is created of changed areas, following an image enhancement procedure, between T_1 and T_2 and then placed as an overlay to the T_2 image. The changed pixels are then identified and classified.

For the Sudan case study, yet another method was deployed, namely the "Isolate" approach within Map-X (Terra Corporation, South Africa). For this procedure, the end-user selects a specific feature of interest in the imagery, in this case, pixels containing vegetation of interest within the Gezira and circumscribes such with a polygon.

The spectral signature of the pixels contained within the polygon are analyzed and searched, within the scene, for matches. In this way, all the specifically sought pixel values are identified and quantified. The procedure is replicated for the second time period and the resulting difference image generated represents only those changes that have occurred between the two time periods for the specific feature of interest. Moreover, the original pixel value is recorded, so that one is able to discern what value displaced the prior time period's value, (e.g.

wetland replaced by urban area; forest replaced by bare soil; agricultural crop in the first scene was already harvested by the time of the second scene).

4.1.3. Future Scenario Generation:

Human fascination with future divination, teleology, prognostication, forecasting and other forms of clairvoyance has been a repeated theme throughout the history of theology, philosophy, theoretical physics, meteorology, social science, literature, pseudo-science and science fiction. Future Studies has joined the ranks of Escatology as a legitimate area of academic inquiry. Remembrance of things past has been judged necessary but not sufficient for some scientific disciplines, whose *raison d'être* is predicated on the ability to discern that which is yet to come.

The tools of their trade go far beyond crystal balls, tarot cards, tea leaves, thrown bones and the entrails of owls. Yet, we still are not dealing with an infallibly exact science. Myriad externalities and unforeseen exigencies can intervene to impinge on the accuracy of astrophysics-based cosmological theories, disease prognoses, weather and crop forecasts, nutritional needs assessments, pork belly futures trading estimates, and global climate change models.

While recognizing the limitations and inadequacies of the methodologies, the gaps in the data and the fuzziness of the logic, scientists are perforce still obliged to churn out quotidian weather reports and, periodically, to make long range strategic plans and seriatim apocalyptic pronouncements concerning global warming and ozone depletion in the next millennium. The irony of this circumstance is that we humans are woefully ignorant about our own history and have but limited awareness about our own space and time; yet, the lure of future knowledge is seemingly ineluctable. Suitably humbled by this recognition and with all appropriate caveats, the following discussion addresses the specific future scenario generation methodology chosen for the Sudan case study.

It was determined that a long-term crop forecasting method, in tandem with a long-term nutritional needs assessment, would be selected for the Gezira. The rationale for this choice is based upon the fact that numerous Global Circulation Models (GCMs) had already been conducted for the Sahel region and that these GCMs had already been composited by Hulme and Kelley (1993). Moreover, both GCMs and Integrated Assessment Models (IEMs) have been critiqued as being better suited for global, or at least continental scale investigations (Cohen, Demeritt, Robinson and Rothman, 1998), rather than for more localized regional studies.

A further consideration related to the particular objectives of this case study, was that our goals were more narrowly targeted toward assessing the potential regional impact of global climate change on food security, rather than on more generic climatic vulnerability. Finally, the choice of method was more consistent with that utilized, albeit for shorter-term horizons than here proposed, by the joint FAO/WFP Assessment Teams, whose semi-annual visitations to Sudan provide the practical basis for crop forecasts, food aid, and critical input to the United Nations and donors as to nutritional vulnerability.

The major benefits associated with the choice of method, as opposed to the GCMs, are that one can more readily include human factors as well as biogenic factors. Moreover, the regularity of the FAO Mission visitations suggests a potentially appropriate deployment opportunity for TARDIS, through designation of a GTOS-staffer/consultant as a perennial member to such missions, suitably armed with a TARDIS laden laptop. Since FAO is the major sponsoring entity for GTOS as well as WFP, the association is potentially compatible.

The benefits to GTOS, primarily chartered to assess global and regional impacts of climate change, would be a pre-existing array of in country contacts and baseline data, thereby facilitating its mission. The immediate benefits to the FAO/WFP mission would be the inclusion of a team member charged with assessing the longer-term aspects of their annual responsibilities, with access to a virtual data warehouse that could facilitate their immediate tasks, through improved data access, archival data files, as well as the more esoteric offerings of three dimensional scientific visualization, change detection capability, *what if* future scenario generation and decision support.

The longer-term potential benefits to the annual FAO/WFP missions would be an early warning for longer-term trends that could conceivably impact agricultural productivity, human nutritional vulnerability, socio-economic entitlements, disease prevalence among human and animal populations, as well as environmental factors, that might not otherwise become manifested in the process of conducting the more shorter-term horizon routine annual crop forecasts and nutritional needs assessments.

There is a recent wealth of literature that addresses aspects of the procedures, linkages and applications of crop forecasting, particularly, in Africa. Several studies specifically address the role of the Normalized Difference

Vegetation Index (NDVI) in crop yield estimation, including its utility for abundance estimation for semi-arid vegetation (Hurcom and Harrison, 1997), for predicting maize production in Kenya (Lewis, Rowland and Nadeau, 1998), for environmental monitoring and millet and sorghum yield forecasting in the Sahel (Maselli, Conese, Petrov and Gilabert, 1992 & 1993), gram yield estimation, under variable soil and management conditions (Verma, Saxena, Hajare and Ramesh Kumar, 1998), millet yield assessment in Burnia Faso (Rasmussen, 1992; Groten, 1993), and forecasting maize yield in Zimbabwe (Cane, Eshel & Buckland, 1994).

Other studies reported on linking remote sensing models with crop growth simulation models, as applied for sugar beet (Bouman, 1991), and for land cover mapping in central Africa, using the National Atmospheric & Oceanic Agency (NOAA) Advanced Very High Resolution Radiometer (AVHRR) (Laporte, Goetz, Justice, Heinicke, 1998).

The specific crop selected for the forecast is *dhurra* (*Sorghum bicolor* L. Moench.*)*. As the primary consumed grain the Sudan, a proven drought-tolerant species, and one that has been displacing cotton production in the Gezira in recent years, it offers the best potential hope for food self-sufficiency within the region. *Dhurra* is the main ingredient in the Sudanese *kisra,* a leavened bread, usually in the form of a thin pancake.

Virtual travel into the future for the follow-on TARDIS prototype will entail some challenges and decisions. My initial preference is for trend extrapolation to be integrated both with manipulation/ distortion of replicated satellite imagery, together with a standard set of animated sequences, so as to produce plausible futures, based on real data projection but with the look and feel of genuine satellite data. Border colors or some other disclaimer labelling could be appended to future scenarios, so that end-users would not unwittingly be duped into mistaking the simulations for genuine satellite imagery.

The future scenario generation possibilities include a wide range, including GCMs, GEMMs, IAMs, STEs, RIMs, etc. There are tradeoffs in each choice. The GCMs and IAMs require access to massively parallel computers that, while available to this project, would likely be unavailable to the vast majority of potential end-users. Moreover, as reported earlier, both these global models are wide of the mark when addressing region-specific planning requirements.

The Russian (Krapivin, et al., 1997) and Vietnamese (Bui ta Long, et al., 1997) GEMMs have the advantage of adaptability to both global and regional domains; yet, they have substantive computational requirements that might limit the array of potential end-users. Alternatively, there is the Butterfield, Harrison & Downing (op. cit.) Regional Impact Models, developed at the Environmental Change Unit (ECU) at the University of Oxford, UK, that were utilized successfully in predicting the potential impact of climate change on European agriculture, horticulture and forestry for the European Economic Commission.

4.1.4. Decision Support:

According to Buclin, Lehman and Little (1998), decision support for marketing is sufficiently pervasive and has come of age to such an extent that they project that by the year 2020 A.D., decision automation will be the accepted norm. It is certain that other fields of endeavor outside the marketing arena have not yet embraced decision support to such an extent. It is also highly unlikely and even undesirable that computer automated decision-making would ever be an option for the complex array of life-threatening decisions faced by the local leadership and by the multi-lateral agency officials with whom the Sudanese leaders on both sides of the current conflict must interact.

Our objective here is to define a toolset that would support and facilitate the decision-making process on the part of the Joint UN Missions and ultimately on the part of agencies within the region, such as the Sudan Gezira Board, and not to propose supplanting human decisions with an automated process.

Certain highly circumscribed technical procedures within TARDIS, such as the computation of the Normalized Difference Vegetation Index (NDVI), image rectification, dekadal merging of imagery to eliminate cloud cover, and georeferencing, for example, might indeed become candidates in future TARDIS versions for automated macro-based processing, transparent to the end-user. However, the really important decisions have a level of profundity and intricacy that would require wise, humane and compassionate consideration of the variables, thereby obviating the consideration of automated decisional approaches.

There are, however, certain routinized operations they may be relegated to automation, such as the calculation of an NDVI for a given regional satellite scene or even the calculation of expected yield of *Sorghum bicolor* given specific inputs, such as temperature, rainfall amount, key event dates, frequency of weeding, application of fertilizers and pesticides, etc.

Since its logic tree origins within the context of military decision applications by Operations Research specialists during World War II and subsequent successes with industrial optimization and simulation applications, (Silver, 1991) decision support has evolved into a complex array of alternative methods and models that requires some triaging in order determine which approach might be best suited for given set of applications. The taxonomies available for classifying decision support systems are almost as ubiquitous as the systems themselves. Lai and Hwang (1994, p. 31) in Fuzzy Multiple Objective Decision Making (MODM) offer the following taxonomy of methods for MODM (Note: Fandel & Gal (1995) prefer "MCDM" (Multiple Criteria Decision Making) and Lootsma (1997) prefers "MCDA"(Multi-Criteria Decision Analysis):`

Table 4-

DECISION SUPPORT METHODOLOGIES TYPOLOGY (Lai & Hwang)

Stage at Which Info. is Needed	Type of Info.	Major Classes of Methods
No articulation or preference of information		Global Criterion Method
A priori articulation of preference information	Cardinal Information	Utility Function Bounded Objective Method
	Ordinal & Cardinal Information	Lexicographic Method Goal Programming Goal Attainment Method
Progressive Articulation of Preference Information (Interactive Methods)	Explicit Trade-Off	Method of Geoffrion Interactive Goal Programming Surrogate Worth Trade-Off
	Implicit Trade-Off	STEM and Related Methods SEMOPS and SIGMOP Methods Displaced Ideal Method GPSTEM Method Steuer Method
A Posteriori Articulation of Preference Information (nondominated solutions generation methods)	Implicit Trade Off	Parametric Method- - constraint method MOLP Method Adaptive Search Method

Source: Y. Lai and C..Hwang, 1994, "Fuzzy Multiple Objective Decision-Making," Berlin: Springer Verlag, p.31.

4.1.5. Graphical User Interface (GUI):

An interim GUI, largely based upon the JPL-developed public domain antecedent of current commercial mission rehearsal software packages, will be deployed for TARDIS, albeit with selection options for current and future TARDIS modules not included in current commercial packages (e.g. decision support, change detection, temporal exploration of historical archives and future scenarios, archival attribute data integration, etc.) Any full model of the TARDIS GUI should be designed in tandem with the National Partnership for Advanced Computational Instruction (NPACI) and Oregon State University, currently commissioned to develop JAVA-based modular GUI elements that are compatible with the standards set forth by the High Performance Computing Modernization Program.

At a minimum, the emphasis will be placed on ease of end-user utility, multi-lingual selection options, given the cultural and linguistic diversity of UN FAO/WFP Mission Teams, a heads-up display that permits navigation over terrain from ground level and from the air, with multiple view angles, and user selectable speed, elevation and direction.

The ability to query objects (i.e. lines, points, polygons, composite symbols and nodes) for vector layers, and to query pixels or related groups of pixels (e.g. contiguous pixels or dispersed pixels having the same spectral signature) for raster layers would relate to both within scene data, archival attribute data and to corresponding geo-location data from a designated alternative time period. A major consideration in systems design would be to have a field unit that would access data housed at various UN offices, both in the host country, at UN FAO headquarters in Rome, and at UN affiliated agencies world-wide, (e.g. WHO in Geneva, UNICEF in New York, UNU in Tokyo and IBRD in Washington, DC).

4.1.6. TARDIS System Flow Charts:

The following two flowcharts, which are discussed in Section 4.1.6., are found in the Appendix:

1. Chart 1A & 1B: TARDIS System Flowchart
2. Chart 2: TARDIS System Configuration
3. Chart 3: Climate Change Scenario

The following commentaries specifically address each of the charts in sequence. Charts 1A and 1B together comprise the Flow Chart for the TARDIS functional modules. Chart 2 depicts the prototypical system components for TARDIS.

1. Charts 1A&B: TARDIS System Flowchart (See Appendix) -

Beginning from the top left on Chart #1and proceeding downward and, then, left to right, in that order, the first required layer for the three dimensional archival data visualization module is a digital elevation model (DEM) or various alternative terrain relief models, such as a digital line graph (DLG), digital terrain elevation data (DTED), elevation data derived from the U.S. Defense Department's constellation of positioning satellites, namely, the Global Position System (GPS) or their Russian equivalent, the GLONAS. The elevation layer serves as a base, over which subsequent satellite imagery layers are draped, so as to create the appearance of a virtual three dimensional landscape.

The remaining parallelograms are representative classes of multi-spectral and radar satellite imagery that TARDIS would routinely be enabled to access and analyze. The multi-spectral data can be roughly divided into three categories: course resolution, medium resolution, and high-resolution imagery. Future iterations of TARDIS would de enabled to support hyperspectral data (e.g. J.P.L.'s AVIRIS) and aircraft-borne sensors (e.g. NASA's Calibrated Air-borne Multispectral Spectral Scanner (CAMS)).

For the course resolution data, TARDIS end-users would have several options, including the National Oceanic and Atmospheric Agency's (NOAA) Advanced Very High Resolution Radiometer (AVHRR) Local Area Coverage (LAC) at 1 km. Resolution, Global Area Coverage (GAC) at 4km. Resolution, and the modified Africa Real Time Environmental Monitoring Information System (ARTEMIS) AVHRR Normalized Difference Vegetation Index (NDVI), which has been bumped up to 7.6 km. resolution, in a Hammar Aitoff Projection. The LAC High Resolution Picture Transmission (HRPT) data is available, in real time, through inexpensive receiving stations (i.e. Less than $10,000.) from companies such as Quorum Sattracker, running MAP-X Ocean Software, with tools for image rectification, georeferencing and real-time viewing.

Alternatively, for the Sudan, the AVHRR LAC and GAC data is available for a nominal fee (i.e. cost of medium and mailing) from the U. N. Regional Remote Sensing Center in Nairobi. UN FAO Headquarters is Rome already has access to

AVHRR LAC Data, which is used as the raw product for the ARTEMIS data set and is then rectified, corrected, georeferenced and merged every ten days to produce "dekadal" cloud free images and transformed into continent-wide NDVI maps of Africa and placed on the world wide web, as part of the long-term archive of multi-temporal data.

Other low resolution data available from the UN FAO's own website or from inexpensive real time receiving stations (i.e. Under $3,000.) is the the European Space Agency's (ESA) Meteosat, a meteorological satellite for monitoring cloud cover. Its American counterpart, GOES, is familiar to viewers of the nightly weather reports on local television news, as its output is regularly graphically portrayed. Real-time GOES data is more expensive than Meteosat. Meteosat's value to the Sudan case study is the use to which the FAO's Global Information and Early Warning Systems (GIEWS) makes of it, namely, as a surrogate for *in situ* rainfall gauge data.

This is particularly important in areas where there is an insufficient network of rain gauges, or where localized disruption or conditions of military insecurity render *in situ* precipitation monitoring unfeasible. Periods of cold cloud duration (CCD) are derived from the Meteosat data by FAO and these have been shown to correlate well with surface rainfall measurement.

Medium resolution sensors are represented by Landsat, formerly managed by NOAA and currently administered by the EOSAT Corporation. Landsat has dual sensors, the Thematic Mapper (TM), with a surface resolution of 30 m. and the Multi-Spectral Scanner (MSS), with a surface resolution of 80m. Real-time receiving stations for these products would be cost-prohibitive in the Sudan; however, EOSAT markets the imagery at discounts to academic institutions and some multi-lateral agencies. MSS data from the older pre-EOSAT archive are not considered to proprietary, and may be low cost satellite data of this vintage may be obtained from a university users consortium affiliated with NASA's Goddard Space Flight Center and also from the United States Geological Survey (USGS) EROS Data Center in Sioux Falls, South Dakota.

JERS was a satellite launched by NASDA, the Japanese Space Agency. Although it had two sensors, one multi-spectral and one xray, its xray sensors was more regularly utilized. The disadvantage of xray sensors was that their images initially appeared as indecipherable grainy grey scenes, requiring specialized software and specially trained personnel for image enhancement and interpretation. New software suites from PCI and ERDAS, among others have dramatically increased the utility and user base for such products and also reduced the level of needed expertise.

The major advantage of such sensors is their capacity for cloud penetration, permitting uninterrupted archival coverage for the case study region. Early in its career, JERS 1 lost its on-board storage capacity, and recently ceased to be operative; however, its global archive is still regularly used, and is reasonably priced. Its data is currently the mainstay of the Global Tropical Rainforest Mapping Project and the Global Boreal Forest Mapping Project. RADARSAT, ALMAZ and a host of subsequent next generation radar satellite data are now available to end-users at FAO and in Sudan.

Higher resolution satellite data can also be accommodated within TARDIS. The French Space Agency, CNES maintains the highly successful *Systéme Probatoire pour L'Observation de la Terre* (SPOT), equipped a multispectral scanner at 20 m. resolution and a panchromatic (grey scale) scanner at 10 m. resolution. The Government of India,s IRS satellite boasts a 5 m. resolution sensor. Russian satellite data, formerly classifed by the Russian military has been released for commercial purchase by GLAVCOSMOS, and marketed in the United States both through EOSAT and through a private company in Houston. Some of these sensors, like KATE have 2-m. resolution.

Several private firms in the United States have scheduled launches this year for sensors with 1-m. resolution. The U.S. military, in collaboration with Vice President Gore, has already started the process of declassifying some its own sensor files, including U-2 spy plane data for commercial, educational, environmental monitoring, and scientific research use.

As stated within the rectangle and alluded to earlier, one or more of the satellite images from the above array of sensors are draped over a terrain model to create a virtual three dimensional scene. One of the three visualization/mission rehearsal software packages depicted in the display ovals is introduced to render virtual fly over, drive on, or otherwise traverse the scene in real time, with user-determined sun angle, flight path, altitude, pitch, roll, yaw, speed, directional bearing, perspective, viewing angle, magnification, and degree of verisimilitude (i.e. full color with shadows and texture, 256 grey scale, monochrome, wireframe).

Clearly, this feature would be a greater utility were the case study area in a more mountainous region, such as Ethiopia, Chile or Nepal, where elevation and ruggedness of terrain have grave implications for agriculture, microclimate sustainability and market transportation, *inter alia*. The relatively flat Gezira offers a less evocative demonstration of system capabilities.

As part of the process for TARDIS system design, I secured two of the software packages for review purposes from the original equipment manufacturers (OEMs)and attended briefings and demonstrations on two more. My objective was to subjectively determine if any of these virtual spatial analysis (VSA)/mission rehearsal packages were sufficiently robust to be identified as one of the Commercial Off-The-Shelf (COTS) packages within the TARDIS suite of modules. My additional criteria included adequacy of documentation, ease of use, GUI, potential compatibility with other packages, degree of integration with GIS and remote sensing image analysis packages, platform constraints, cost, basic features, rendering speed, and realistic look and feel.

The results of the benchmark follow on Table 3 :

Table 5-

VIRTUAL SPATIAL ANALYSIS/MISSION REHEARSAL COMPARISON

Software	**Features**	**GIS/RS**	**GUI**	**Ease**	**Cost**	**Platform**	**Real.**	**Speed**	**Docs.**
Autometrics Edge Wings (demo only)	Advanced; Special Modules	No	OK	OK	High	UNIX SGI SUN	OK	OK	OK
ERDAS Virtual GIS (software eval)	Advanced	Yes- Imagine Ortho, Radar	OK	OK	Low	UNIX WIN NT	OK	OK	OK
PCI FLY! (software eval.)	Advanced	Yes- Spans Ortho Radar	OK	OK	Low	WIN NT	OK	OK	OK
GOV. Beta. (demo only)	Basic	No	OK	OK	No	UNIX	OK	SLOW	MIN

Based upon the results achieved, it was decided that the three commercial packages would be supported as options within TARDIS, since each had the requisite array of features and support needed to achieve the objectives of the case study; however, for longer-term deployment, a three tiered approach for TARDIS implementation is recommended, as shown in Table 4:

Table 6-

TARDIS IMPLEMENTATION STRATEGY: 3 TIERED APPROACH

LOCATION	SOFTWARE	PLATFORM	SUPPORT	FUNCTION
GTOS/FAO HQ – Rome	Autometrics Edge Wings GIS & Remote Sensing Image Analysis Decision Support TARDIS	SCALABLE SYSTEM WITH POWERWALL High Speed Connectivity to UN Regional Remote Sensing Centers UNIX OPERATING SYSTEM	Real Time Sat. Receiver Dish Training Center for Field Operatives Accompanying FAO Missions	GlobalClimate Impact Assess. On Regions – in Africa, Asia, Latin America ADAPTIVE RESPONSE & MITIGATION PLANS
FAO-Sudan Res. Rep. Staff	ERDAS IMAGINE & VIRTUAL GIS TARDIS	PENTIUM III WORKSTATION DUAL PROCESSORS WINDOWS NT	Real Time AVHRR LAC & GOES	Food Security Monitoring; Support for Missions
FAO/WFP/ GTOS MISSIONS	PCI FLY! EASIPACE TARDIS AGIS (AGRICULTURAL GIS)	PENTIUM II LAPTOP & CD, MODEM, HISTORICAL ARCHIVE OF SATELLITE DATA	ACCESS TO GLOBALLY DISTRIBUTED DATA BASES, GIEWS, ANDREX, ARTEMIS & GPS UNIT W/ DATA LOGGER	CROP FORECAST & NUTRITION VULNERABILITY ASSESSMENT; CLIMATE CHANGE IMPACT MONITORING

At this stage in the TARDIS configuration (Chart 1B), data integration and model calibration facilities enable preparation for the Future Scenario Generation Module. The methodologies listed on the chart are merely representative of the array of models used to generate trend extrapolation and and what if future scenarios. Included are Global Circulation Models (GCMs), Integrated Assessment

Models (IAMs), Ocean Circulation Models (OCMs) and Crop Forecast Models (CFMs). With the exception of the latter, the models are widely used for climate modeling within the literature. CFMs, on the other hand, are traditionally associated only with annualized estimates of crop yields. It is here suggested that, particularly for estimating the impact of climate change on agricultural regions, an extrapolated crop forecasting methodology might have some utility.

Continuing with Chart 1-B, as a result of whatever forecasting model is utilized, *x* number of alternative future scenarios could be generated, representing, for example, alternative multiple future time periods, alternative constraints or opportunities within a single future time period, alternative geographic locations within a single future time period, gradations in the quantity of inputs or outputs or variations among a given array of ufture policy alternatives.

These Future Scenarios, in turn, feed into a decision support module, with user-selectable choice between rule–based or quantitative decision support software, employing optional Expected Monetary Value (EMV) assignations and von Neuman-Morgenstern Utility Theory indexation (Stokey and Zeckhauser, 1978). At this point, the trapozoid symbolizes the requirement for human intervention, namely, the development of an Adaptive Response Plan (ARP), based upon an assessment and analysis of the alternative futures.

Such an ARP might be based upon an identified likely future that one selects as a desirable goal, toward whose actualization, resources are marshalled and human energy expended. Alternatively, an ARP may be developed in reaction to a generated alternative future, whose avoidance now becomes the major objective. Hence, resource and labor allocation are directed at preventing this undesirable future option from ever becoming a reality. Finally, the ARP could be developed as a responsive adaptation to a seemingly ineluctable future alternative, regardless of one's positive, negative or neutral feelings toward that probable future.

Subsequent to the completion of the ARP, the final element on Chart 1B is an arrow, signifying the availability of the TARDIS for iteration of the modular process for the next round of problems or for the same problem in another region.

Chart 2: TARDIS System Configuration (See Appendix) -

The proposed configuration of the TARDIS is portrayed as a triadic system, with the main hub based in Rome, Italy, at the United Nations Food and Agriculture Organization (FAO) Headquarters. The hub is represented in this diagram as being based upon a Cray SV-1 Supercomputer, supporting an array of in-house databases (e.g. the Africa Real Time Emergency Management Information System –ARTEMIS; the Global Information and Early Warning System –GIEWS; World Food Programme -WFP) and access to globally distributed databases maintained by other agencies of the United Nations, including:

World Bank
World Meteorological Organization (WMO)
United Naitons Environmental Programme (UNEP)
Global Terrestrial Observing System (GTOS)
United Nations Childrens Fund (UNICEF)
International Labor Organization (ILO)

United Nations Confernece on Trade and Development (UNCTAD)
United Nations Educational, Scientific and Cultural Organization (UNESCO)
United Nations High Commission on Refugees (UNHCR)
United Nations Development Programme (UNDP)
United Nations University (UNU)

At the national level, the proposed TARDIS deployment would be based at the facilities of FAO Resident Representative. In the case of the Sudan case study, this facility is located in Khartoum. The recommended configuration includes a Windows NT workstation, digital video projector and a real-time satellite receiving station, ideally for higher resolution data that could be used for monitoring the major Irrigated Schemes.

The TARDIS field unit, to be deployed with the various FAO/WFP Crop Forecasting & Nutritional Needs Assessment Missions, includiing the visitations to Sudan and to Southern Sudan, is based on a laptop computer, with optical drive, modem and removeable storage and with a selection of software packages, from which the Mission's primary designated systems manager could choose, based upon the specific objectives and needs of the of the Mission. The array of choices include software for: decision analysis, global positioning, geographic information systems (GIS), remote sensing image analysis, database management, statistical analysis, scientrific visualization word processing and a spreadsheet.

This overall configuration is based upon the assessment that a combination of tiered support for Field operations, at FAO world headquarters and at the national level will enable the Mission team to download their basic requirements, including satellite imagery during the mission planning stage, before entering the host country, more country-specific data at the Resident Representative's offices, at the capital city, and having with them a field deployable unit, represents a potentially replicable model for usage in other regions, addressing a wide array of development problems.

The international and national installations will initially permit a simplified laptop to to used. As such portables become more sophisticated, faster, less expensive, more graphics-capable and more easily and cheaply linked to international wireless communications, field operatives will have greater facility in performing visitations to remote areas, will become less dependent upon the centralized facilities, and will have greater on-site analytical capability. This last feature is critical even for the initial deployment, that is, the *in situ* availability of TARDIS thereby permits the inclusion of datalayers on-site that are region-specific and consequently unavailable in disaggregated form at either national or international level.

Moreover, such location-specific data is essential in facilitating more precise, accurate and regionally relevant forecasts and needs assessments.
A surrendipidous benefit is the facilitation of multi-disciplinary collaboration among members of the joint Mission, in that their individual data layers can be cross-referenced and correlated, more easily.

Field-level major insect infestation, village-level epidemics and microclimate perturbations may all escape the macroscopic view and wide fishnet approach associated with nationally aggregated data; yet, a more localized fine mesh approach may be crucial to determining where next to deploy scare resources to contain an outbreak of Ebola, HIV, Cutaneous Leishmaniasis, Trypanosomiasis or Onchocerciasis.

Chart 3: TARDIS Climate Change Scenario (See Appendix) -

This chart displays a flow process for a TARDIS multi-module application to a prototypical long-term forecast of the regional impact of global climate change on Sudan's Gezira region, with specific reference to the fate of the *Sorghum bicolor* crop yield, under anticipated increased temperature and decreased precipitation, circa the year 2050 A.D. This is an example of the potentially wide range of TARDIS applications.

In the scenario depicted in Chart 3, the ARTEMIS NDVI archive is downloaded from the FAO website and ingested into ERDAS Virtual GIS. These AVHRR scenes as well as their higher resolution parents (i.e. 1 km. HRPT LAC) for Sudan's Gezira, and even higher resolution data (e.g. TM, MSS, IRS or SPOT) are draped over an appropriately scaled Digital Elevation Model (DEM). Virtual reconnaissance routines are conducted to permit interactive spatial/temporal analysis of the multi-spectarl multi-temporal, seasonally-matched images, which have previously been geoferenced. Specific features of interest are noted, based upon a combination of spectral signature and surface data from the Sudan Gezira Board, indicating areas planted by specific cultivar, and any temporal variation in inputs deployed.

Inter-annual differentiation in ambient temperature and precipitation is also noted from the archives of the World Meteorological Organization (WMO) and

FAO's databases. These are compared to rainfall estimates, based on Cold Cloud Duration (CCD), as derived from the date-matched imagery of Meteosat or GOES satellites, for future estimates in areas where rain gauge data is sparse.

Change is dectected using one of the established techniques described earlier, specifically to denote the status of pre-harvested *Sorghum bicolor*, at peak green-up. Inter-annual "greeness" density is compared with actual crop yields, so as to derive a correlation. The end-user selects from among the array of future scenario generation methodological alternatives, including General Circulation Models (GCMs), Integrated Assessment Models (IAMs) and long range Crop Forecasts. In this instance, the latter is chosen.

Utilizing the results of field studies and laboratory tests, documenting the limits to growth imposed on *S. bicolor* by moisture deprivation and dessication, occasioned by projected decreased rainfall and temperature induced evapotranspiration, a long term forecast is projected, assuming constancy for a range of extraneous variables (e.g. agricultural workers' health, insectivoral abundance with no increased resistance to pesticides) and with a doubling of atmospheric CO_2.

What-if scenarios are generated and virtually explored utilizing visualization techniques, based on a variety of probable conditions (i.e. ranges of rainfall and temperature, public policy alternatives, different cultivar options, variations in inputs, variations in latitude for areas planted, aggressive vs. *laissez faire* modes of production, capital intensivity vs. labor intensivity, etc.)

Based upon an evaluation of these results, the end-user(s) selects a course of corrective action, that is to say, an adaptive response. Such response could be based upon an attempt to bring about a particular future state, based upon the current state of scientific (and political/cultural) knowledge. The response might be predicated upon a determination to avoid one or more unwelcomed outcomes identified as possible futures, representing extrapolations of current trends. The adaptive response strategy could be designed to mitigate the impact of an apparent ineluctable externality. A combinatorial response could take into account two or more of these objectives. At this point the TARDIS functions have been completed and are at a ready state for deployment on another set of problems and/or deployment within another region.

4.2. TARDIS: DATA SOURCES, SOFTWARE AND HARDWARE OPTIONS:

4.2.1. Biogenic Data

Data sources for the TARDIS include 80m. resolution Landsat Multispectral Scanner (MSS) data over a seventeen year period during peak greenup for drought periods in 1972/73, 1984 and a wet period in 1989. The data were obtained from the Jet Propulsion Laboratory at the California Institute of Technology, during my tenure as a NASA/JOVE Fellow. Acknowledgement is given to Dr. Nevin Bryant of the Cartographic Applications Group for his able assistance and staunch support.

The data were synoptically geo-encoded for four study sites in Sudan, including the Gezira (i.e. Wad Medani Area), Juba, Wau and Damazine/Rosaries, all sites I had surveyed during my field assignments in Sudan. The Gezira study site was selected, in consultation with my dissertation committee, for continued scrutiny given its unique potential among the other study sites for having the possible infrastructure to support adaptive response.

Also georeferenced were data from the Advanced Very High Resolution Radiometer (AVHRR) Local Area Coverage (LAC) at 1 km. resolution, Global Area Coverage (GAC) at 4 km. resolution and the FAO Africa Real Time Emergency Management Information System (ARTEMIS) NOAA AVHRR NDVI Image Bank for Africa, bumped up to 7.4 km. Resolution and converted to a Hammer Aitoff projection. There is a procedure developed by Clark University's Geography Dept. in Worcester, MA for converting Hammer Aitoff projections into IDRISI format and subsequently into either ERDAS or ARC/INFO format. The program is called NDU HA2LLIMG (Hunting Technical Services, 1994).

The design specifications and Beta Version of the TARDIS contemplated for this study will utilize one of three candidate virtual spatial analysis (VSA) tools as the basis for modification and adaptation to virtual temporal analysis (VTA) capability. These candidate commercial off-the-shelf packages include the Wings module of Autometric's EDGE family of products. Wings was initially designed for defense-related mission rehearsal and mission preview. Its features include 2D and 3D mission planning and preview, a joystick interface, heads up display, user defined tracks, multiple mission simultaneous display and movie recording capability. ERDAS Virtual GIS has a similar array of features and is integrated with the IMAGINE raster-based image analysis capabilities. Both packages run on higher-end SGI and SUN Workstations. PCI's FLY! is implemented on PC, UNIX and MacOS platforms and also features interactive visualization and 3D perspectives, utilizing SGI Liquid Crystal Eyes Shutter Glasses.

TARDIS development will also require the draping of the satellite data over a digital elevation model. The region in question within Sudan does not include the Jebel Mara hills and therefore is rather flat. Some minor exaggeration will be introduced to highlight known relatively elevated physical features, including townships, riverbanks, irrigation canals and planted fields.

The National Aeronautics and Space Administration (NASA) is well represented, given the voluminous contributions to the literature on remote sensing of the African environment by Compton Tucker, Chris Justice and Steve Prince, all affiliated with the Goddard Space Flight Center. Goddard continues to quality control for the NOAA AVHRR 4 km. resolution GAC data for FAO. This data is subsequently resampled to 7.6 km. resolution by FAO.

NASA's major contractor, the Jet Propulsion Laboratory (JPL) of the California Institute of Technology (CalTech), has a long history of research and database development relating to Africa, including desertification monitoring, using shuttle imaging radar, in the Sudanese Sahara, as well as the archival and image processing contributions to the current project on Sudan, provided by JPL's Cartographic Applications Group (CAG) in the Image Processing Section.

One extremely significant contribution to African ecosystems monitoring is the Famine Early Warning System (FEWS) Program of the United States Agency for International Development (USAID). At its inception, the FEWS program was managed by Tulane University's School of Public Health and Tropical Medicine's

Office of International Programs, with support from the Pragma Group. It is currently managed by ARD, Inc. of Arlington, BA.

The FEWS program combines satellite data with a compilation of data sources collected *in situ* by field personnel based in each country within the African Sahel. Deteriorating security conditions within Sudan prompted the recall of the FEWS operative from that country. FEWS was expanded to cover Southern Africa, and the Horn of Africa.

Field personnel access surface data relating to agricultural productivity, exports, pricing, population relocations, food supplies, distribution, consumption, disease outbreaks, and a variety of social and economic conditions that impinge upon nutritionally vulnerable groups. Sources of such data include reports from and direct contact with governmental ministries, U.N. agencies, U.S. government personnel and non-government organizations (NGO's).

Data is entered by FEWS into a PC-based spatial data display and analysis software package, IDA, developed by Eric Pfirman and associates. This allows for the simple comparison of ten day (decadal) AVHRR global area coverage (GAC) normalized difference vegetation index (NDVI) data for the African continent with preceding data norms, utilizing the ten year archived AVHRR dataset.

4.2.2 Anthropogenic Data:

As a prelude to this discussion, "anthropogenic factors," as the Greek root would indicate, can be defined as those variables, which have an etiological linkage to human activity. Within the context of the Sudan case study, such variables include: poverty, civil war, international political isolation, public policies relating to agricultural production, distribution and export, effective demand, and environmental degradation caused by human action.

TARDIS, in its full implementation, should incorporate a multi-layered geographical information system (GIS), whose data layers will include: elevation, multi-temporal satellite imagery, precipitation distribution, roadways, normalized difference vegetation index (NDVI), population density, demographic data from the Sudan Dept. of Statistics, income data from a variety of surveys, nutritional status as derived from household nutrition surveys by Ali Taha and others, epidemiological data for both chronic and infectious disease incidence and/or prevalence, areas of reported armed conflict, and regional export/import.

For the beta version proof-of-concept prototype TARDIS, a more limited array of variables are incorporated. Future scenario generation, for example, will be based upon extrapolation of trends not only as relates to biogenic factors (i.e. rainfall, temperature, CO_2 concentrations) but also to anthropogenic factors. Clearly, the determination of the potential sustainability of food security and adaptive response to climatic change cannot be solely dependent upon analysis of natural occurrences.

Human-induced factors are critical to the alternative future scenarios generation and to the archival satellite data analysis. During the archival data exploration, attribute files can be associated with terrain segments, indicating associated socio-economic variables. Change detection can be configured to monitor both major changes in land cover as well as major changes in population and other designated anthropogenic variables. The multivariate decision support systems, both the quantitative and the rule-based versions, will also prominently feature human-induced factors.

4.2.3 Software and Hardware:

1. Is there a role for state-of-the-science visualization of remotely sensed data, as a tool for planning adaptive responses to sustainable food production and distribution constraints, to income insecurity, and to impending climatic change?

While sensitive to the potential critique that one is touting a high tech solution in search of a problem, a case will be made for utilizing remote sensing and scientific visualization as tools for planning the complex adaptive responses to the vulnerability triad. It will be further argued that there are major limitations to the appropriate technology movement, which perhaps unwittingly, would relegate the third world to so-called intermediate technology. In many instances, "intermediate" becomes prolonged and terminal. Implemented with sensitivity, state-of-the-art technology may have the capacity to enable underdeveloped societies to "leapfrog" the learning curve experienced earlier by the developed economies.

In the specific case of remote sensing, we are observing a potentially "equal opportunity technology", in the sense that data with the same degree of resolution and frequency is as available to the third world as it is to the first world. The cost of data acquisition has plummeted, as has the user-hostility of earlier hardware and software systems. In the case of visualization technologies, (Nielson, Hagen & Muller, 1997; Rosenblum, et al., 1994) there is the potential of increased access to decision-making within information-rich environments, as well as to regional data self-sufficiency/autonomy and consequent regional empowerment.

2. What can be learned from an analysis of the archival satellite data for Sudan's Gezira, from an assessment of current conditions (i.e. including civil war and international political isolation), and from an analysis of alternative future *what-if* scenarios, that might facilitate informed decision-making and policy formulation?

This question cannot be adequately addressed prior to conducting the historical and current analyses and constructing the likely alternative future scenarios. The underlying premise is that too many decisions that impact the future significantly are made, perforce, without the benefit of hindsight. No one decision-maker has the benefit of institutional memory, voluminous attribute databases and archival imagery at his/her disposal at the time a decision is required. No committee usually operates with such advantages, either.

Moreover, even with the benefit of historical perspective, few decisions significantly affecting the future, whether in the USA, Europe, Asia, Latin America or Africa, have the luxury of reviewing the potential outcome of their decisions under a variety of *what-if* scenarios. There is no escaping the political parameterization of the selected array of potential future constraints, without retreating into mechanistic percentage gradations, and that has political overtones as well. Nonetheless, an informed decision-maker may minimize the impact of the externalities.

3. How might archival satelite imagery, tabular historical data and analytical capability be of practical utility to the various vested hierarchical constituents (i.e. the Gezira tenant farmers, the Gezira Board, the Government of Sudan Ministry of Agriculture, the SPLA Opposition Forces, Bi-lateral Aid/Trade Partners, NGOs/PVOs operating in Sudan, the UN FAO and the Global Terrestrial Observing System (GTOS)?

The relevance and potential utility of the data and its manipulation will be addressed for the primarily targeted end-users, namely, the FAO/WFP Annual Crop Forecasting and Nutritional Needs AsessmentMission to Sudan. Follow-on subsequent research might actually place a turnkey prototype system with representatives of each of the constituent groups, so as to examine whether or not the assumed utilities were correct and to observe any further serendipitous benefits, or lack thereof.

My initial assessments would lead me to recommend a three tiered approach to TARDIS technology deployment and dissemination, within the Sudanese context. A multiple-processor, potentially massively parallel, computer with significant graphics capability (e.g Upgraded versions of the SGI Onyx, Sun Sparc Station 450, etc.) with direct access to the UN AFO ARTEMIS DIANA network and receiving stations for GOES, RADARSAT, and either SPOT or IRS, loaded with Autometric's EDGE Product line would be proposed for installation at GTOS, so as to facilitate monitoring and visualizing the impact of global change on selected regions.

At the national level, even without assuming propitious and timely resolution of the current conflict, a dual processor workstation (e.g. IBM RISC. SUN, SGI, etc.) with ERDAS IMAGINE and Virtual GIS software, and real-time data from the next iteration of the NASDA JERS-1, along with a Landsat TM product delivery contract and access to archival MSS would be deployed at the headquarters of the UN FAO Resident Representative in Sudan.

At the regional level, real-time ESA Meteosat, NOAA AVHRR and periodic access to monthly high resolution products on CD (e.g. Russian data or Indian satellite data or the yet-to-be-launched 1 meter US commercial sensor data) and Pentium Iis with PCI's FLY and a low cost GIS package (e.g. IDRISI, Delta Data Systems MapX, ESRI's Arc View or Tydac SPANS) would be deployed with the FAO/WFP Sudan/Southern Sudan bi-annual crop forecasting and nutrition needs assessment team, potentially through assignment of a GTOS staff member or consultant as an adjunct member of the Assessment Mission. As of the present, GTOS does not have a long term ecological study site in Sudan.

4.3. SUDAN GEZIRA DATA SIMULATED TEST RUNS (STRS):

Given that TARDIS in its present form is a development of concept, rather than a full-blown prototype, it was necessary to formulate a surrogate or simulated mode of testing the various TARDIS components, to enable one to visualize the tool as a virtual integrated turnkey package. The purpose of conducting simulated test runs (STRs) were twofold. First of all, it was necessary to demonstrate the potential utility and relenace of a TARDIS-like tool for the Sudan case study. Secondly, in the process of implementing the STRs, one might discern potential improvements that could benefit the design process for the follow-on development of an actual TARDIS prototype. Accordingly, the following STRs were carried out and results are presented.

4.3.1. STR: Visualization of Archival Data:

Multi-date Landsat Multispectral Scanner (MSS) and National Oceanic and Atmospheric Agency (NOAA) Advanced Very High Resolution Radiometer (AVHRR) Local Area Coverage (LAC) imagery, were georeferenced and ingested into TERRA/Delta Data Systems MAP-X software. A wide array of traditional spatial image analysis tools are available within the package. In order to utilize the visualization fly-over capabilities of ERDAS Virtual GIS, it was necessary to convert and import the data files in a .tiff format. A prerequisite for such overflights, however, is a digital elevation model (DEM), digital terrain elevation data (DTED) or elevation coordinates obtained from the Department of Defense (DOD) global positioning system (GPS) or the Russian equivalent, GLONAS. Alternatively, with stereo paired imagery and packages such as ERDAS Orthomax Professional in a UNIX environment or PCI's OrthoEngine, in a Windows, NT or UNIX environment, one can produce one's own DEMs and orthrorectify imagery from satellites and air-borne sensors and digital cameras.

Since stereo pairs were not available for the Gezira, it was necessary to obtain an appropriately scaled DEM for the MSS imagery. In the absence of a

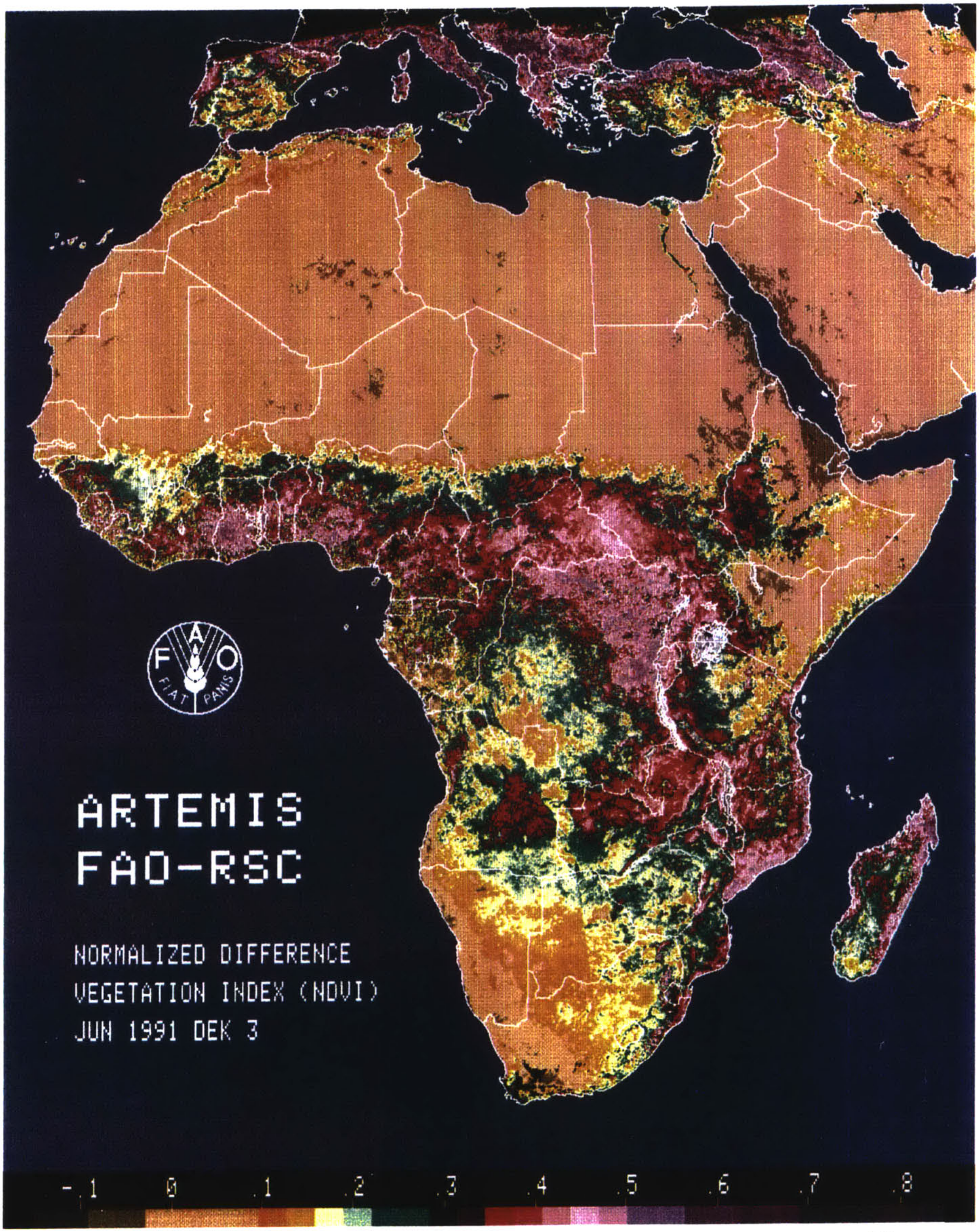
DEM for the Gezira, the STR had to rely upon visualization of two dimensional imagery for the Gezira (without fly overs) and utilize surrogate DEM and Remotely Sensed data from two other geographic areas for visualization of the three dimensional data. The two data sets available for that purpose were a MSS data set and DEM for Venezuela and a SPOT/TM merged data set with DEM for New Orleans, LA. While the Venezuela imagery was more visually interesting given its mountainous terrain, the below sea level flat terrain of New Orleans with the Mississippi River crescent was, topographically, a closer fit to the relatively flat Gezira, with the bordering Blue Nile River. One must perforce make allowances for the significant differentiation between an agricultural landscape and an obvious urban area.

Aside from "virtual piloting" skills, which I discovered have a learning curve for those not immersed in video gaming, the three dimensional spatial overflights revealed a significant data loss resulting from sampling techniques required to render imagery in real time, and on a laptop, more quickly. Serious analysis of the image data is clearly best done in two dimensions; although, high performance computing would have allowed less sampling or even no sampling, without major speed hinderences. There are instances when analysis is elevation dependent, such dwarf cloud forest ecosystems, or mountain goat habitat studies, or microclimate studies of canyons, where one would require the actual dataset , without sampling.

All these issues are, so far, only relating to virtual spatial analysis (VSA) of multi-temporal data. For the next iteration TARDIS to achieve Virtual Temporal Analysis (VTA) of multi-temporal data, it will be necessary to modify the commercial packages to permit sequential passage from T_1, T_2 through Tn three dimensional scenes, without "going to black". Alternatively, one could tolerate a brief iterated animated sequence during the transition, a "morphing" from one time period to the next, or even a virtually seamless transition, marked only by some type of heads-up display for navigation and for a "chronometer", indicating the specific period and data type under observation (i.e. AVHRR LAC, April, 1999, 1st dekad, Horn of Africa, with UTM coordiantes).

4.3.2. STR: Change Detection:

The Isolate module within MAP-X permitted manually-controlled feature extraction, polygon circumscription and scene-wide or window-wide locate-same capability. Iteration was carried out on a subsequent T_2 scene and differenced. In this case, the feature extracted represented pre-harvested crop at peak green-up within the Gezira. Other traditional methods of change detection would be available as standard classification and differencing tools. The isolate method was chosen for this STR since in this case we were not as much concerned with identification of the maximum number of classes within the scene, but rather with the extent and concentration of vegetation within the scene.


ARTEMIS
FAO-RSC
NORMALIZED DIFFERENCE
VEGETATION INDEX (NDVI)
JUN 1991 DEK 3
-.1
0
.1
.2
.3
.4
.5
.6
.7
.8

4.3.3. Generation of Future Scenarios

As stated earlier, herein, the mode of future scenario generation selected for inclusion within the TARDIS proof-of-concept was crop forecasting for *Sorghum bicolor* within Sudan's Gezira, under a hypothetical period wherein CO_2 was doubled, temperature increased by 5° C and precipitation was reduced by 20%, projected to occur approximately aroun 2050 A.D., based upon maintenance of current trends. Following Hargreaves (1984), an agroclimatic model for sorghum yield estimation was selected for inclusion within the TARDIS. The future scenario generation module for TARDIS will ultimately include end-user options for GCMs, IEMs, and coupled ocean/atmosphere models.

Additionally, the parameters for a long range nutritional needs assessment for the region are specified, based upon the UN FAO/WFP semi-annual nutritional needs assessment and crop forecast missions to Sudan and to Southern Sudan.

Virtual exploration of putative future scenario imagery in the follow-on iteration TARDIS beta version prototype will require the same inputs as was the case for the visualization of archival data module, that is a DEM or equivalent terrain model, and sequential, georeferenced Future Time scenes (i.e. FT_1, FT_2 through FT_n). There are two major options for future data depiction. One would entail the use of yet another software package, this one for developing animated sequences of future time periods with the "look and feel" of satellite imagery and simulated overflights. The false color, faux topology and fake texture would have a realistic landscape look, although the image would, in truth, be an animation sequence and **not** satellite imagery. However, the data representations as depicted by the color coding, virtual feature classification, elevation, concentration and extent of landcover (e.g. agricultural vegetation, forests, rangeland, surface water, NDVI, etc.) would be based upon actual data extrapolated for that particular date and not some arbitrary futuristic backdrop.

The current recommendation at the international level for future scenario animated sequences is ALIAS MAYA, the more fully featured successor to the popular ALIAS WAVEFRONT, running on an SGI Onyx "Infinite Reality Monster" configuration. As the software cost, hardware cost and level of required training exceeds potential implementation, except at the international level or perhaps the national level for some countries, an alternative approach is warranted at the regional and, in many cases, at the national level as well.

That suggested approach for the regional and national TARDIS future scenario generation module is the creation of a classification mask (e.g. NDVI, supervised Principal Component Analysis, supervised Maximum Likelihood, etc.) based upon *what if* Boolean operatives. The mask for each future time period would represent projected land cover (i.e. vegetation extent under specific conditions of moisture deprivation, heat-induced excess evapotranspiration and ambient CO_2 sequestration and utilization by the vegetative cover.)

The mask is then used as a layer or overlay for a generic "base image" of the same region with the same spectral bands and RGB false color band associations. In order to best approximate the resemblance to features and enhance the appearance of the mask, those areas of the mask that conform to the actual features of the base, can be rendered to be transparent. Hence, overflights of this future world would be virtually indistinguishable from actual satellite imagery.

CHAPTER V : DECISION SUPPORT EXAMPLES:

This chapter explores the parameters for decision support for an array of postulated applications for the Gezira region in Sudan, addressing short-term and long-term issues affecting agricultural production, under prototypical constraining conditions, including insect and nematode infestation of the food crops and cash crops, desiccation associated with drought, and debilitation of the agricultural workforce, resulting from an epidemiological crisis.

The objective of this exercise is to demonstrate the potential utility of the previously described TARDIS tool for enabling decision-makers to better perform their on-site planning tasks, forecasts, formulating adaptive responses and, where warranted, taking corrrective action, *in medias res*. In actuality, what all these decision tree examples have in common, is the temporally sequential portrayal of the complex decision-making context. The Sudanese context may be more complex than most; however, the TARDIS implemention proposed for this s\case study is only exempletive of the potentially wide array of applications and regions to which a TARDIS-type tool can be deployed.

Another common feature is the rationale for having such a tool immediately available on site. The dynamic nature of local conditions and the multiple life-threatening and crop-threatening exigencies make the case for prompt response and for adaptability in the face of adversity. A scenario wherein the computer facilities for decision support are preloaded in Rome and more locally specific information downloaded at FAO Offcies in Khartoum have merit. Yet, there is no substitute for the ability to georefernece anomalies in the field and thereby obtain early warning of impending crisis situations.

I have herein used the term "externalities" in referring to these crisis phenomena, in the sense that the term is utilized in Sloan School of Management case studies, namely, that which is extraneous to the immediate strategic plan. This is not to imply that these events are uncharacteristically exotic or foreign to the case study region. In fact, since they represent the mere unfolding of biogenic events for elements perennially present within the Gezira ecosystem, they could just have easily been referred to as "internalities".

Obviously, the inhabitants of the case study area, the Gezira in Sudan, have been surviving such onslaughts and others, without the benefits of computer-based decision support, since the time of Tia, mother of Akhnaton, who left her native Nubia and Meroe, in what is now present day Sudan, to join her Pharoah son, when he constucted the new Egyptian capital at Amarna.

The hubris of purporting to offer new technologies to ancient cultures is not without its irony and its legitimate trepidation. Yet it is the modern face of ancient enemies that we are confronting in today's Gezira. Decision-makers of today must perforce contend with descendants of Triassic insects, helminths and molluscs who have only recently evolved with resistence to contemporary chemcial pesticides, and a rapidly changing global climate whose regional manifestation may take the form of higher surface temperatures and an accelerating southward migration of the African rainbands. Such acceleration has been associated with the anthropogenic increase of carbon dioxide and other greenhouse gas emissions into the atmosphere.

TARDIS is **not** the *Deus ex machina* that has been dispatched to rescue mankind from the triadic scourges of famine, drought and plague. It is merely a simple pre-loaded and pre-configured laptop computer, supported by home base installations, that, hopefully, in the right hands, and under ideal circumstances, will facilitate the decision-making process, by offering end-users a wealth of region-specific tabular and satellite information, augmented by a visualization context. The expectation is that the timely availability of a superior array of knowledge, presented evocatively, will enable decision-makers to render better-informed and more rapid judgements, to intervene more precisely, and to make more logical mid-course corrections and responsive adaptations.

The case study selected to demonstrate the potential efficacy of such tools is long and sort-term crop management in Sudan's Gezira, under a typical set of constraints. Using this vehicle, we first examine the issue of crop choice in a cursory manner, utlizing a sequential tablular listing of labor intensive "best practices" for cultural containment of insectivoral and nematodal pests. In recent years, as these practices have fallen into disuse and chemical pesticides usage has dramatically increased, the result has been the emergence of pesticide resistant insect populations, the need for more frequent spray applications and skyrocketing pesticide costs.

El Tigani, El Amin and Ahmed (1991) of the Agricultural Research Corporation in Wad Medani, Sudan (Gezira area) offer us domain expertise in recommending that cultivators revert to the proven cultural practice ways of yore in combatting pests. I have subsequently incorporated their scenario within a preliminary decision-tree structure, as represented in Charts 4A-4D (See Appendix). This four part chart is presented to enable one to view the basic temporal sequence of events with respect to crop protection and yield enhancement activities, throughout the course of the crop cycle. The alternative highlighted paths represent (a) an aggressive labor and capital intensive low-risk approach and (b) a cost containment high-risk approach.

Decision options are then presented, within the context of a more detailed intervention strategy, as depicted in Chart 5 (See Appendix), namely a mitigative response to endemic schistosomiasis among the agricultural workforce in the study area, in which mid-stream corrective action is required and combinatorial choices must be made, among a wide array of potential intervention strategies. Chart 6 then offers a composite representation of Adaptive Response scenarios, within the context of the decision to plant cotton as a cash crop or sorghum as a food crop, under a range of environmental constraints.

Subsequent to the detailed discussion of each of these decision examples, the role of the designated initial end-user, namely, the Joint United Nations Mission Team is addressed. These Missions were selected as the likely entity to introduce the technology and to initially benefit form its resources. Such teams are composed of interdisciplinary domain experts, thereby reducing the length of the learning curve. Moreover, they have ready access to home base facilities at FAO in Rome and the host-country FAO Resident Representative's offices. Finally, given the current preoccupation of the Government of Sudan with civil war and other strife, the issue of indigenous technology transfer would appear to be premature, at best.

It was decided that a good way to demonstrate the independence of TARDIS modules, allowing users to pick and choose one, two or all modules, depending upon the nature of the problem at hand and to demonstrate its utility for adaptive response, as well as climate impact assessment, would be to conduct a Simulated Test Run (STR), using data from the study area that was supportive of enhancing crop yield, through improved pest control practices. The decision context then emerges as how best to minimize crop insect infestation, primarily utilizing cultural practices, rather than sole reliance upon chemical pesticides.

Following El Tigani, El Amin and Ahmed (1991), relating to strategies for integrated control of cotton pests in Sudan, it became evident that pesticide applications in the Sudan were netting diminishing returns. Although cotton has been harvested commercially in Sudan since 1867, data on average yield in kg/ha have only been available since 1925. No pesticides were applied for the period 1925-1945. The following chart abstracts from the annual available data & samples the *Gossypium spp.* yield every ten years, together with frequency and cost of spraying.

Table 7 -

COTTON CROP PROTECTION : SUDAN - GEZIRA

YEAR	NO. SPRAYS	YIELD kg/ha	SPRAYING COST Ls/ha
1925	0	1622.208	0
1935	0	1258.563	0
1945	0.01	1137.253	3.063
1955	1.10	1644.175	2.149
1965	2.50	1142.981	6.138
1975	6.26	914.520	39.420
1985	8.49	1193.460	315.500

Source (Sudan Gezira Board; El Tigani El Amin & M. Ahmed (1991)

It is readily apparent that, although the frequency of pesticide applications within the Gezira targeted for cotton pests has dramatically increased in the sixty year period reported, and the cost of spraying has increased a hundredfold, yield per hectare has declined. Possible explanations include the probable buildup of pesticide immunities among the Gezira's insect population.

In an attempt to address these problems, the authors (El Tigani, et al., 1993) recommend reverting to cultural practices which were used to control insect infestation, before the advent of pesticide applications. Since these practices, according to the authors, have largely been abandoned in recent years, there appears to be a need to reintroduce them to the newer generation of agriculturists. One method of so doing would be in the form of the TARDIS Decision Support

Module. An outline of the data elements to be included within the decision structure follows:

COTTON CROP PROTECTION

DECISION SUPPORT

GEZIRA, SUDAN

WILL YOU PLANT LONG OR SHORT/MEDIUM STAPLE COTTON?

LONG STAPLE (240 days)
Gossypium Barakatensis

SHORT/MEDIUM(180days)
Gossypium aegypti

Source: El Tigani, El Amin & Ahmed (1991)
Agricultural Research Corp. Wad Medani, Sudan

APRIL:
- Field Sanitation: Clean fields from previous season to reduce *Pectinophora gossypiella* (Pink Bollworm Saund.) & *Stenophora gossypii* (Stem Borer)
- Allow cattle, goats and sheep to graze on cotton fields

MAY:

-Before May 31, Uproot cotton stalks, sweep cotton debris, fallen seed cotton & BURN all part sof cotton plant

JUNE:
- June to mid. Sept.: Law prohibits growing okra (*Hibiscus esculentus*),Kenaf (*Hibiscus canabinus*) and Kerkede (*Hibiscus sabdariffa*) which harbor pests.
- Land Prep.: Deep Plow to expose or bury and kill diapausing stages of flea beetle (Heliothis pupae, Sudan bollworm (Diaparapsis watersi) & leaf worm
- Flood fields for 2-3 days after land prep to kill pupae of *Spodioptrera, Caliothrips, Heliothis and Diparapsis*

Long Staple Cotton
Gossypium Barakatensis

Short/Medium Staple Cotton
Gossypium aegypti

JUNE & JULY: If sown during this period, yield loss 40%-60% due to pests cotton flea beetles (*Podagrica* puncticollis Weise) & (P. pallida Jac) attacking seedlings
JULY: After early rains, Eradicate Volunteer/Pioneer Cotton Seedlings
- Application of balanced nitrogen fertilizer, good for cotton growth & shortens life of white fly by "two days", when ingesting nitrogen rich leaves.

AUGUST: BEST TIME TO SOW!
AUG.-SEPT: *Caliothrips fumipennis Caliothrips sudanensis* Bagn. & Cam. Suck leaves & kill seedlings.
- Regular weeding in & near fields is necessity to stop pest migration & reinfection.
-Water every 2 weeks throughout growing period.
- After August, its TOO LATE to SOW lest pink bollworm attacks fruiting bodies.

-SEPT.: -After mid Sept. OK to plant "trap crops" like *Hybiscus spp.* (i.e. orka, kenaf and kerkede) to divert flea bettle away from cotton and Lubia (*Lablab niger*) to attract moths *(Heliothis, Spodoptera* and adult whitefly away from cotton)
OCT.: Be alert for Termites (*Macrotermes thoracalis*), which bore into cotton roots and kill some plants during flowering and fruiting stage.

DEC.-LATE MARCH: PICK LONG STAPLE COTTON (*Gossypium Barakatensis*)

NOV.-JAN.: PICK MEDIUM/ SHORT STAPLE COTTON (*Gossypium aegypti*)
DEC.: Stop Watering. This reduces build-up of white fly & lint stickiness

Feb.-March: Late Season Infestation by Pink Bollworm (*Pectinophora* gossypiella Saund.), causing losses in yield of late picks & leaves diapausing larvae in cotton seeds damaging next years crop w/o thorough clean-up campaign.
Also: Cotton Stainer (Dysdercus fasciatus Sign.) attacks mature bolls, feeds on seed contents; transmits spores of fungi, causing internal boll rot.
Feb.-Aug.: Eradicate *Abutilon spp. & Solanum dubium*, safe harbor to pests.

JUNE 15: DEADLINE FOR ALL COTTON GINNING TO BE COMPLETED

- Cotton Seed and Seed Cotton storage must be outside the cotton growing area to avoid early pink bollworm.
- Cotton Seeds in Mills must be heated to 60°C or kept in insect proof containers
- Place cotton seeds in sun at 60°C for two hours to destroy pink bollworm's larva OR
- Heat cotton seeds at ginneries for 5 to 10 minutes at 55-65°C for 5 –10 minutes
- Clean Fields, burn cotton parts, and permit grazing, then plowing, flooding, weeding, fertilizer and removal of *Hybiscus spp.*, as before
- Rotate crops with a clean fallow period within the cycle
- Consider utilizing insect resistent cultivars of cotton (e.g. Sudack, with white fly resistence, and others w/ hairy leaves that resist jassids.

Source: El Tigani M. El Amin & Musa A. Ahmed. "Strategies for Integrated Cotton Pest Control
in the Sudan: Culturasl & Legislative Measures
Insect Science & Applications. Vol. 12, No. 5/6, pp. 547-552, 1991, pp. 547-552.

The cotton decision structure, while extremely informative and Gezira-specific, evidenced little differentiation in the decision tree structure for the two varieties of cotton, as apparently is the case in real life; yet, a more complex decision structure would make for a more challenging exercise for the computer-based TARDIS system. Nonetheless, the exercise gives one a new level of appreciation for the thoroughness of on site agricultural research within the Gezira region and a deeper understanding of the complexity of tilling the soil to eke out an existence for any crop.

An alternative method for displaying the above listed procedures would be in the form of a decision tree structure. This would provide an opportunity to comparatively observe alternative paths toward improved crop yield, namely, one relying upon low risk, aggressive labor and capital intensive approach and one relying upon a high risk, cost containment minimalist approach, both temporally portrayed over the crop year.

Moroever, it would provide an opportunity to depart from the mechanistic mere listing of sequential procedures, so as to observe the role of human decision-making, the range of options posed by externalities or "acts of God", and the potentially propitious adaptive responses undertaken, in reaction to constraints imposed by the externalities. Accordingly, the scenario described in Charts 4A-4D, as found in the Appendix, are described below:

CHARTS 4A-4D, CHART 5 & CHART 6::
Sudan-Gezira: Crop Yield Enhancement Decision Tree for Cotton & Sorghum

- Charts 4A through 4D represent an extended decision tree for crop yield enhancement decisions, largely focusing on cultural control methods for pest management in Sudan's Gezira.

- Chart 5 is a more detailed insert occurring at Node 59 on Chart 4C, wherein a putative externality occurs, requiring an adaptive response or mid-stream adjustment, namely, intervention decisions for mitigating endemic schistosomiasis among the Gezira's agricultural workforce.
- Chart 6 illustrates Adaptive Response to Externalities During Growing Season

The three charts, listed and discussed below, can be found in the Appendix. It should be noted that Chart 4 is, in actuality, a temporal sequence of four charts (i.e. 4A through 4D), which prototypically chronicles the vicissitudes of Crop Year 2000 A.D. in the Gezira, selecting short and long staple cotton and an insect resistent cultivar as the planted crops for monitoring, under siege by an array of complex externalities. The multi-page decision tree for cultural management practices for pest control, as affects the Gezira's crop of long and short staple cotton, is presented for the Crop Year, (CY) 2000 A.D.

The chart covers preliminary soil preparation decisions, including sanitization of fields, deep plowing and flooding to reduce the quantity of insects in their diapausing stage, a decision to sow short vs. long staple or hybridized insect resistent "improved" cotton, further decisions with respect to fertilization, application of pesticides, weeding, watering, planting of so-called "trap crops" to decoy insects from the actual crop and early, late or on-time harvesting decisions, depending upon the specific cultivar planted.

At the time of planting, an unanticipated variable is introduced, namely a prototypical public health crisis, in which the available labor force for planting, and subsequent crop season activities, is threatened due to a combination of endemic schistosomiasis with epidemic levels of cholera and/or malaria.

The eventuality signals a segway to a more detailed insert chart (Chart 5, which picks up at Node 59 of Chart 4C and, after a extensive array of decisional considerations of alternative intervention modalities (i.e. minimization of exposure to health risk, therapuetic treatment of victims of schistosomiasis, habitat reduction of the snail species which serve as initial hosts for the helminth organism which causes the parasitic infection, eradication of these hosts and various combinations of the above choices), the segment of the labor force that is "cured" of the disease, in a timely fashion, "returns" from Node M of Chart 5 to weed, water and harvest the cotton crop varieties at Nodes 73, 75, 77, 79, 81, 83, 84 and 85 of Chart 4 C.

It is instructive to note that several potential strategies are potentially viable, ranging from a minimal fiscal expenditure/high risk approach to a labor and capital intensive/lower risk approach. In the minimal cost/high risk scenario, good fortune could still theoretically smile upon the cultivator choosing this path by providing adequate rainfall, minimization of insect infestation during that particular crop season and rapid recovery of the afflicted labor force to produce a modest cotton crop yield, which given the lower cost of production, still represents a net profit.

Alternatively, it is theoretically possible that a tenant farmer following the low risk, labor and capital intensive route might encounter "acts of God" such as reduced rainfall, major infestation of *Pectinophora gossypiella,* despite best cultural and commercial control efforts, a severe treatment-resistent public health crisis affecting the labor force, "acts of man" such as delays or other inadequacies in irrigation water availability, funding depletion at a critical period such as harvest time, when cotton pickers need to be hired, or lower than expected market prices for the harvested crop, failure of equipment for harvesting or ginning, or some combination of these or other factors which result in either crop failure, or a yield whose value, after discounting the higher cost of production, results in a net loss.

The basic decision to be considered within the context of the TARDIS decision module is the fundamental issue that has recurrently faced the Gezira: Should the Gezira tenant farmer plant cotton as a cash crop or sorghum as a food crop. Before the advent of the British in Sudan, the area now known as the Gezira scheme grew sorghum under rainfed conditions. Rainfed cotton production was then introduced, followed by monoculture cotton production, supported by a network of irrigation canals and subsequently augmented by smaller scale pump schemes.

In recent years, *dhurra* or sorghum cultivation has begun to displace cotton within the Gezira, for several reasons, (1) The nutritional vulnerability of the population associated both with drought and with dislocations caused by the civil war necessitated increased food production, (2) sorghum has been shown to be a sturdy drought-resistant crop, (3) cotton production costs have risen dramatically since 1920 largely due to pesticide and weeding costs, without a concomitant increase in average yield, (4) cotton prices have fluctuated and have experienced a downward trend, as synthetic fibers have proliferated.

The complexity of the decision as to whether to plant cotton vs. sorghum transcends a simple decision between rival crops, their anticipated yields, varying inputs required, differentiating among pests with a predilection for one crop as opposed to the other, market value of the harvest or labor requirements. The decision speaks to the fundamental relationship that the Gezira tenant farmer maintains with the global economy. In each instance, regardless of crop planted, the primary cultivator is essentially a share cropper, deriving livelihood from that segment of the harvested proceeds remaining after the Central Government, Sudan

Gezira Board and local "Islamic lending" institutions have received their shares of the harvest profits, in lieu of interest charges.

In the case of the cash crop option, the tenant farmer is more integrated with and dependent upon the global economy for crop pricing decisions that transcend local influences. The General Agreement on Tarriffs and Trade (GATT), market fluctuations, futures trading, etc. are generally beyond the purview of the primary producer. Nevertheless, the primary producer must await the sale of the harvest before resources are available for longer-term acquisition of basic human needs, including familial nutritional requirements.

The grain producer, on the other hand, particularly during the period of prohibition of grain exports, is at least able to set aside some produce for direct consumption and, while still dependent upon the local *souk* (marketplace), is more marginalized on the periphery of the global marketplace. Such marginality has the benefit, in this case, of eliminating intermediary economic transactions between the consumer and the consumable good, thereby potentially supporting food self-sufficiency and food security.

The scenario cited earlier in this chapter, depicting cultural methods for cotton crop yield protection, has been placed within the structure of a summarised traditional decision tree. Additionally, the decision to plant a food vs. a cash crop is included within the summation exercise.

Moreover, three plausible externalities for the Gezira area have been introduced into the decision analysis model, mercifully sequentially and not simultaneously, namely, drought with elevated temperatures (not unlike that forecast for the region under Global Climate Change scenarios for *circa* 2050 A.D.), an invasion of *Schistocerca gregaria* (desert locust), affecting the *Sorghum bicolor* crop yield, and epidemic levels of malaria *(Plasmodium falciparum)* and/or cholera *(Vibrio cholerae)* in conjunction with already endemic schistosomiasis, *(Schistosoma mansoni)* and *(Schistosoma haematobium)* within the study region, among the Gezira's tenant farmers and hired agricultural workers.

Each of these phenomena, individually, could apparently dramatically impact upon the region's crop forecast and the nutritional needs assessment. Moreover, they each have grave implications for increasing the vulnerability, and diminishing the self sufficiency, food security and sustainability of food production capacity in Sudan. Depending upon when in the crop calendar it would occur, drought frequently leads to crop failure and can result in massive population dislocation, famine and death, and, eventually, subsequent massive externally-generated relief activities. Sudan is no stranger to this scourge, having endured multiple droughts in the past three decades, each one diminishing the array of available coping mechanisms among the population at risk.

Locust invasions can also be devastating, resulting in virtually complete destruction of crops within affected areas. A major outbreak of schistosomiasis can impair the health and productive capacities of a region, resulting in severe labor shortages at critical times in the crop calendar, particularly for soil preparation, planting, application of fertilizers and pesticides, weeding, and, especially, at harvest.

CHART 5: SCHISTOSOMIASIS CASE STUDY:

Heretofore, we have discussed a wide range of diseases that afflict cotton and sorghum. Unfortunately, the Gezira's human population is also at risk. The population of the Gezira has endured frequent medical and economic studies associated with the plethora of hardships they endure. Climatic vulnerability must take its place in line among a host of other more immediate problems.

In addition to the concerns with periodic drought, famine, civil war, political instability and poverty, cited earlier, there is a substantial literature detailing the variety of health problems in the Gezira, which plague the agricultural workers, their families and their livestock. Taha (1996), on the basis of 1,348 in-hospital cases with 812 controls and 275 cases in the community with 1,248 controls, concluded that maternal malaria during pregnancy was significantly associated with low birth weight. While malaria continues to exert an impact on agricultural workers in the Gezira (Nur, 1993; Suzuki, 1991), its prevalence in the Gezira has declined significantly since the epidemic levels reached in the early 1970's. El Gaddal, et al. (1985) report that control was re-established in 1975, resulting from annual spraying of houses with malathion and subsequently with fenitrothion.

Conflicting results were obtained concerning the potential association between Hepatitus B and schistosomiasis in the Gezira, with Daneshmend, Homeida, Satir & Vandervelde (1984) identifying an association and El Toum, Ghalib, et al. (1991) reporting no such association. Based on yet another study of 851 subjects from two villages in the Gezira, Hyams, Al Tagani, et al. (1984)

found that 63.9% of the subjects were seropositive for a hepatitis marker. El Shafie (1992) found that 17.3% of 110 blood donors in the Gezira were Hepatitis B carriers, as were 12.1% of the technical staff at the facility where the blood was being collected.

Other studies in the Gezira found a high prevalence of inflammatory heart disease (Richter, Dengler, et al., 1990), Salmonella typhi O and S. paratyphi A (El Shafie, 1992), toxoplasmosis based on a 41.7% positive rate for 386 blood samples from the Gezira (Abdel Hameed. 1991). 76% of patients exhibiting symptoms of Brucellosis in the Gezira were found to have a combined infection of *Brucella abortus and B. melitensis,* presumably from the practice of eating raw meat and liver (a delicacy called *marrara*) (Mohammed, 1989). Of 29,615 school children from rural areas of Gezira and Khartoum provinces who were screened for Vitamin A deficiency, 2.9% were found to be decifient. The Gezira fared better than Kassala Province's Hawata District, however, where co-endemicity was found for malaria, brucellosis, enteric fever, tuberculosis and visceral leishmaniasis.

By far, the most substantial public health literature pertaining to the Gezira dealt with the causes, organism, life cycle, vectors, intermediate hosts, morbidity, diagnosis, treatment and control of schistosomiasis, a disease caused by a microfiliarial that spends part of its life cycle in certain snails and part within human hosts, where it causes an array of complications. The Gezira has been determined to be an endemic area for *Schistosoma (S.) mansoni, and S. haematobium.* Numerous field trials for the schistosomide phramaceuticals praziquantel (Kardaman, Amin, et al. 1983; Kardaa, Fenwick, et al., 1985; Homeida, et al., 1989; oxamniquine (Abdel Rahim, et al., 1988; Daneshmend & Homeida, 1987); and oltipraz (el Igail, el Tayeb, et al., 1985; Kardaman, Fenwick, et al., 1985) were conducted in the Gezira. While these medications were judged to be effective, their costs were usually beyond the reach of many victims.

Given the debilitating effects of schistosomiasis on the Gezira's agricultural and irrigation workers (el Karim, et al., 1987; Abdel-Rahman, et al., 1990; Satti, et al., 1996), on women (Parker, 1992) and on school children (Elsheikh, et al., 1989), it is logical that those tasked with recommending appropriate intervention strategies have access to the best possible relevant information sources, so as to maximize the potential for successful intervention outcome.

When encountering a level of severity for schistosomiasis prevalence in a area such as Sudan's Gezira, sufficient to trigger major intervention strategies Decision-Makers could conceivably benefit from knowledge about the baseline public health of the region, sanitation practices and, preferably, from satellite imagery, revealing potential habitat for the snail hosts for the microfilarial schistosome, as well as fiscal and human resources available to acquire and administer one of three antihelmintic pharmaceuticals, praziquantel, oltipraz or oxamniquine, and the environmentally applied mollucicides, such as Niclosomide.

Moreover, close collaboration with local domain experts on the history of control mechanisms applied within the region would be essential. In the case of the Gezira, the literature evidences that such expertise is vested with the Blue Nile Health Project (el Gaddal, 1985; Homeida, et al., 1994).

The life cycle of *Schistosoma spp.* offers numerous, complex and mutually inclusive potential points of engagement, where an eradication campaign might be waged. This is reflected in the accompanying decision tree example. For convenience, one might visualize these within the context of an intervention typology:

- Eradication of the initial host for the microfilarial, namely *Biomphalaria pfefferei* and *Bulinus truncatus*, using commercial mollucicides or local plants with biogenic mollucicidal properities, such as *Acacia nilotica's* subspecies *tomentosa* and *astringens* (Hussein, 1985). As humans are the intermediate host, this approach should contribute to a decline in disease incidence.
- Rendering the habitat of the snail host less hospitable.
- Introduction of predator and/or competing exotic species, as a biogenic control mechanism
- Improved early diagnosis and treatment of human victims, including drug trials calculated to enhance effectiveness under local conditions, reduce side effects and reduce costs of the treatment regimen.
- Environmental sanitation improvement to prevent reintroduction of the microfilarial into the aquatic ecosystem.
- Developing procedures to minimize the risk of workers who would otherwise be hyperexposed to the schistosome.

It should be emphasized that the probability of an outbreak of *Schistosomiasis ssp.* within the Gezira, beyond its already endemic levels, is unlikely, given the limitation of Nile embankments and the irrigation canal network extents in the transmission sequence. Recent field studies in two Gezira villages (Khein, El Toum, Saad, Ali, Baraka and Homeida, 1999) estimate the current incidence of Schistosomiasis within the Gezira to be 51/100,000 per year, with a fatality rate of 1/1,000 infected persons. The relative containment of Schistosomiasis within Gezira-Managil may also be credited to the efficacy of mass chemotherapy, based on prospective studies, as reported by Homeida, et al. (1996) and by detailed studies of the infection and transmission patterns in the Gezira-Managil irrigation schemes (Hilali, et al, 1995; Homeida, 1994). Focal mollusciciding in Sudan's Rahad irrigation scheme has also been evaluated (Meyer-Lassen, et al., 1994).

The reported occurance of *Schistosoma interculatum* in East Africa, with "probable hybridization with *S. haematobium*" (Villaverde, Santana, et al., 1997), might present further epidemiological and treatment challenges. A more likely scenario, however, would be the potential increased levels of debilitation among the Gezira's agricultural workforce caused by a combination of schistosomiasis prevalence with malarial and/or choleral epidemics.

Recent literature relating to unstable malaria areas in the Sudan (Theander, 1998; Babiker, 1998), and seasonal changes in the *Plasmodium falciparum* population in individuals, based on longitudinal studies in Sudan (Roper, et al., 1998), are potentially alarming, particularly given the ready availability of the Gezira's irrigation canals for harboring *Anopheles* mosquitoes and the emergence of chloroquine-resistent strains of malaria throughout the region.

With regard to cholera (*Vibrio cholerae*), UNICEF has been active in promoting safe potable water within the Gezira's villages, through introduction of bore wells and *hafir* rectification programs. *Medecins Sans Frontieres* reported in excess of 1800 cases of cholera in Sudan, apparently originating in fishing camps along the Nile River, with at least 700 fatalities (Preslau, 1996). This is despite the unveiling four years earlier of the oral cholera vaccine CVD103-HqR, developed by the Swiss Serum and Vaccine Institute (Cryz, Levine, Kaper, et al., 1992), which is obviously more easily administered than its parenteral predecessor.

For purposes of the decision analysis case study, we will, largely, confine ourselves to the sufficiently complex schistosomiasis example. As depicted in Chart 5 (Appendix) entitled "Schistosomiasis Intervention Decisions." Following Chart 5, in devising an appropriate response strategy, one would first consult the TARDIS pre-loaded baseline data, indicating the past history of *S. mansoni and S. haematobium* within the region. A vector-based incidence map could be overlaid on the current day's satellite overpass, unless excessive cloud cover warrants dekadal amalgamation. Patterns in the distribution of this disease, with a waterborne element in its cycle should implicate specifc irrigation canals or other slow moving bodies of water, since, unlike the vector for onchocerciasis, rapids are not preferred by the schistosome cercariae, nor by its snail hosts, *Biomphalaria pfefferi* and *Bulinus truncatus*.

The first objective would be to locate and identify the specific geographic areas where humans encounter the helminth and its snail hosts. Pavlovsky (1966) first articulated the concept of "landscape epidemiology," an emerging field concentrating on the geo-location of ecosytems wherein disease transmissions occur. Since that time, the emergence of satellite remote sensing has revolutionized the capability of public health practitioners to monitor the spread of environmentally associated infections and infestations and other vector-borne diseases, from space.

The list of diseases that have been specifically targeted for epidemiological investigations using remote sensing is already large and growing. They include Lyme disease (Dister, et al., 1997), Rift Valley Fever (Linthicum, et al., 1987; Pope, et al., 1992), Dracunculiasis (Ahern & DeRooy, 1996), Filiariasis in the Nile Delta (Malone, et al., 1997), Onchocerciasis in Bahr El Ghazal, Sudan (Baker & Abdelnur, 1986) and in Guatamala (Richards, 1993). Malaria monitoring and control, in recent years, has been one of the major beneficiaries of remote sensing technology (Beck, et al., 1994; Roberts, 1996; Thompson, 1997; Kawabata, 1998; Lindsay, et al., 1998; Hay, Snow and Rogers, 1998; Connor, 1999.)

Remote sensing applications for schistosomiasis has also been investigated by Cross, et al. (1984) and, specifically, for *Schistosoma mansoni* in the Nile Delta (Malone, et al., 1997). In addition to human morbidity, remote sensing has been applied to several diseases afflicting animals and plants, such as the control and epizootiology of anthrax among bison (Gates, Elkin and Dragon, 1995) and the monitoring of the invasion of agricultural areas by locusts (Hielkema, 1983; Bryceson, 1989; Cherlet and DiGregorio, 1993).

In the specific prototypical case study presented herein, the Gezira area is encountering externalities beyond the usual array of complex local conditions that have been expected, such as periodic drought, on-going civil war, political instability, undernutrition, rural to urban migration, emigration of technically trained Sudanese to the Arabian Gulf states, influx of refugees from domestic and foreign conflicts, immediate perennial insectivoral and nematodal threats to crop yield and anticipated long-term aridification and temperature increases.

Within the context of the prototypical case study, the new additional threat to the yield of food and cash crops and subsequently to regional food security for Crop Year (CY) 2000 comes in the form of identified *(prototypical yet plausible)* critical labor shortages, resulting from a confluence of public health crises affecting the Gezira tenants, agricultural workers and their families, namely epidemic levels of malaria (*Plasmodium falciparum*) and cholera (*Vibrio cholerae*), in combination with already endemic schistosomiasis (*Schistosoma mansoni and S. haematobium*).

All of the three maladies are seriously debilitating, can be life threatening, and, in actuality, are prevalent within the study area. Hence, local oficials are faced with a network of decisions, propaedeutic to devising an intervention strategy in collaboration with the Sudan Gezira Board, and potentially with agencies within the United Nations, and to the donor community. The feasibility of utilizing remote sensing technology to support this public health crisis has recently become more realistic, as organization support for research and intervention has reached a new plateau.

There is an increasing awareness within NASA, the Center for Disease Control (CDC), the World Health Organization and academe, that remote sensing has a potentially major role to play in the monitoring of vector-borne diseases. This awareness prompted NASA to establish the Center for Health Applications of Areospace Related Technologies (CHAART), with a mandate to develop disease surveillance tools, utilizing remote sensing technology. As of its last website update [http://geo.arc.nasa.gov/esdstaff/health/sensor/dataneeds.html] on May 5, 1999, CHAART had posted preliminary disease monitoring data needs for Hantavirus, Lyme disease, Plague, Rift Valley Fever and Cholera. Both Malaria and Schistosomiasis are on the proposed list for such articulation of data needs; however, as of this writing, they have not yet been developed by NASA.

One can, however, extrapolate from the journal literature to arrive at similar estimates for the two diseases of particular concern to the Gezira case study. In the case of schistosomiasis, Omer, Hamilton, Marshall & Draper (1976), based on Gezira village surveys in 1973, concluded that in the previous 25 years (i.e. as of 1948) the Gezira area of Sudan probably experienced a significant increase increase in *S. mansoni.* The symptoms they encountered were anemia, abdominal pain, exhaustion, hepatosplenomegaly, and bloody diarrhoea (Omer, et al., 1976). With *S. haematobium*, the urine is usually bloody.

The World Health Organization (WHO) is supporting both the Center for Research on Meningitis and Schistosomiasis (CERMES), established in 1977 and based in Niamey, Niger, and the Blue Nile Health Project, founded in 1979 and based in the Gezira area of Sudan. CERMES manages laboratories for experimental and clinical trials of vaccines and is currently performing efficacy and immunogenicity trials for a new vaccine for schistosomiasis, Sh28GST. CERMES is also equipped and tasked to process remotely sensed data in support of schistosomiasis mapping and control (Chippaux, 1998).

The Blue Nile Heath Project was awarded a ten year grant of $154 million, based on 1978 exchange rates, to improve strategies for controlling water-borne diseases within irrigation schemes. Its study sites are the Gezira-Managil and the Rahad Schemes. Based upon its preliminary findings, the appropriate strategy is to de-emphasize dependency upon pharmaceutical helmintocides, and environmental mollucicides, since their costs are beyond the reach of the vast majority of Sudanese and of their counterparts in areas of Africa, Latin America, and Asia, where schistosomiasis, diarrhoeal disease, malaria and cholera are prevalent. Their approach is to push participatory involvement with the community for sanitation, Public Health education, safe potable water supply, and re-institution of cultural practices to reduce vectors, hosts and disease reservoirs (el Gaddal, 1985; Haridi, el Safa & Jobin, 1985).

The accompanying global distribution map of schistosomiasis, prepared by NASA's CHAART , based upon WHO 1997 epidemiological data overlays on a 1987 global mean NDVI AVHRR scene, clearly shows the thin red line of high *Schistosoma* incidence bifurcating the Sudan from South to North, coinciding with the flood plain of the Nile River. The Blue Nile, which borders the Gezira-Managil, Wad Medani and Barakat area, joins to the North with the White Nile at the triadic intersection of Khartoum, Khartoum North and Omdurman, to form the Nile River, and proceeds northward, subsequently bifurcating Egypt. As the Blue Nile serves as the source of water for the Gezira's irrigation canals and the terminus for the canals' effluent and agricultural land run-off during the rainy season, the snail hosts for the schistosome cercariae have a convenient mode of transport and dissemination in the riverine wetlands, especially since these waters are still used for swimming, animal watering and, in many areas, for household usage, as well.

With the recent unprecedented severe flooding of the Nile in Khartoum, the potential for urban and peri-urban deposition of the requisite ecological conditions for schistosomiasis range expansion may be possible, if not probable. The potential may exist, inasmuch as there has also been a flood of rural refugees from agricultural areas in the South, whose peri-urban riverine squatter settlements have less in the way of sanitation infrastructure than their rural village counterparts. Remote sensing to support prediction of areas endemic for schistosomiasis, using Landsat, was described by Cross, et al. (1984) and thermal band data was utilized to identify schistosomiasis distribution in Egypt by Malone, et al., (1994).

There have been even more investigations that have utilized remote sensing to monitor malaria. The French government satellite, *Systeme Probatoire d'Observation de la Terre* (SPOT), was utilized to locate habitat and predict village-level abundance rates for *Anopheles albimanus,* (Rejmankova, et al., 1995), which along with *An. darlingi, An. pseudo-punctipennis, An. arabiensis and An. gambiae sensu stricto,* comprise the principal vectors for *Plasmodium falciparum*, the etiological pathogen for malaria. The latter two mosquito species are of primary concern to Africa (Lindsay, Parson & Thomas, 1998). The Landsat Thematic Mapper (TM) imagery was deployed to predict anopheline concentrations in Mexican villages (Pope, et al., 1994) and course resolution meteorological satellite data as used in Kenya to predict malaria seasonality (Hay, Snow and Rogers, 1998).

In the case of the decision example presented to plant sorghum vs. cotton, the simulated barrage of externalities, specifically, insect infestation of each crop, drought and an epidemic among the agricultural labor force, each have potential adaptive response scenarios that can thwart compelte disaster. In reality, thwarting disaster on a regular basis increasingly requires higher levels of sophistication in the the variety and potency of analytical tools and associated data access available to the field practitioner.

More sophisticated software add-ons might be warranted, at some point, depending upon the particular requirements and needs of the team members. Such possibilities include PC Version visualization packages (e.g. Data Explorer, FAST or AVS), and mission rehearsal packages (e.g. ERDAS Virtual GIS or PCI Fly). Likely specific crisis functions, data layers and their sources inlcude the following:

UNFAO-ROME	*UN FAO-KHARTOUM*	*SUDAN GEZIRA BOARD*	*UNICEF-WAD MEDANI*	*BLUE NILE HEALTH*	*WHO-KHARTOUM*
AVHRR	Coordinate Temp. Labor w/ILO&GOS	Area Planted	borewells	Incidence	Pharmaceutical Availability
Arrange Funding	Logistics & Travel	Cultivars	Hafirs rectified	Prevalence	Moluscacide Availlability
ARTEMIS & GIEWS	Interface w/UNDP	Pest Reports	ORT survey	Control Measures	Support for Primary Health
Past Mission Reports	High Res. Real-time Satellite Data	Inputs: Fertilizer, Pesticide, Water	MCH data	Location-Specific Data	Coordination with Sudan Ministry of Health
Demograph socio-econ. IBRD data	Maps: DEM Land use	Workers' Villages, Job sites	Infant Mortality	Vector & Host Control	Coordination w/NGOs,PVOs & Int'l. Donors
Epidemiol. Data - Past	Nutritional Survey/Food Supplies	Sick Leave Records	Educate Youth re: Swim.	Hospitals, Clinics	Media &Public Relations Coordination

In addition to completing the team's initial objectives, namely the annual crop forecast and the nutritional needs assessment, the Mission Team, in this prototypical simulation, undertakes to assess and make recommendations as to the mitigation of the current public health crisis, to adapt to the reality of labor shortfalls by invoking contingency plans, and to estimate the impact that the epidemic(s) will have upon (1) bringing the crop to successful fruition and (2) meeting the nutritional and food security needs of the region. Selection of the appropriate satellite sensor data is highly contingent upon the nature of the multiple objectives sought, the fiscal resources available, the degree of sophistication of the team member primary responsible for TARDIS operations, and the resolution, frequency, and longeviety of the imagery archive, among other variables.

The **mutually-inclusive** array of options facing the Mission, with regard to schistosomiasis intervention, would be, *inter alia*:

- Minimizing further exposure by the tenant famers, other agricultural workers and their families.
- Identifying appropiate treatment modalities and facilities for victims
- Reduction of snail habitat and food supply
- Improved sanitation so that feces and urine are not reintroduced into the waterways
- Eradication of snail hosts.

Three initial options were identified under the exposure minimization category, all based upon options actually attempted or implemented within the region in the past. These inlcuding issuance of hip boots to workers, such as canal cleaners/grass cutters, who are at risk for hyperexposure to schistosomiasis. The effectiveness range for this option is contingent upon worker compliance. During my own field visits to these sites, while accompanying Mission teams, I noted that very few workers in the canal waters utilized this equipment.

The responses to my inquiries were always the same. It was too hot and uncomfortable to work in rubber hip boots when the temperature was 110° F. Another option to be considered would be to change the schedule of the irrigation workers' shifts to early morning hours, when the schistosome cercariae were presumably less active (Tameim, Abdu, et al., 1985). While this had greater compliance, since the workers had no choice, it was extremely unpopular, since it meant a work schedule beginning a dawn, a long unpaid lunch break and work continuing into the evening hours.

The least popular option was the replacement of workers in the canals by machinery, namely flat bottom boats, tractors with long cutting arms that operated from the earth impoundment (levee) or from the adjacent roadway. While seemingly merciful and humanitarian, the end result was lack of wage employment, which was financially catastrophic to the worker and to his extended family, all of whom were nutritionally and otherwise dependent upon their "entitlements" accuring from the one paycheck.

With regard to the treatment of victims, two basic options have been tried within the Gezira. The first is simply to treat victims showing severe symptoms with one of three available schistosomide pharmaceuticals, praziquantel, oltipraz and oxamniquine. Each has been shown to be clinically effective during field trials in the Gezira. The rationale for the variability range is that the cost of a therapeutic dosage for any one of these medications represents in excess of a monthly salary (for those who are actually employed rather than dependent upon a share of *dhurra* or cotton at harvest).

There is the possibility of becoming eligible for a field trial, wherein the medication would be freely dispensed; however, one could potentially be in the cohort receiving the placebo. As a result of bi-lateral and multi-lateral donations, certain endemic villages received *en mass* treatment either annuallly or bi-annually. It is believed that this approach may be more beneficial, since it arrests the problem during the asymtomatic phase, particularly for children, and subsequently arrests the sequellae.

Reduction of the snails' habitat and food supply is another option. These include the introduction of workers to cut the grass (both food & habitat for *Bulinus truncatus* and *Biomphaleria pfefferei*) in the canals or their replacement by machinery, both discussed in the previous context. An inovative approach was the introduction of Chinese carp into the canals who competed successfully with the snails in consumption of the grasses; however, the effectiveness range is used here since the carp became a popular item for local fisherman, who thereby supplemented their family's protein requirements, at the expense of a schistosomiasis control mechanism.

The improved sanitation option would include the recommended erection of toliet facilities in the field, to prevent reintroduction of the helminths into the waterways. This was tried elsewhere and included western style toilets. Without instruction to the local population, they became stables for field animals with adequate watering facilities. By far, the most effective deterrent appears to have been a combination of Public Health Education, provision of a clean source of potable water and therapeutic treatment in for the villages (Tameim, Zakaria, et al., 1985). The provision of safe water supplies in villages, through UNICEF supplied bore wells and a campaign of *hafir* rectification was primarily conducted in support of cholera (*Vibrio choleriae*) control. There methods offered an alternative to the use of water from the irrigation canals for domestic purposes.

The eradication of the snail hosts has taken many routes, both in Africa, Asia and Latin America. The Chinese used labor-intensive campaigns to dig up, stamp out and burn the snails, with varying success. In the pump schemes, water presssure is periodically increased to flush the snails from the canals. In the Gezira, this approach is unavailable, since it is a gravity-based system. However, the water level can be suddenly lowered, leaving the snails, who prefer the area near the water line, high and dry. Other methods include application of the mollucicide, Niclosamide, and the naturally occurring mollucicidal bark from the local *Acacia nilotica*'s subspecies, *tomentosa* and *astringens* (Hussein, 1985).

Another exotic species was experimentally evaluated, namely, the Puerto Rican ampullarid snail, *Merisa cornuarietis* (Haridi, el Safi and Jobin, 1985; Haridi and Jobin, 1985). *Merisa* is larger than either *Bulinus or Biomphalaria.* It is therefore preferred by the schitosome cercariae, perhaps as a bigger target. Once inside the exotic snail, however, the cercariae do not reach maturity. It was speculated though that this snail might prefer the waters of Puerto Rico to those of the Gezira's irrigation canals. It has also been suggested that the Nile Rat (*Arvicanthus Niloticus*) might be a significant reservoir host (Karoum & Amin, 1985). The likelihood of eradicating this hardy creature is as probable as the eradication of its cousins in the United States.

Chart 6 presents in an attenuated summary fashion the plausible Adaptive Response Scenarios to Externalities during a Prototypical Growing Season, based upon an initial decision to plant a food crop or a cash crop. In this particular case study, the alternative options to be chosen are to plant as the food crop, *dhurra (Sorghum bicolor),* or as the cash crop, long staple cotton *(Gossypium Barakatensis)*. In Nodes A', B' and C', the Decision Makers observe meteorological and climatic conditions for the region, the epidemiology of illnesses among the labor force and their families, including vector-borne diseases, parasitic afflictions, as well as the degree to which the food and cash crops are at risk from insectivoral, viral, fungal, bacterial and nematodal invasion.

In Nodes D', E', and F', local agricultural management is faced with choosing appropriate adaptive responses concerning water management strategies, public health interventions and insect control strategies. In Nodes H' and G', The local agriculturists observe yield, with respect to the degree of insect damage, which is differentiated based upon the predeliction of certain insects for specific crops. In this case, the locusts prefer sorghum and the pink boll worm prefers cotton.

The critical feature of Chart 6 is its triaging of the crop management decision process into its component stages: (a) the basic decision as to what to plant, (b) the observance of intervening events beyond the direct control of the cultivator, (c) the formulation and initiation of adaptive response strategies and (d) the observance of crop yield, accuring from a combination of the viability of the initial decision, the accuracy and timeliness of the observations identifying and correctly classifying the intervening phenomena and the appropriateness and efficacy of the chosen adaptive responses.

It is at each of these chirotic moments that the TARDIS, righteously wielded, could offer substantive support to decision-makers. Briefly, the conjunction of satellite imagery and *in situ* data ingested into one of many integrative image analysis and spatial database packages can discern the range of appropriate crops to plant, based upon soil type, climatic conditions, terrain, elevation, slope, aspect, precipitation amount, fertilization, weeding and other cultural practices, irrigation facilities and control mechanisms for known preditory insect species.

In like manner, the system is ideally adapted to assist in the early warning of "intervening events" (e.g. drought, desert locust swarms and the monitoring of disease incidence and prevalence). Surely, the adaptive response determination is the primary rationale for relying upon the globally available best practices and wisdom to generate appropriate interventions. Finally, the crop yield monitoring function is one of the frequently utilized features of satellite and areal surveillance.

The strategies face constraints such as drought, medically-warranted labor force reductions, resulting from an epidemic, and crop infestations by pink boll worm (*Pectinophora gossypiella*), in the case of cotton, and by the desert locust (*Schistocerca gregaria*) in the case of sorghum.

It will be important for the follow-on TARDIS prototype to make use of the current state-of-the-art computer based decision support technology combining multimedia technologies & web interaction, (Beroggi & Wallace, 1998; Flavin & Totton, 1996; Smith, 1998; Poe, Klauer & Brobst, 1998), and to secure appropriately specific domain expert decision process data for *Sorghum bicolor* and, possibly for *Pennisetum typhoides*.

It will be even more important to be cognizant of the specific contributions that decision support can offer under the conditions of uncertainty encountered regularly in contexts such as the Sudan case study. The degree to which TARDIS can assist in eliminating some of the uncertainty is evidenced in a briefly described scenario, derived from the schistosomiasis example. Assuming availability of high resolution imagery for the study area ffrom FAO-Khartoum, e.g. SPOT or IRS, the intervention scenario would utilize the higher resolution imagery to periodically monitor the opening and closing of locks within the canal system.

With the acquisition from the Sudan Gezira Board of data relating to worksite location and home village for the Gezira workforce and schistosomiasis incidence from the Blue Nile Health Project, it would then be theoretically possible to correlate incidence with worksite, canal opening and associated availability of schistosome cercariae with hgome village, where the cycle become complete. A more targeted intervention would then be possible, utilizing Acacia Nilotica or Niclosomide at the site of the suspect waterway adjacent to the worksite and oltipraz or praziquantel at the implicated village. Such targeted intervention would not be possible without on-site technology, such as TARDIS.

THE UNITED NATIONS MISSION TEAM:

During my two three-month research assignments in Sudan, initially as a United Nations University (UNU) Fellow and, subsequently, as a member of the National Advisory Council for the U.S. Committee for UNICEF, I had office facilities at both agencies and had the opportunity both to attend briefings and to accompany several Mission teams, as they performed their assessments throughout the Sudan. These experiences convinced me that ready access to archival data on the regions, the ability to dynamically interact with the data and to incorporate more accurate ground truthing, and identify location-specific implementation constraints, could substantively facilitate and enhance the contributions rendered by the U. N. FAO Expert Missions.

The UN interdisciplinary Mission team would be faced with offering recommendations to the host government and to their respective multi-lateral agencies concerning a hypothetical epidemic of *Schistosoma mansoni* and *S. haematobium*. The Mission team's representative from the U.N. World Health Organization (WHO) would have a vested interest because of the threat to public health and because that agency has been the primary source of funding epidemiological investigations and disease control within the Gezira-Managil and Rahad Irrigation Schemes, through support of the Blue Nile Health Project and the Sudan Ministry of Health's Primary Health Care Programme. Double blind drug trials and longitudinal studies have been carried out under these auspices.

The U.N. Food and Agriculture Organization (FAO) representative's main function would be to determine the degree to which the debilitation of the labor force impinged upon agricultural production, and the projections thereof, within the region and, accordingly, to assist in the collective determination as to how to mitigate the effects of the epidemic.

The World Food Programme (WFP) representative's primary objective would be to determine how the epidemic among the Gezira's tenant farmers and agricultural workers might impact deficits in food production and otherwise contribute to the increased nutritional vulnerability among the Gezira's population and, concomitantly, increase their dependency upon the largesse of external donors. Such dependency, in the prototypical case study, would presumably be the result, in the event that crop yield is negatively impacted by labor shortages during critical labor-intensive phases of crop production, such as land preparation, planting, weeding, fertilizing, pesticide application, and harvesting.

All three members of the team would have as their immediate objective the assessment of potential intervention strategies designed to control the epidemic and thereby both attenuate human suffering, abate the environmental hazard and restore the previous level of productive capacity in support of regional food self sufficiency. Accordingly, there is a demonstrable need for support tools to assist teams members, who, although experts within their own disciplines, may not necessarily be briefed on the local history of prior efficacious treatment modalities, intervention strategies, demographics, and locally available resources that can be marshalled to confront the public health problem.

To address this apparent need, the TARDIS approach is offered, based upon the assumption that important decisions, even when rendered by experts, dererve to be made in an information-rich environment.

During the pre-Mission planning period at FAO headquarters in Rome, the team members are provided either with an additional team member skilled in the operation of the standard suite of optional software packages, which are assembled in accordance with the specific nature and locus of the mission. Alternatively, one or members of the team would be offered participation in a two day training program at FAO offices, suitably equipped for such short-term hands-on instruction or, ultimately, available to the team member at their home institution, prior to arrival at the Rome briefing, through distance learning. The short-term self-paced training courses would be designed to provide team members with the essential operational tools for addressing the more common array of problems.

Upon arrival at FAO headquarters, after completion of the training modules, team members would have access to the FAO help desk for assistance with any unclarity or for specialized functions, as needed by the particular objectives of the Mission. The array of high performance computing resources already in place at FAO and its sister agencies would be transparent to the mission team members.

Macro commands enabling rapid access and pre-authorization certifications for the team members to remotely access FAO and other UN agnecy databases from the host country destination would be pre-loaded on the TARDIS lap-top assigned to each Mission. One team member would be designated as being the primary operator with singular responsibility for its security.

The team would have pre-loaded on removable storage or CD, the corpus of the archive of time series AVHRR NDVI data for the study area, as derived form the FAO ARTEMIS database, the reports of all previous annual missions to the region, and demographic baseline data from WHO and the World Bank's ANDREX database. These databases are available to the UN community and other academic researchers, free of charge. Other more specialized data and software would be available for pre-load, as needed to carry out any specific functions demanded by the U.N.

All TARDIS field laptops, would have a standard set of software, including decision analysis, GIS, GPS, wordprocessing for report preperation, and a spreadsheet.The available optional software packages from which the Mission operatives could select on an as-needed basis are packages supporting: remote sensing image analysis, an object oriented relational database, a statistical analysis package and software for scientific visualization.

Upon arrival in the host country, more region-specific archives would be available, including low cost (to FAO and, of course, gratis to the Mission team) higher resolution real-time satellite imagery, acquired on site at the FAO Resident Representative's headquarters, a large srcreen display for mission rehearsal, logistics and planning purposes, and relevant unaggregated data on local production and associated socio-political constraints. Once in the field, the discovery of anomalies or problems could necessitate immediate access to the Resident Representive's workstation or satellite imagery archive via mobile satellite telecommunication. Similarly, emergency situations prompted by regional hostilities, disease outbreaks, unanticipated crop failures, sitings of *Schistocerca gregaria* (desert locust) hordes, etc. could occasion direct linkage to FAO headquarters.

Since Sudan is the prototype beta test for the mission, the graphical user interface (GUI) would be specific to the region. Ultimately, once the system is approved for wider deployment, UN Mission teams would have access to user selectable global databases, from which one could select any given country, and groups of countries, as dictated by the need to conduct comparative analyses *in situ.*

The semi-annual interdisciplinary UN Crop Forecasting and Nutritional Needs Assessment Missions to Sudan and to Southern Sudan, led by the Food and Agricultural Organization (FAO), accompanied by representatives or consultants retained by the World Food Programme (WFP), and, depending upon the nature of the set of anticipated problems faced within the region, are sometimes augmented by representatives of agencies such as the United Nations Childrens Fund (UNICEF), the World Health Organization (WHO), or the United Nations High Commissioner for Refugees (UNHCR).

It has earlier been suggested that the mission team might further be augmented by a representative of the Global Terrestrial Observing System

(GTOS), so as to contribute to a better understanding of the array of adaptive responses that might be warranted as a result of predicted climatic change within the region.

The intended primary contribution of TARDIS to is provide such UN Missions with a decision support tool that would facilitate the carrying out of their primary functions, enhance the accuracy of projections, foster interdisciplinary collaboration within the team, and take advantage of advances in the state-of-the-science mobile computing, remote sensing, global positioning, satellite telecommunications, real-time global database access and scientific visualization technologies.

Accordingly, Chart 2 (See Appendix.) illustrates the relationships among the various componets and support networks for the TARDIS. Specifically, a simple laptop computer is recommended, with a basic array of software for remote sensing image analysis, geographic information systems (GIS), global positioning system (GPS) receiver, data visualization capability, decision support system software, word processing and spread sheet software for mission report preparation, ideally satellite telecommunications to FAO headquarters in Rome and to the FAO Resident Representative headquarters within the host country, and modem access to globally distributed databases, via the internet.

Ancillary uses could ultimately include potential benefits to orienting UN staff and consultants, new to a given region, to training UN field support personnel and to assist in providing evocative feedback to host country officials with regard to the missions' findings and their implications for public policy and adaptive response.

The sophistication of these laptop field computers could be minimized by pre-mission planning and downloading of relevant archival data at the UN FAO headquarters in Rome. These downloads would include, for example, archival tabular data on agricultural productivity for the selected region, past FAO and affiliated agency Mission Reports for the host country, relevant epidemiological, demographic and socio-economic data for the region(s) to be visited, and multi-temporal satellite imagery for the area.

Upon arrival in the host country, usually with logistical support from the United Nations Development Programme (UNDP), the Mission Teams meet at the sponsoring UN Agency headquarters for orientation, mission planning and location-specific briefings. In the case of the end-using teams to whom TARDIS is directed, such briefings would occur at the FAO Resident Representative offices. For the Sudan case study, this offices are located in Khartoum. Ideally, the FAO offices within the host country could be equipped with inexpensive real-time receiving stations for satellite imagery of the region, to empower their own staff to incorporate satellite imagery into their planning and assessments related to meteorology, land cover, land use and to readily identify anomalies in comparison with the archival imagery as well as to support the periodic U. N. expert Missions to the country.

Such an eventuality, although prototypical, dramatizes the potential utility of improved information at the field level. Initially, the UN FAO Mission Team scenario is proposed, wherein superior knowledge, as typified by the TARDIS, based upon a combination of archival tabular data and satellite data, real-time higher resolution data, ability to integrate region-specific contemporary data and model the extrapolation of that data, can be used to make a mid-term adjustment to cultivation strategies.

Ultimately, subsequent to successful protyping, beta-testing, improvements in user friendliness and lowered costs of production, TARDIS technology could be transferred to the local agricultural management entity, in this case, the Sudan Gezira Board. Thereby suitably empowered, it is conceivable that the Board eventually could choose among a larger set of visualized alternative futures: that which one aspires to replicate, that to be avoided at all costs, and that with which one might more reasonably formulate an adaptive response, in the face of inevitable environmental changes in the regional context.

In its crop forecasting and nutritional needs assessment role, the UNFAO must take into consideration a wide array of variables that could potentially affect crop yield. Diseases afflicting crops at various stages of their development represent only one such array of variables. Especially in areas where multiple crops are produced, even this one variable can present a level of complexity that could potentially benefit from structured decision support. The comparison between diseases differentially affecting cotton *(Gossypium spp.*) and sorghum *(Sorghum bicolor (L.) Moench)* illustrates the complexity and can be found in the Appendix.

Decision support structures for each of these phenomena, exempletive of the variables to be encountered by the UN FAO Mission teams, are provided herein to underscore the potential utility of a TARDIS support tool in field settings. In each case, the emphasis is placed on the kinds of decisions a prototypical such interdisciplinary team would likely be called upon to make in the process of formulating their reports to the host country and to FAO headquarters in Rome. Consequently, it would not be anticipated that such a constituted team would either be providing logistical support for direct relief activities during a drought, or selecting and deploying pesticides for locusts or offering diagnosis and treatment of individual patients with shistosomiasis.

Rather, the Mission's context for decision-making is centered on those aspects of the externalities that impact, directly or indirectly, upon the region's continuing capacity to bring agricultural produce to term, to assign a quantitative measure to expected agricultural productivity and harvest yield, and to ascertain, assess and quantify the factors which contribute to regionally disaggregated nutritional deficits, within the host country.

As is frequently the case in more industrialized countries, local prophets are seldom recognized. The magisterium of recommendations from a joint U. N. Expert Mission can usually carry more weight with potential funding sources for preventive or therapeutic interventions within a host country than can the scholarly publications of indigenous planners and practitioners. Accordingly, it would be important for the U. N. Missions to willingly utilize their credibility in support of sound practice and priorities articulated by the host country's domain experts.

This commentary on potential schistosomiasis intervention strategies, are not to preclude the wisdom of the FAO/WFP/WHO Mission experts, who may very well derive combinatorial or novel approaches to this problem; rather, they are presented merely to serve as an indicator of the contextual complexity and wide range of decision options. In so doing, the Mission might still benefit the wide range of relevant biogenic and anthropogenic data sources that could be integrated and made accessible to the team, as a result of TARDIS availability.

The UN Mission team in the Gezira, in this example, have at their disposal a laptop computer, with wireless telecommunication links to the U.N. Resident Representative's headquarters in Khartoum and, in case of emergency data needs, with the FAO Headquarters in Rome. The team's basic TARDIS configuration includes a mobile GPS Unit (e.g. Trimble, Ashtech, Rockwell, Garmin or Magellan) for geopositioning specific vector habitats or heat/water/insect stressed agricultural plots that can subsequently be entered as vector data layers, a portable data recorder, a hand held radiometer, a GIS software package capable of ingesting, analyzing and displaying raster and vector data (e.g. Terra's Agricultural GIS (AGIS), ERDAS Imagine, ESRI's ARC/INFO, PCI's SPANS, Clark University's IDRISI, NASA Stennis' ELAS, the Corps of Engineers' GRASS, New Zealand's EPIC), a spreadsheet with charting capability, a statistical package (e.g. MATLAB, SPSS, etc.), a word processing package for notation and for preparation of the team's report, a relational database package (e.g. PC Focus, Informix SQL, PC Oracle or even DBASE), into which local data on crop inputs, worker disease incidence, row seperation, interstitial cropping, evidence of nematodes, weeding status, termites (*Macrotermes ssp.*) or the pink boll worm (*Pectinophora ssp.*), sorghum panicle size and stalk height, reliability of mechnization, etc. might be entered in the field.

The salient feature of the UN Mission's presence in the field, with a locked and loaded laptop-based decision support tool, is not so much how many commercial software packages and external databases it can readily access and manipulate, but, rather, the more fundamental contribution that field-based adaptive response, based upon intelligent usage of inter-agency archival data, satellite imagery and trend projection capabilities, itself, is a technology allocation policy alternative whose time has come.

The era of insular proprietary scientific data archives available only to the authorized host agency cognoscenti, who issue annual reports, has given way to the realization that the complexity of decisions in the primary producing sectors, not to mention those within the manufacturing and the service indutries, warrants both collaborative archival access and the flexibility to intervene quickly under dynamic field conditions. As reflected in the accompanying decision trees, the initial decision paths taken, need not lead one ineluctably to the brink of disaster, even if based upon short-sighted prespectives at the outset, provided that the capability to make mid-course correction is maintained.

Having reviewed the decision trees as applied to specific events within the crop cycle, the life cycle of the schistosome, the cyclical meterological events that impact on Sudan's Gezira, and the role of the periodic U.N. Missions to Sudan, it may be helpful to identify certain overarching themes that transcend the dicretized decisions. First of all, no set of decision(s) are so etched in stone and so sacrosanct that they cannot benefit from an opportunity to be corrected at mid stream. Secondly, it follows that inasmuch as decisions are only as good as the data inputs upon which they depend, then a dramatically improved set of data inputs should provide a basis upon which to improve the quality of the decision-making enterprise. The corollary of these "themes" is that the TARDIS emphasis on provision of mid course adaptative response capability and information-rich global data accessibility would appear to be well founded.

CHAPTER VI: CONCLUSIONS AND RECOMMENDATIONS:

In the preceding Chapters, we explored the complexity of the decisional context faced by the indigenous decision makers and by the UN Team in its supportive role to local agriculturists and Public Health officials. Moreover, we described the component modules and associated array of support tools inherent within TARDIS and its linked home base installations. Subsequently, we advocated on behalf of formulating decisive plans within the context of an information-rich environment, so that rapid deployment of appropriately targeted intervention strategies and adaptive responses could occur with a higher probability of success.

In the process of synthesizing the multi-source data relating to Sudan's Gezira and subsequently constructing the decision trees, the potential role of the prototypical UN Joint FAO/WFP/WHO/GTOS Misson to Sudan, or some similar combination of collaborating UN agencies, began to emerge with greater clarity. Such Joint UN Missions (with variations in agency composition) have been dispatched around the Third World for decades and have performed their tasks admirably. They have also adapted to changing conditions and revised their estimates, based upon "mid stream corrections," an appropriate and essential action working within a context fraught with uncertainty.

The essence of the argument herein is not predicated upon any assessment that such UN Missions have been ineffective in the carrying out of their functions. On the contrary, it was precisely because of the level of commitment to painstaking detail, to a high level of professionalism I was privileged to observe during several Missions to Sudan, to aggressive reliance upon interdisciplinary data sources and to the regularity of visitations to discrete regions, even amidst armed conflict conditions, (It was reported that UN FAO WFP Mission team members were ambushed and killed in Sudan this very day that I write this concluding chapter.) that prompted me to recommend that such UN Missions are best positioned to play a vanguard role with respect to deploying state-of-the-science technology in support of food security, sustainable agricultural productivity, pest management, control of infectious and parasitic diseases in man, and adaptive response to impending climate change.

To this end, the TARDIS concept offers some capabilities that transcend the array of resources currently available to such UN Missions. In the accompanying decision trees, an attempt was made to depict specific examples as to how the process might unfold within the Gezira case study. Within our basic framework, the UN Mission's experts are confronted with prototypical complex externalities which threaten to significantly impinge upon the production one of the region's historically important cash crops, cotton, and the most important food crop for the region, sorghum.

The specific externalities selected represent a direct impact on crops (i.e. major insect infestation), on the agricultural workers, themselves, and their families (i.e. malaria and cholera epidemics, in conjunction with endemic schistosomiasis) and a climatic phenomenon (i.e. drought) whose effects are shared by humans, plants and animals. These selections are by no means meant to be exhaustive of the set of maladies afflicting the region, to which TARDIS might also have been focused.

The looming threat of the HIV infection epidemic in Africa and its debilitation of the workforce is a tragic reminder that we have not attempted herein to address the complete set of infectious diseases in the region. Moreover, this particular region does not represent the sole appropriate locus of deployment for the TARDIS development concept. Any natural resource management issue in any geopolitical arena might conceivably benefit from a decision support system, linking archival and real-time satellite imagery, tabular past and current data and future scenario generation.

Within this geographical context, however, and with these specific externalities, we should have sufficient complexity with which to elucidate and dramatize the prototypical options facing the UN Mission. In the Adaptive Response to Externalities During the Growing Season Chart, for example, the initial decision to be made is whether to plant sorghum or cotton. Obviously, the role of the UN in this instance, as in most of the examples, herein, is advisory. The Mission can offer recommendations, provide incentives, and, where warranted, bring diplomatic pressure to bear.

Nor is the decision left to the judgement or whims of the tennant farmer. The Gezira retains vestigial management structures carried over from its Birtish/Egyptian Condominium colonial plantation sharecropping days, from its Soviet-style collectivized farming days before Nimiery’s metamorphosis, from its right-wing military dictatorship days subsequent to Nimiery’s metamorphosis, to its current hierarchical fundamentalist theocratic regime days, under Omer el Bashir. Ironically, for all of these divergent ideologies and associated modes of production there has been a common feature as relates to Sudan's Gezira, namely, the centralized control of decision-making for such mundane matters as what to plant, where to plant, when to plant, what inputs to use, where to market, what price to receive, what percentage the sharecropping tenant farmer receives for compensation and when such emolument might become available.

The social disadvantage of distancing the cultivator from the decision process is that creativity is stiffled and the potential for incorporating domain expertise or adaptive response on an individuated basis is severely compromised. The rationale for centralizing decision-making in the hands of the Gezira Board, is said to be that, thereby, one can more equitably allocate scarce resources such as water, mechnization, pesticides, fertilizers, and hybridized cultivars.

For the UN Mission, this *status quo* structure was initially convenient, in that the source of cropping data is uniform and centralized, and the potential partner in an ultimate TARDIS technology transfer scenario is clearly designated. For the long run, however, the system suffers when it is bereft of the informed judgement and local expertise that can only come from working one's land. The emancipation of localized decision-making must apparently await yet another iteration in Sudan's socio-political process. It must, therefore present a challenge for the Sudan Gezira Board to render sound judgements, without such input on a regular basis.

Independent of the identify of the local decision-making entity, is the need to strucutre the agricultural monitoring process, such that it follows the initial crop choice strategy with observation of weather conditions, worker health status, and degree of insect infestation, *inter alia,* so that one can choose an appropriate set of adaptive responses, impproved irrigation management, health intervention techniques and pest control strategies. The observed crop yield is subsequently more than merely the result against which the accuracy of the previous year's crop forecast can be rated, it is also the residue from the perennial battle against the bugs, the reward for careful management of water resources and the vindication of the campaign to restore the health of the agricultural labor force.

Tucker, Gillespie, Starr and Twiddy (1994) describe a process for scientific visualization of land cover changes from Landsat Thematic Mapper (TM) and Multi-Spectral (MSS) data archives, utilizing the twenty year archive of satellite imagery for the period from 1972 to 1992. They employ the red, blue and green color channels to provide a degree of photo-realism, a digital elevation model to render the images three dimensionally and Alias Wavefront Composer Video Editing software to produce animated sequences, allowing the end-user to view landscape changes from helicopter perspective. Moreover, they use date/time-matched imagery, so as to minimize gross differentiation in shaddowing over time (cavallo@leaf.gsfc.nasa.gov).

The initial sophistication of TARDIS, by contrast, need only be that which is required to address the demands of the case study. The Gezira's relatively flat terrain would probably allow two dimensional imaging to be sufficient. The important point to be made is that the field deployment of TARDIS facilitates the ability to adjust to changing circumstances, to input local data critical to nutritional needs assessments, crop forecasting or climate monitoring that is either unavailable or too aggregated at the scale downloaded in Rome or even at the Resident Representative's offices in Khartoum.

Both conclusions and recommendations are bi-polar. A set of each relate to the Sudan case study and the other set relate to the TARDIS tool. With regard to the Sudan case study, we have reviewed the current context in which decision-makers and planners perforce must operate. The picture painted thus far has admittedly been grim, a confluence of events and circumstances that challenge the ingenuity and resilience of those faced with making hindcasts and forecasts of various descriptions in the midst of civil war, endemic infections, undernutrition, insect pests, and climatic change.

Yet, if one deliberately opts to identify positive signs, they can be discovered. The December, 1998 Report from the UN FAO/WFP Crop Forecasting and Nutritional Needs Assessment Mission to Sudan) reveals the following Mission Highlights:
(http:www.fao.org/faoinfo.../english/alertes/1998/Srsud986.htm)

- A record harvest of 6.51 million tons of cereals is forecast, of which 75% will be sorghum, due to well distributed rains from July onwards, timely availability of agricultural inputs and few outbreaks of pests or diseases.
- High production plus carryover stocks due ban on sorghum exports in previous years will result in large cereal supplies in 1999.
- Sorghum market prices have fallen below production costs in the main farming areas, which could result in sharp reductions in areas planted next year.

The remaining 1999 mission highlights do go on to confirm that 2.36 million people will be in need of emergency food assistance, but that this could be locally purchased & distributed given current surpluses. If record harvests can occur in the midst of all the biogenic, political, economic and military dislocation, there is some hope that under a more normalized set of circumstances, adaptive response to longer term challenges could potentially be mobilized.

The threat to business as usual posed by the climatic trends appear real, but not insurmountable, particularly given the resilience of the Sudanese people who have survived under harsh conditions for millenia. The array of pests afflicting cotton, millet and sorghum appear formidable; yet, the domestic agricultural research capacity is strong and active. The regionalized malnutrition persists; yet, the international aid community is no longer barred from intervention and the periodic famine outbreaks are no longer denied. This is not to say that the widely reported human rights violations and inequities are inconsequential. To the contrary, there is every reason to remain vigilant and steadfast in using every pressure to bear in resolving these crises.

As to the specific vulnerabilities posed by aridification and warming, the time series data available to us revealed that the irrigated sector at peak greenup showed minimal reduction in vegetative cover within the agricultural fields during the drought years; however, there were significant reductions in non-irrigated vegetation, including forests, grasslands and rainfed agricultural areas. The tabular records do show reduced yield in the irrigated sector, despite the remotely sensed appearance of uniform vegetative cover. The threat to savannas and forests and to rainfed production is significant, not only with respect to yield, but also with respect to soil conservation, desertification, carbon sequestration and to grazing potential for farm livestock and from transhumant populations, such as the Rufa'a, and their herds.

The diminishing returns, increasing insect immunities to pesticide applications, and increasing costs of pesticides argues well for a return to the cultural control practices as recommended by El Etigani and Ahmad. The mitigating factor here is the year-round labor intensiveness of such control measures, particularly given the need for farmers to find off season wage employment to cover costs associated with input purchases and family food security. Moreover, the cost of regular weeding exceeds the costs of pesticides when such work cannot be fully accomplished by family members.

For the TARDIS development of concept, several areas of improvement were identified in the process of the case study that should be included in the subsequent design and operationalization of the system. For the Archival Visualization, the existing control panels on overflight software are too cumbersome and unresponsive. The should benefit from long-term existing video game technology, such a flight simulator controls, which are more steady and allow operators greater degrees of freedom. The rendering of terrain suffers from data minimization to enhance speed, but at the cost of realism. The image classification and change detection features within the major raster GIS packages are adequate. For the next iteration, a comparative analysis of the alternative methods would permit the development of an expert system to steer end users to the particular set of analytical tools best suited for their specific array of tasks.

As stated earlier under the decision support section, a more challenging complex decision structure would have provided a better test of computer assisted decision support. The cotton pest model was initially seductive because of its level of detail, time dependence, and specificity to the Gezira's agricultural productivity. The differentiation between long and short staple cotton was subsequently discovered to require uniform land preparation, inputs, pest control methods, and post harvest maintenance. The only differentiation that emerged was in sowing and picking dates. An array of suitably complex yet still useful points of decision will be generated for the follow-on TARDIS prototype.

The future scenario generation should in future include the standard set of Global Circulation Models (GCMs) and Integrated Assessment Models (IEMs) so that any innovative regionally-based approach could be legitimately compared with the "industry standards," and thereby be suitably benchmarked. The long term crop forecast idea appeared to have merit initially; however, too many extraneous factors can impinge upon crop forecasts from year to year. This was evident from **UNFAO's** missions' forecasts, which have to be adjusted annually to conform with the reality. The prospect of making such predictions for 10 to 50 or 100 years into the future stretches them beyond the elasticities of their capabilities.

This is even more so with respect to nutritional needs assessments. The initial intent was to utilize all the socio-economic and political data along with the yield, pricing and export/import data, just as the World Food Program does annually in Sudan, and elsewhere, to come up with a composite need based on the gap between local production, local market availability, pricing constraints, and the largesse of international donors. The feasibility of multivariate extrapolation of that magnitude and the foregone conclusion that the result would be meaningless became too apparent. That still leaves the task of reformulating the IEMs & GCMs to be more regionally relevant, more cognizant of social, political and economic realities and not just temperature, gas forcing, evapotranspiration and cold cloud duration.

Plan for Future Development of TARDIS:

Subsequent TARDIS iterations will be driven by ascertaining client agency interest in and perceived need for a TARDIS-like tool. To permit clients to make such an informed determination more easily, it will be necessary to develop an operating TARDIS prototype that can be demonstrated utilizing client data. A TARDIS version implemented in a scalable high performance computing UNIX environment is envisioned for implementation at the international multi-lateral agency, a dual processor NT workstation variant at the national level and a Windows-based high end laptop at the field mission level.

Parallelization is clearly not needed for operation of the Pentium II Windows-based laptop unit to be utilized as part of the field Missions within the host country. Nor would it be essential for the NT workstations that are eventually envisioned at the national level at UNFAO Resident Representative headquarters within the host country, although such workstations could easily come with dual processors, each running at 550 Mtz.

GTOS/FAO offices in Rome, has worldwide responsibility for global and regional scale monitoring of terrestrial, oceanic and atmospheric climate change impacts and their interactions. Ideally, for purposes of supporting regional-scale planning and decision support, the agency could dedicate a UNIX-based multiple processor scalable high performance computing system, with real-time satellite receiving capability for, at a minimum, AVHRR, Meteosat or GOES, and periodic higher resolution imagery for Long Term Ecological Research Sites and high risk regions. This would represent a significant adjunct to current support services for regional-scale climatic impact assessment.

The Rome-based facilities might ultimately allocate additional support, as the number of regions-at-risk are identified and expanded. Such facilities could include high band width communications, high resolution graphics capability, and peripherals to support multiple media data exchange among the regions at risk would be essential to support mission planning, training and long term ecological research, a visualization capability is recommended, possibly, but not necessarily including technologies such as Powerwall, Immersidesk, CAVE environments or their future technological successors.

For the Sudan case study, the proof-of-concept TARDIS was an amalgam of discrete components, hypothetically united by a common set of tasks relating to an identical geo-location, and conceptually linked as part of a cohesive array of logically sequential functions. For subsequent follow-on research the expectation is that TARDIS' evolution would entail full modular integration and that, moreover, it would itself serve as an integrative mechanism, facilitating the merger of satellite imagery, tabular archival data, *in situ* environmental measurements and a wide array of social, political and economic data, of relevance to food security attainment, under adverse climatic perturbations.

Bouchon-Meunier (1998) in Aggregation and Fusion of Imperfect Information , categorizes data fusion and information aggregation techniques into two major categories, those which are predicated either on the **aggregation of individual or group preferences** or on **criteria satisfaction aggregation and the multi-source fusion of evidence**. In each instance, emphasis is placed on the fact that imprecision, uncertainty and lack of completeness within the data inputs are inherent to many, if not most, decision settings, requiring the intervention of approaches, based upon probability theory, possibility theory, evidence theory or fuzzy set theory.

A promising knowledge-based data fusion and triage approach was being developed by William Campbell and Nicholas Short at NASA Goddard Space Flight Center, in support of facilitating the intelligent identification and integration of the daily terrabyte of data flows anticipated from NASA's Earth Observing System (EOS).

A priority for the next iteration of the TARDIS concept, the TARDIS 1.1 Beta Version would be the development of a coherent and user-friendly documentation set. While a standard printed volume might be feasible at the central facility in Rome and even at the FAO Resident Representative's headquarters in Sudan, it is clear that field missions will require a users manual that is available on-line, on CD and preferably accessible through the Help menu. Simplicity must be maintained, given the multi-cultural make of both U.N. staff and consultants. Wherever possible, international symbols and objects will be utilized to maintain a familiar look and feel with software packages commonly used by U.N. personnel.

Prior negotiations will be necessary with the OEMs for the various COTS that comprise TARDIS modules, so that a distillation of essential instructions relative to their specific packages, or at least to those segments of their packages that are basic to TARDIS, might be integrated without violation of intellectual property restrictions. It is conceivable that such documentation may require translation into Arabic for wider accessibility among the staff of the FAO Resident Representative in Khartoum, and possibly other languages, based upon the nationalities represented on the FAO/WPF Missions to Sudan and to Southern Sudan.

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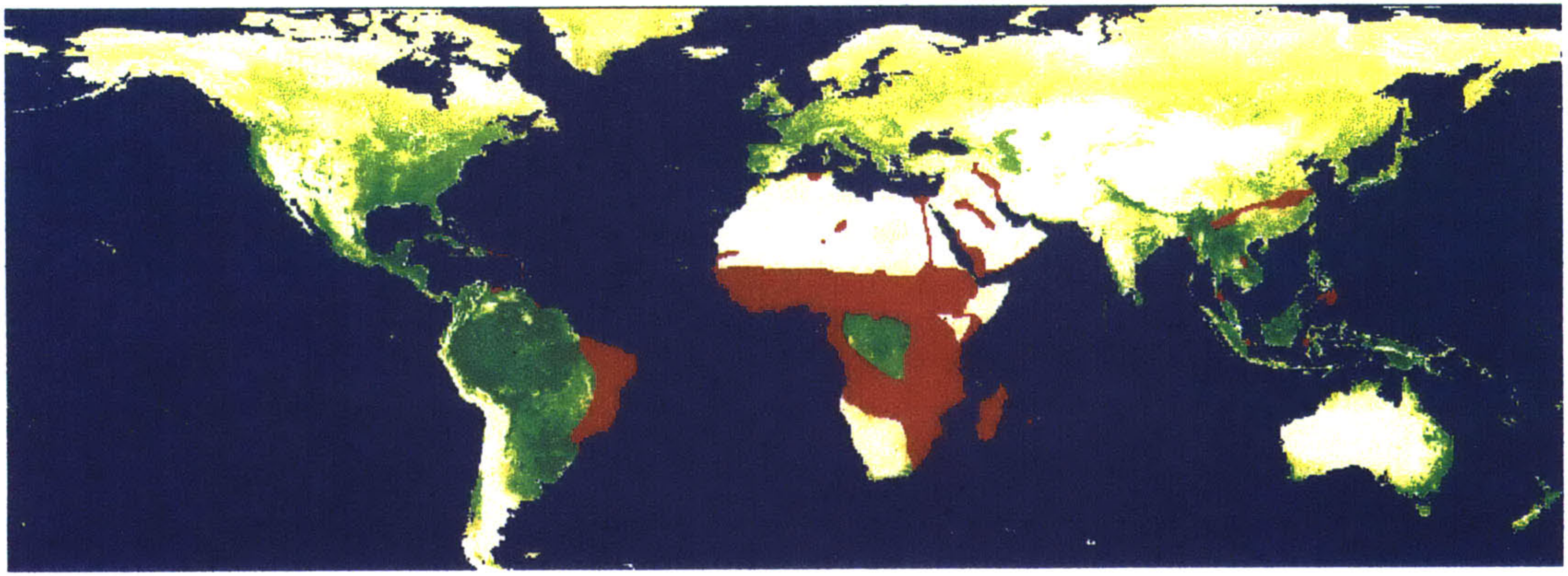
BIOGRAPHY:

Gilbert L. Rochon receives the Ph.D. from MIT in June, 1999 in Urban and Regional Planning, with dual concentrations in Planning Support Systems and in International Development and Regional Planning. His dissertation, "Scientific Visualization of Multi-Temporal Remotely-Sensed Data for Monitoring Drought-Related Famine Conditions: Nutritional, Socio-Economic and Climatic Vulnerability in Sudan's Gezira," was based, in part, upon research conducted in Sudan as a United Nations University (UNU) Fellow. He holds a Master of Public Health (M.P.H.) degree in Health Services Administration from Yale University, and a B.A. degree from Xavier University of Louisiana.

He is currently the Conrad N. Hilton Professor of Urban Studies and Public Policy and directs the Remote Sensing & GIS Lab at Dillard University in New Orleans, LA, where he has taught for 15 years. He has a joint appointment as University Affiliates Coordinator for the high performance computing modernization initiative at the DOD Major Shared Resource Center (MSRC) - Naval Oceanographic Office, Programming Environments & Training (PET) Program. Rochon has conducted environmental research as Principal Investigator, using Remote Sensing and GPS, in Russia's Eastern Siberia, the Brazilian Amazon, Puerto Rico, Sudan and Viet Nam. He is a member of the IEEE Geoscience & Remote Sensing Society and URISA.

Rochon held appointments as a Visiting Faculty Fellow at Oxford University's Environmental Change Unit, a NASA/JOVE Faculty Fellow at the Jet Propulsion Lab (JPL) at CalTech, a NASA/ASEE Fellow at NASA Goddard and at NASA Stennis, as a Physical Scientist with NAVOCEANO, a Geographer with the USDA Forest Service, a DOT Dwight David Eisenhower Faculty Fellow, a Dorothy Danforth Compton Fellow, a UNCF/Andrew Mellon Doctoral Fellow and a Lecturer in Health Systems Management at Tulane University's School of Public Health and Tropical Medicine.

He resides in New Orleans Louisiana, with his wife, Patricia Saul Rochon, a Professor of Mass Communications, a daughter, Hildred, a Freshman at the University of California at Santa Barbara, and a son, Emile, a Sophomore at Benjamin Franklin High School in New Orleans.



reference

APPENDIX: DISEASES AFFECTING COTTON & SORGHUM

Sources: C.W. Horne and R. A. Frederiksen, “Diseases of Sorghum (Sorghum Bicolor (L.) Moench),” Common Names of Plant Diseases. American Phytopathological Society (APS). APSnet, 1997.
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BACTERIAL DISEASES

(COTTON)|

Bacterial blight

Xanthomonas campestris pv.

malvacearum(Smith) Dye

(SORGHUM)

Bacterial leaf spot

Pseudomonas syringae van Hall

Bacterial leaf streak

Xanthomonas campestris
pv.*holcicola* (Elliott) Dye

Bacterial leaf stripe

Pseudomonas andropogonis
(Smith)Stapp

FUNGAL DISEASES

(COTTON)

Anthracnose

Glomerella gossypii Edgerton

(anamorph: *Colletotrichum gossypii* Southworth)

Areolate mildew

Mycosphaerella areola J. Ehrlich & F.A. Wolf

(anamorph: *Ramularia gossypii* (Speg.) Cif.

= Cercosporella gossypii Speg.)

Ascochyta blight

Ascochyta gossypii Woronichin

Black root rot

Thielaviopsis basicola (Berk. & Broome)
Ferraris

Boll rots

Various microorganisms, mostly fungi

Charcoal rot

Macrophomina phaseolina (Tassi) Goidanich

Escobilla

Colletotrichum gossyppi Southworth

(teleomorph: *Glomerella gossypii* Edgerton)

Fusarium wilt

Fusarium oxysporum Schlechtend.:Fr. f.sp.

Vasinfectum (Atk.) W.C. Snyder & H.N. Hans.

(SORGHUM)

Acremonium wilt

Acremonium strictum W. Gams

= *Cephalosporium acremonium*
Auct. non Corda

Anthracnose (foliar, head, root and stalk rot)

Colletotrichumgraminicola (Ces.)

G.W. Wils

(teleomorph: *Glomerella*
graminicola Politis)

Charcoal rot

Macrophomina phaseolina (Tassi)

Goidanich

Crazy top downy mildew

Sclerophthora macrospora
(Sacc.)Thirumalachar *et al.*

= *Sclerospora macrospora* Sacc.

Damping-off and seed rot

Aspergillus spp., *Exserohilium* sp.,

*Fusarium*spp., *Penicillium* spp.,

Pythium spp., *Rhizoctonia* spp.,and

other species.

Ergot

Sphacelia sorghi McRae

(teleomorph: *Claviceps sorghi* P.
Kulkarni *et al.*)

FUNGAL DISEASES CONTINUED

(COTTON)

Leaf spots

Alternaria macrospora A. Zimmerm.

A. alternata (FR.:FR.) Keissl.

Mycosphaerella gossypina (Atk.)

Earle; also other species of fungi.

Phymatotrichum root rot (cotton root rot)

Phymatotrichopsis omnivora-Duggar Hennebert

= *Phymatotrichum omnivorum* Duggar

Powdery mildews

Leveillula taurica (Lev) G. Arnaud

(anamorph: *Oidiopsis sicula* Scalia)

Oidiopsis gossypii (Wakef.) Raychaudhuri

Salmonia malachrae (Seaver) Blumer

Sclerotium stem and root rot (southern blight)
Sclerotium rolfsii Sacc.
(teleomorph:*Athelia rolfsii*(Curzi)Tu&Kimbrough)
Seedling disease complex

Fusarium spp.

Pythium spp.

Rhizoctonia solani Kühn

(teleomorph: *Thanatephorus cucumeris*

(A.B. Frank) Donk)

Thielaviopsis basicola (Berk. & Broome)

Ferraris

(SORGHUM)

Fusarium head blight, root and stalk rot

Fusariummoniliforme J. Sheld.

(teleomorph: *Gibberella fujikuroi*

(Sawada) Ito in Ito & K. Kimura)

Fusarium spp.

Grain storage mold

Aspergillus spp., *Penicillium* spp.

Gray leaf spot

Cercospora sorghi Ellis & Everh.

Latter leaf spot

Cercospora fusimaculans Atk.

Leaf blight

Setosphaeria turcica (Luttrell) K.J.

Leonard& E.G. Suggs & E. Muller
(anamorph: *Exserohilum turcicum*
(Pass.) K.J. Leonard & E.G. Suggs
= *Helminthosporium turcicum* Pass.)

Milo disease (Periconia root rot)

Periconia circinata

(M. Mangin) Sacc

Oval leaf spot

Ramulispora sorghicola E. Harris

Pokkah Boeng (twisted top)

Gibberella fujikuroe var*subglutinans*

FUNGAL DISEASES CONTINUED

(COTTON)

Southwestern cotton rust

*Puccinia cacabata*Arth. & Holw. in Arth.

Tropical cotton rust

Phakopsora gossypii (Lagerh.)Hiratsuka

Verticillium wilt

Verticillium dahliae Kleb.

(SORGHUM)

(Edwards)

(anamorph: *Fusarium moniliforme* var. *subglutinans* Wollenweb. & Reink.)

Pythium root rot

Pythium spp

P. graminicola Subramanian

Rough leaf spot

Ascochyta sorghi Sacc.

Rust

Puccinia purpurea Cooke

Seedling blight and seed rot

Colletotrichum graminicola(Ces.) G.W. Wils.

Exserohilum turcicum (Pass.) K.J. Leonard and E.G. Suggs

Fusarium moniforme J. Sheld.

Pythium spp.

P. aphanidermatum (Edson) Fitzp.

Smut, covered kernel

Sporisorium sorghi Link in Willd.

= *Sphacelotheca sorghi* (Link) G.P. Clinton

Smut, head

FUNGAL DISEASES CONTINUED

(COTTON) **(SORGHUM)**

Sphacelotheca reiliana (Kühn) G.P. Clinton

= *Sporisorium holci-sorghi* (Rivolta) K. Vanky

Smut, loose kernel

Sporisorium cruentum (Kühn) K. Vanky

= *Sphacelotheca cruenta* (Kühn) A.A. Potter

Sooty stripe

Ramulispora sorghi (Ellis & Everh.)

Olive &Lefebvre in Olive *et al.*

Sorghum downy mildew

Peronosclerospora sorghi (W. Weston& Uppal)

C.G. Shaw = *Sclerospora sorghi* W. Weston & Uppal

Tar spot

Phyllachora sacchari P. Henn.

Target leaf spot

Bipolaris cookei (Sacc.) Shoemaker

= *Helminthosporium cookei* Sacc.

Zonate leaf spot and sheath blight

Gloeocercospora sorghi Bain & Edgerton ex Deighton

NEMATODES, PARASITIC

(COTTON)

Dagger, American

Xiphinema americanum Cobb

Lance, Columbia

Hoplolaimus columbus Sher

Lance

Hoplolaimus galeatus (Cobb) Thorne

Lesion

Pratylenchus spp.

Needle

Longidorus africans Merny

Pin

Paratylenchus hamatus Thorne & Allen

Reniform

Rotylenchulus reniformis Linford & Oliveira

Ring

Criconemella spp.

Root-knot

Meloidogyne incognita

(Kofoid & White)Chitwood

Spiral

Helicotylenchus spp.

Scutellonema spp.

(SORGHUM)

Awl

Dolichodorus spp.

Dagger, American

Xiphinema americanum Cobb

Lesion

Pratylenchus spp.

Needle

Longidorus africanus Merny

Pin

Paratylenchus spp.

Reniform

Rotylenchus spp.

Ring

Criconemella spp.

Root-knot

Meloidogyne spp.

Spiral

Helicotylenchus spp.

Sting

Belonolaimus longicaudatus Rau

Stubby-root

Paratrichodorus spp.

P. minor (Colbran) Siddiqi

NEMATODES, PARASITIC CONTINUED

(COTTON)

Sting

Belonolaimuslongicaudatus Rau

Stubby-root

Paratrichodorus spp.

Stunt

Merlinius spp.

Tylenchorhynchus spp.

(SORGHUM)

Stunt

Tylenchorhynchus spp.

Merlinius brevidens (Allen) Siddiqi

VIRAL DISEASES

(COTTON)

(Also mycoplasmalike organisms [MLO] and uncharacterized graft transmissible pathogens [GTP])

Abutilon mosaic

Abutilon mosaic virus

Anthocyanosis

Cotton anthocyanosis virus

Blue disease

Virus

Leaf crumple

GTP

Leaf curl

Cotton leaf curl virus

Leaf mottle

Cotton leaf mottle virus

Leaf roll

Virus

(SORGHUM)

(Also mycoplasmalike organisms [MLO])

Maize chlorotic dwarf

Maize chlorotic dwarf virus

Maize dwarf mosaic

Maize dwarf mosaic virus

Sugarcane mosaic

Sugarcane mosaic virus

Yellow sorghum stunt

Yellow sorghum stunt MLO

VIRAL DISEASES CONTINUED

(COTTON)

(SORGHUM)

Mosaic

Virus

Phyllody

MLO

Psylosis

Virus

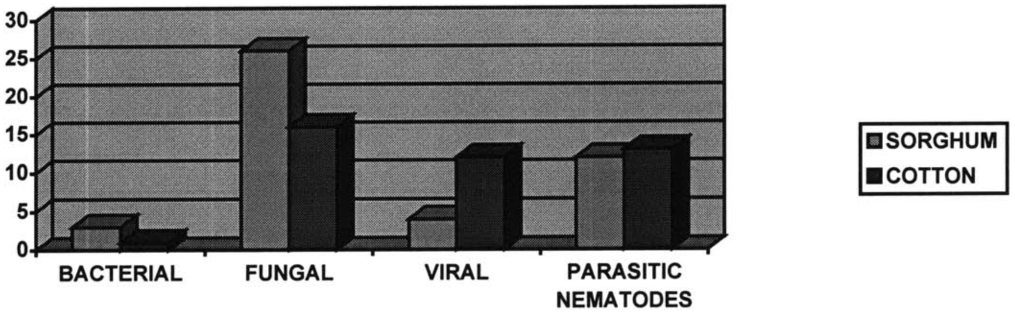
Small leaf

MLO

Terminal stunt

GTP

NUMBER AND VARIETY OF DISEASES AFFECTING COTTON AND SORGHUM



Sources: C.W. Horne and R. A. Frederiksen, "Diseases of Sorghum (Sorghum Bicolor (L.) Moench)," Common Names of Plant Diseases. American Phytopathological Society (APS). APSnet, 1997.

Stuart D. Lyda and G. M. Watkins, "Diseases of Cotton (Gossypium Spp.)," Common Names of Plant Diseases. American Phytopathological Society (APS). APSnet, 1997.

According to the UN FAO Food and Nutrition Series # 27 (1995), to make kisra, one combines 9 parts sorghum flour, two parts water and one part yeast, derived from previously fermented kisra batter. The ingredients are usually mixed in an earthenware pot, forming a paste, and allowed to ferment for 18 hours, overnight. The dough is then thinned and spread on a hot iron plate with a spatula. (UN FAO recommends 100 ml each; although I have never seen it so accurately measured.) After baking for about thirty seconds, it is stacked and stored, covered with a cloth and served with *ful massri* (broad beans), vegetables, meat, soup or stew, usually with a hot pepper spice, *shatta*, in Sudan, and *mittmitta* or *awaze* in neighboring Ethiopia.. *Dhurra* is also made into a porridge, called *aceda* in Sudan.

Depending upon whether it is whole grain or decorticated, *Sorghum bicolor's* approximate chemical composition is listed in the table below: (UN FAO, op. cit, 1995).

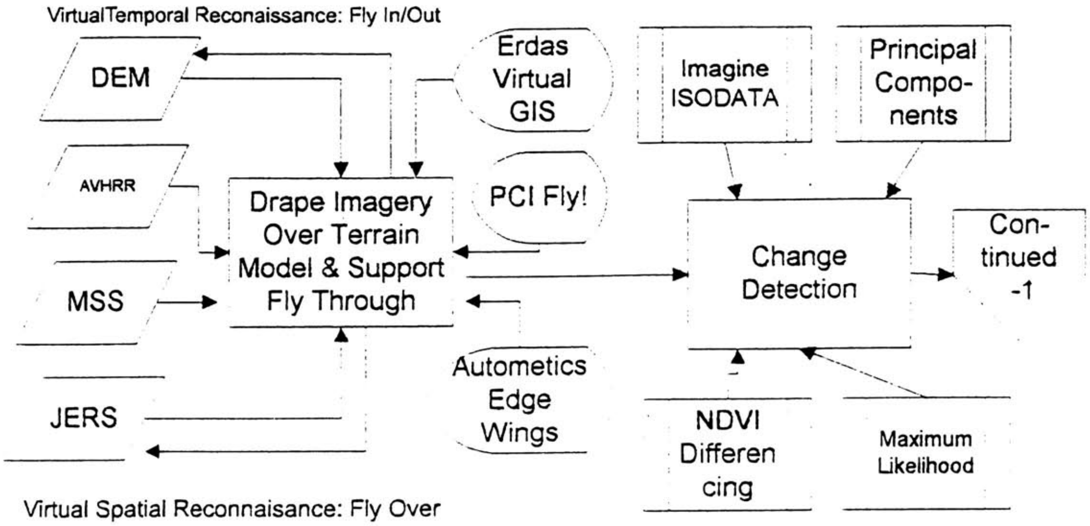
CHEMICAL COMPOSITION OF *SORGHUM BICOLOR*

	Protein (N x 6.25)	Ash (%w/w)	Fat (%w/w)	Crude Fibre (%w/w)	Starch & Sugar (% w/w)
Tetron: Whole Grain *Kisra*	11.3	1.80	5.3	2.1	71.2
Feterita: Whole Grain *Kisra*	14.1	1.59	5.1	2.4	68.8
Dabar: Kisra, Decorticated	12.6	1.23	4.2	1.1	74.8

SOURCE: UN FAO, 1995

Flow Chart: TARDIS

Chart 1A



Flow Chart:TARDIS-Continued

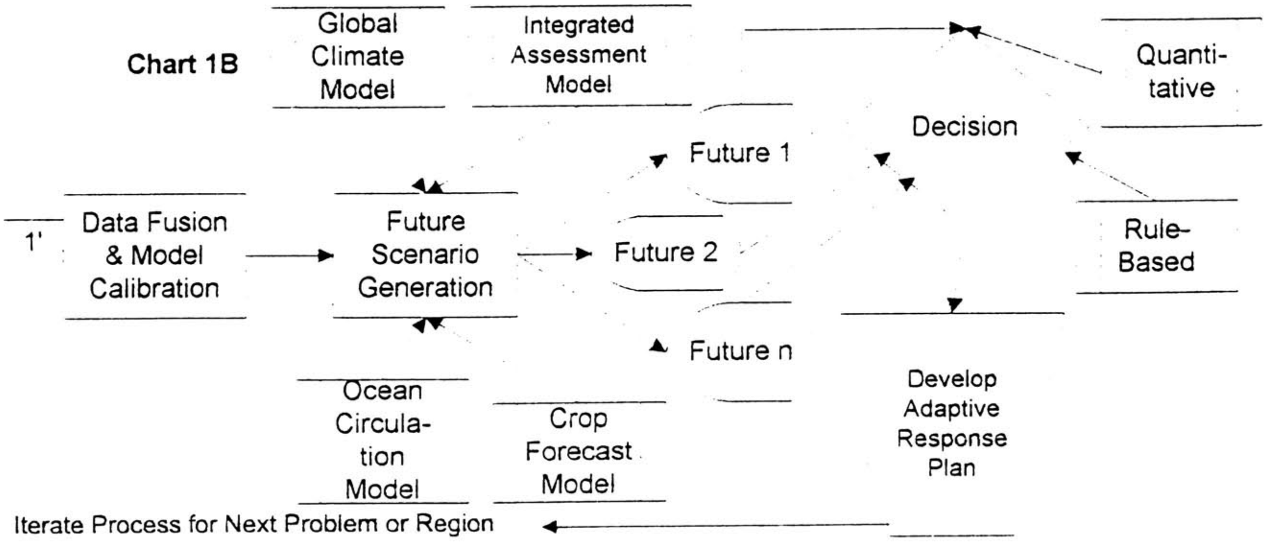
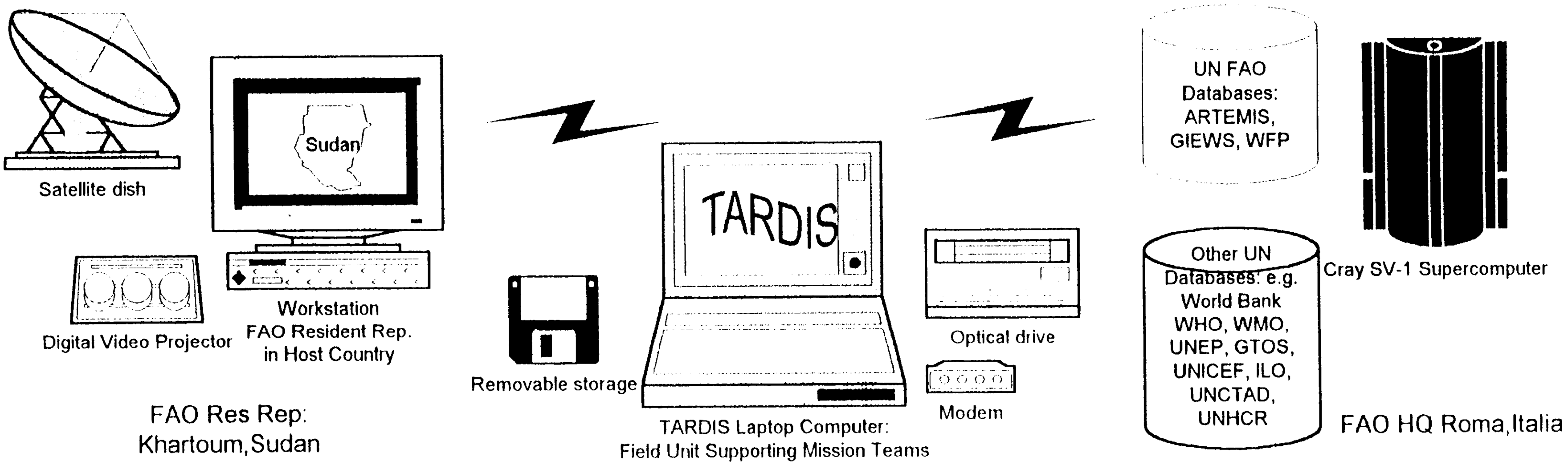


Chart 2

TEMPORAL ANALYSIS, RECONNAISSANCE & DECISION SUPPORT SYSTEM



OPTIONAL SOFTWARE COMPONENTS:
- Decision Analysis
-Global Positioning System (GPS)
- Geographic Information System (GIS)
- Remote Sensing Image Analysis
- Object-Oriented Relaional Database
- Statistical Analysis
- Scientific Visualization
- Word Processing
- Spreadsheet

Gezira (Field Equipment)

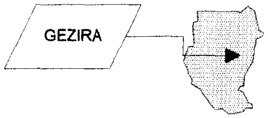
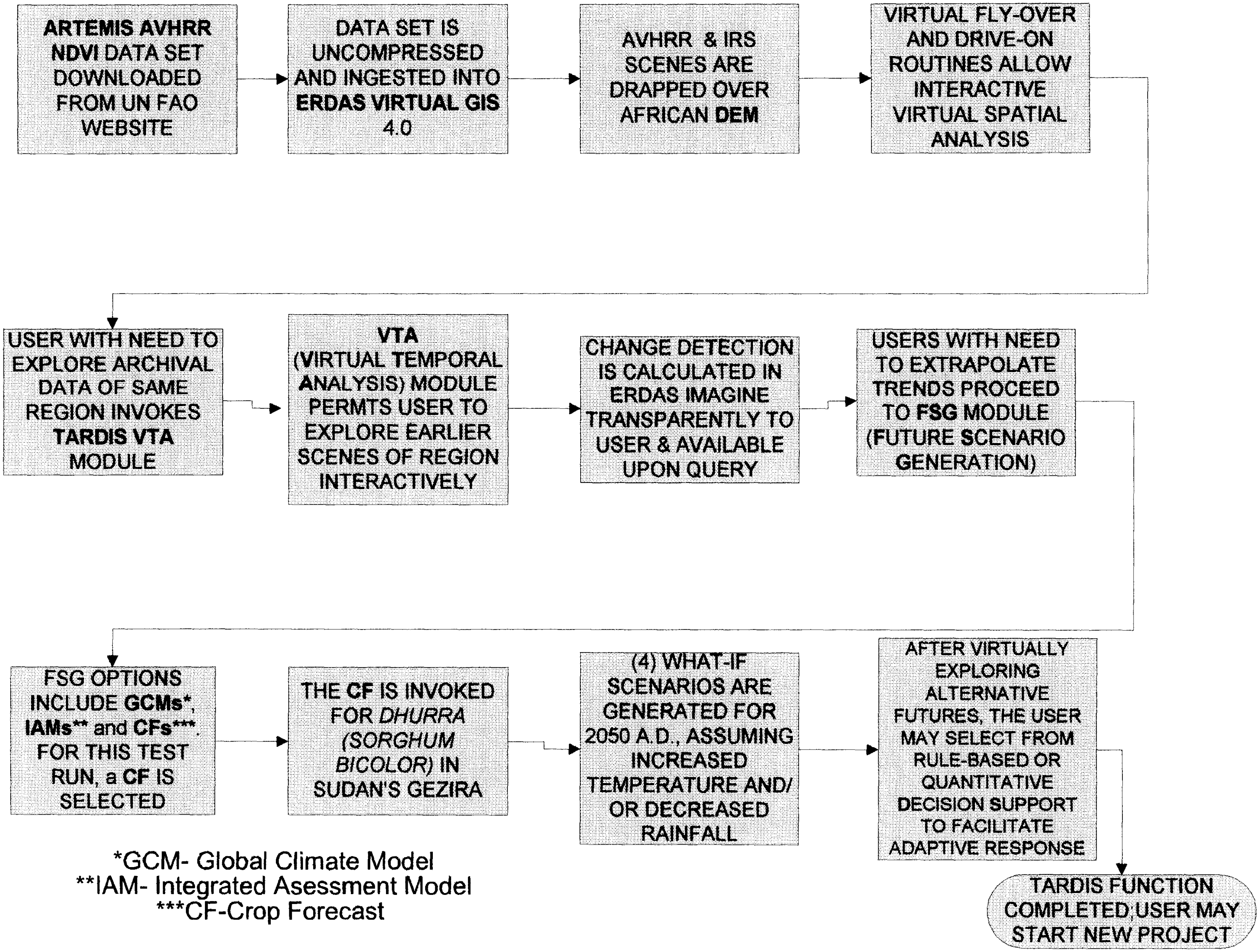


Chart 3

TARDIS (TEMPORAL ANALYSIS, RECONNAISSANCE & DECISION INTEGRATION)



ARTEMIS AVHRR NDVI DATA SET DOWNLOADED FROM UN FAO WEBSITE

DATA SET IS UNCOMPRESSED AND INGESTED INTO **ERDAS VIRTUAL GIS** 4.0

AVHRR & IRS SCENES ARE DRAPPED OVER AFRICAN **DEM**

VIRTUAL FLY-OVER AND DRIVE-ON ROUTINES ALLOW INTERACTIVE VIRTUAL SPATIAL ANALYSIS

USER WITH NEED TO EXPLORE ARCHIVAL DATA OF SAME REGION INVOKES **TARDIS VTA** MODULE

VTA (**V**IRTUAL **T**EMPORAL **A**NALYSIS) MODULE PERMTS USER TO EXPLORE EARLIER SCENES OF REGION INTERACTIVELY

CHANGE DETECTION IS CALCULATED IN ERDAS IMAGINE TRANSPARENTLY TO USER & AVAILABLE UPON QUERY

USERS WITH NEED TO EXTRAPOLATE TRENDS PROCEED TO **FSG** MODULE (**F**UTURE **S**CENARIO **G**ENERATION)

FSG OPTIONS INCLUDE **GCMs***, **IAMs**** and **CFs*****. FOR THIS TEST RUN, a **CF** IS SELECTED

THE **CF** IS INVOKED FOR *DHURRA (SORGHUM BICOLOR)* IN SUDAN'S GEZIRA

(4) WHAT-IF SCENARIOS ARE GENERATED FOR 2050 A.D., ASSUMING INCREASED TEMPERATURE AND/ OR DECREASED RAINFALL

AFTER VIRTUALLY EXPLORING ALTERNATIVE FUTURES, THE USER MAY SELECT FROM RULE-BASED OR QUANTITATIVE DECISION SUPPORT TO FACILITATE ADAPTIVE RESPONSE

TARDIS FUNCTION COMPLETED,USER MAY START NEW PROJECT

*GCM- Global Climate Model
**IAM- Integrated Asessment Model
***CF-Crop Forecast

SUDAN-Gezira: Crop Yield Enhancement Decisions

Chart 4A

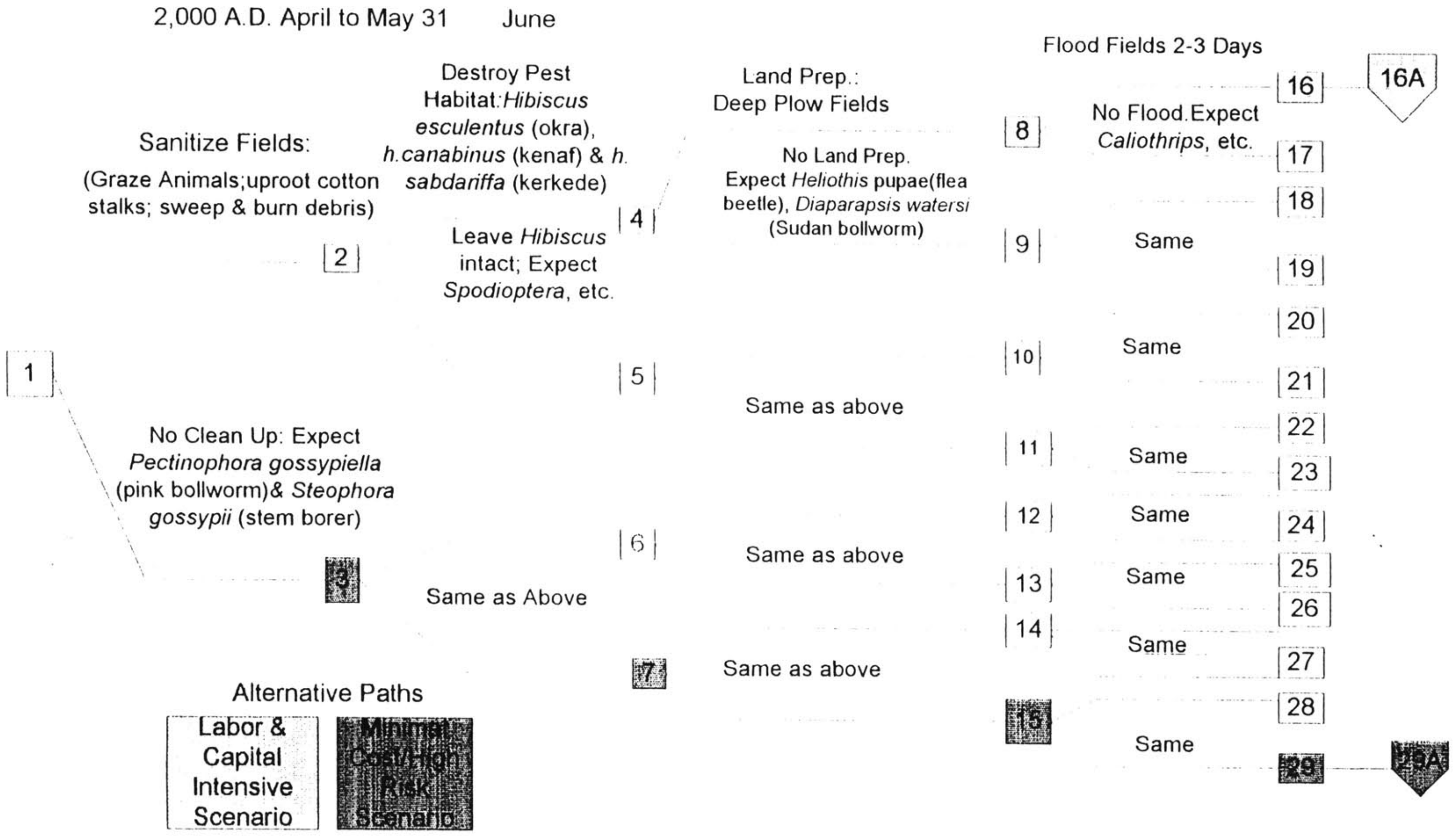
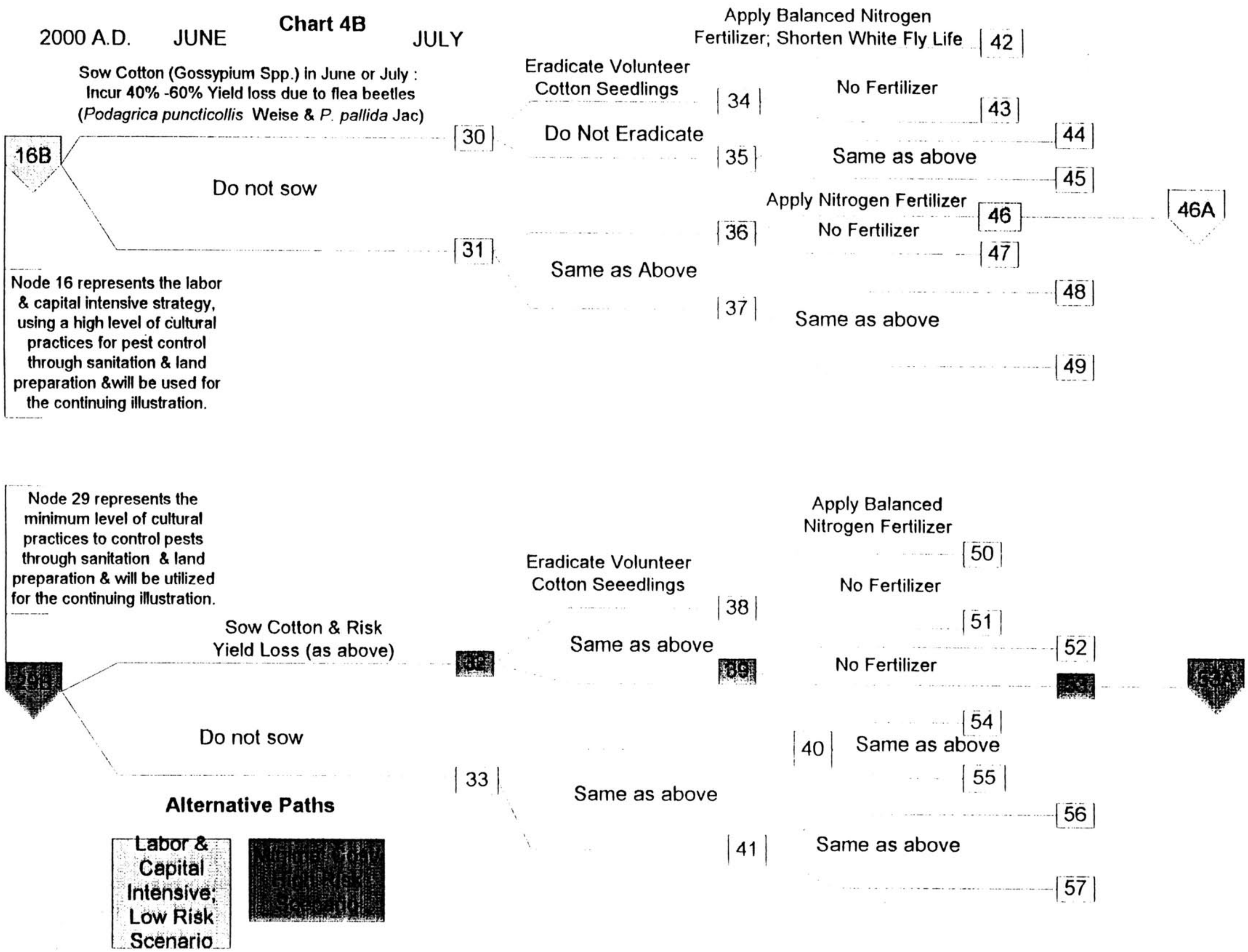


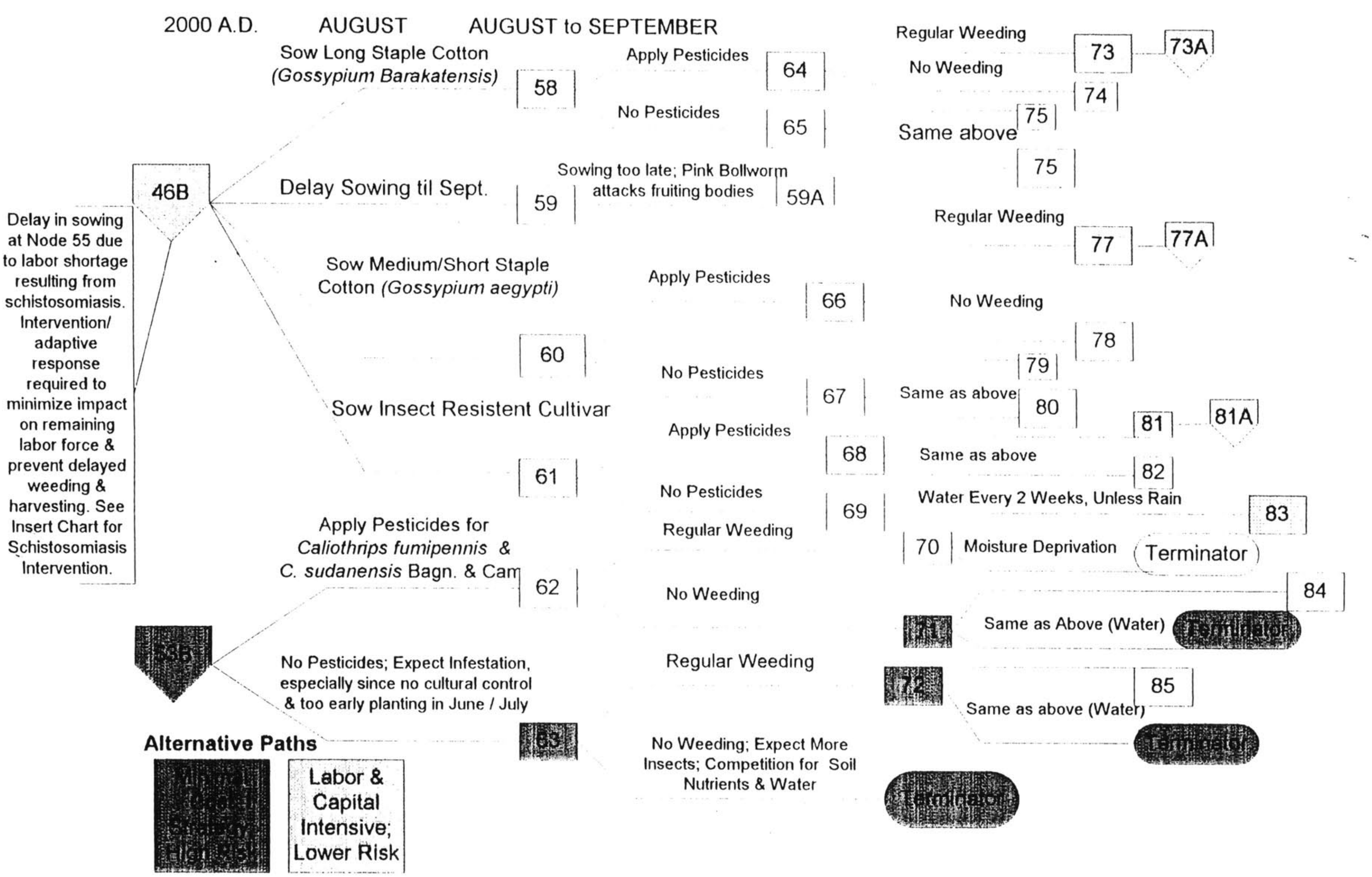
Chart 4B



Node 16 represents the labor & capital intensive strategy, using a high level of cultural practices for pest control through sanitation & land preparation &will be used for the continuing illustration.

Node 29 represents the minimum level of cultural practices to control pests through sanitation & land preparation & will be utilized for the continuing illustration.

Chart 4C


2000 A.D.
AUGUST
AUGUST to SEPTEMBER
46B
Delay in sowing at Node 55 due to labor shortage resulting from schistosomiasis. Intervention/ adaptive response required to minimize impact on remaining labor force & prevent delayed weeding & harvesting. See Insert Chart for Schistosomiasis Intervention.
Sow Long Staple Cotton (Gossypium Barakatensis)
58
Delay Sowing til Sept.
59
Sow Medium/Short Staple Cotton (Gossypium aegypti)
60
Sow Insect Resistent Cultivar
61
Apply Pesticides
64
No Pesticides
65
Sowing too late; Pink Bollworm attacks fruiting bodies
59A
Apply Pesticides
66
No Pesticides
67
Apply Pesticides
68
No Pesticides
69
Regular Weeding
No Weeding
73
73A
74
75
Same above
75
Regular Weeding
77
77A
No Weeding
78
79
Same as above
80
81
81A
Same as above
82
Water Every 2 Weeks, Unless Rain
83
53B
Apply Pesticides for Caliothrips fumipennis & C. sudanensis Bagn. & Cam
62
No Pesticides; Expect Infestation, especially since no cultural control & too early planting in June / July
63
Regular Weeding
70
Moisture Deprivation
Terminator
No Weeding
84
71
Same as Above (Water)
Terminator
Regular Weeding
72
85
Same as above (Water)
Terminator
No Weeding; Expect More Insects; Competition for Soil Nutrients & Water
Terminator
Alternative Paths
Minimal
Strategy;
High Risk
Labor & Capital Intensive; Lower Risk

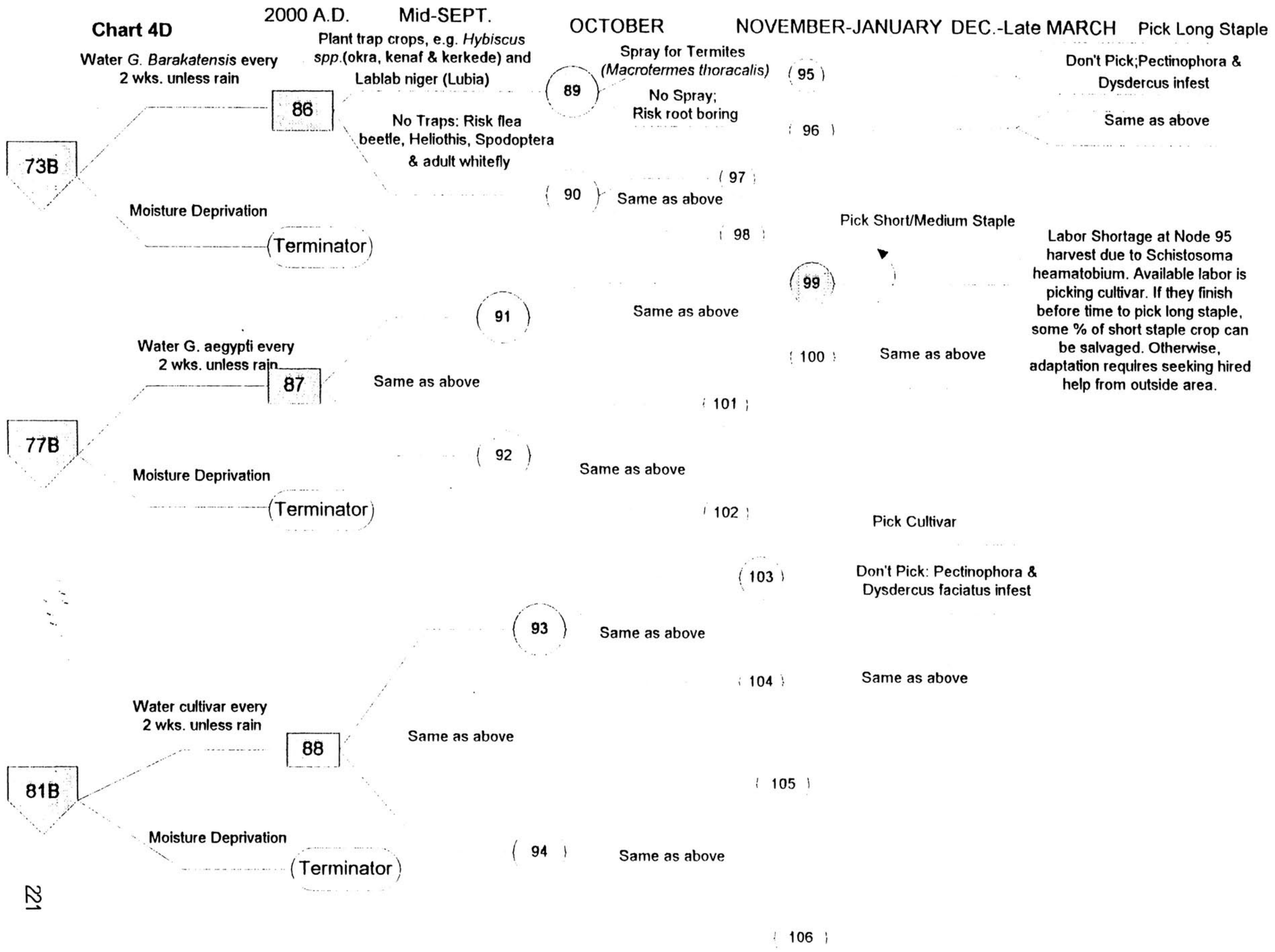
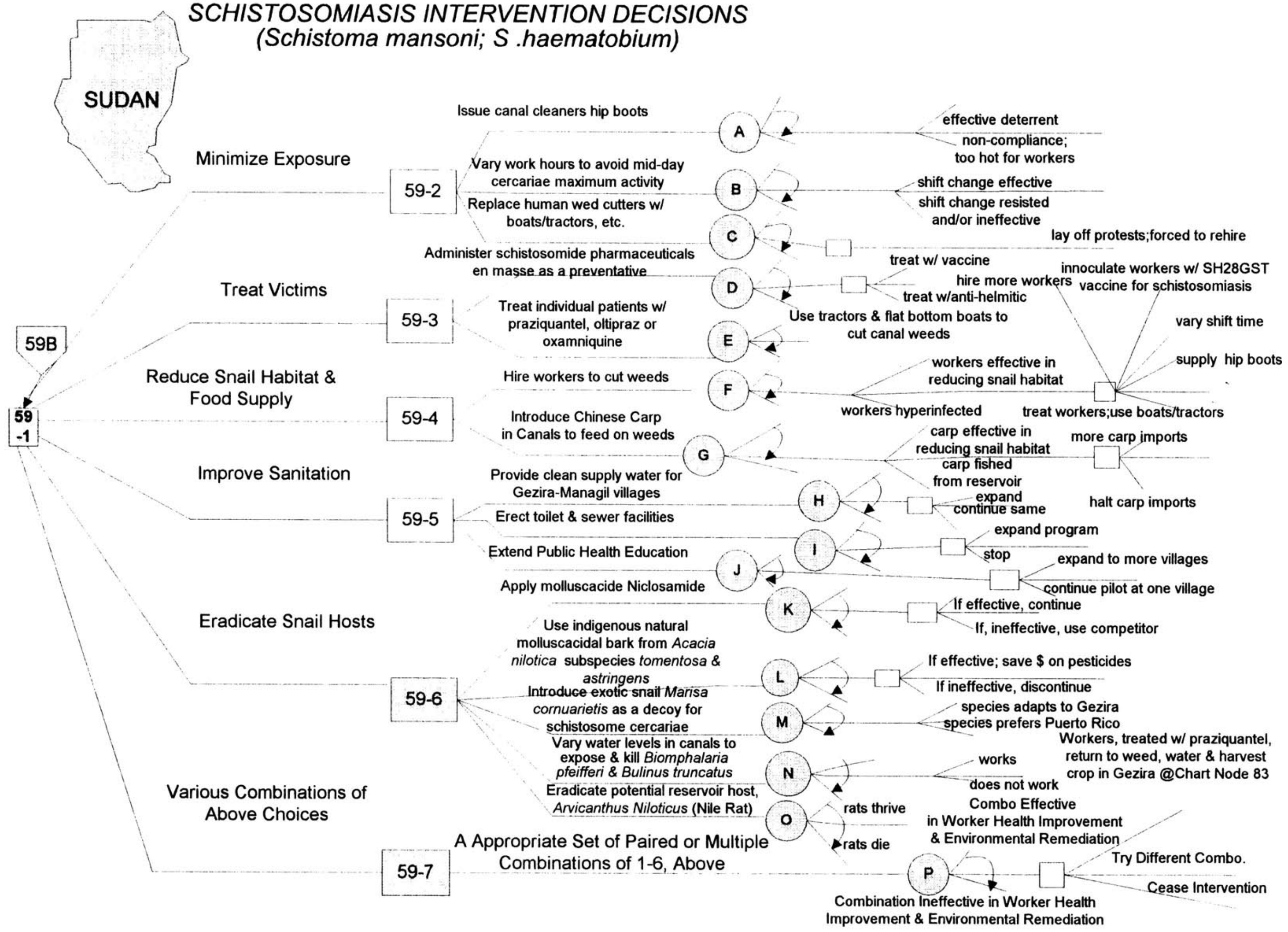
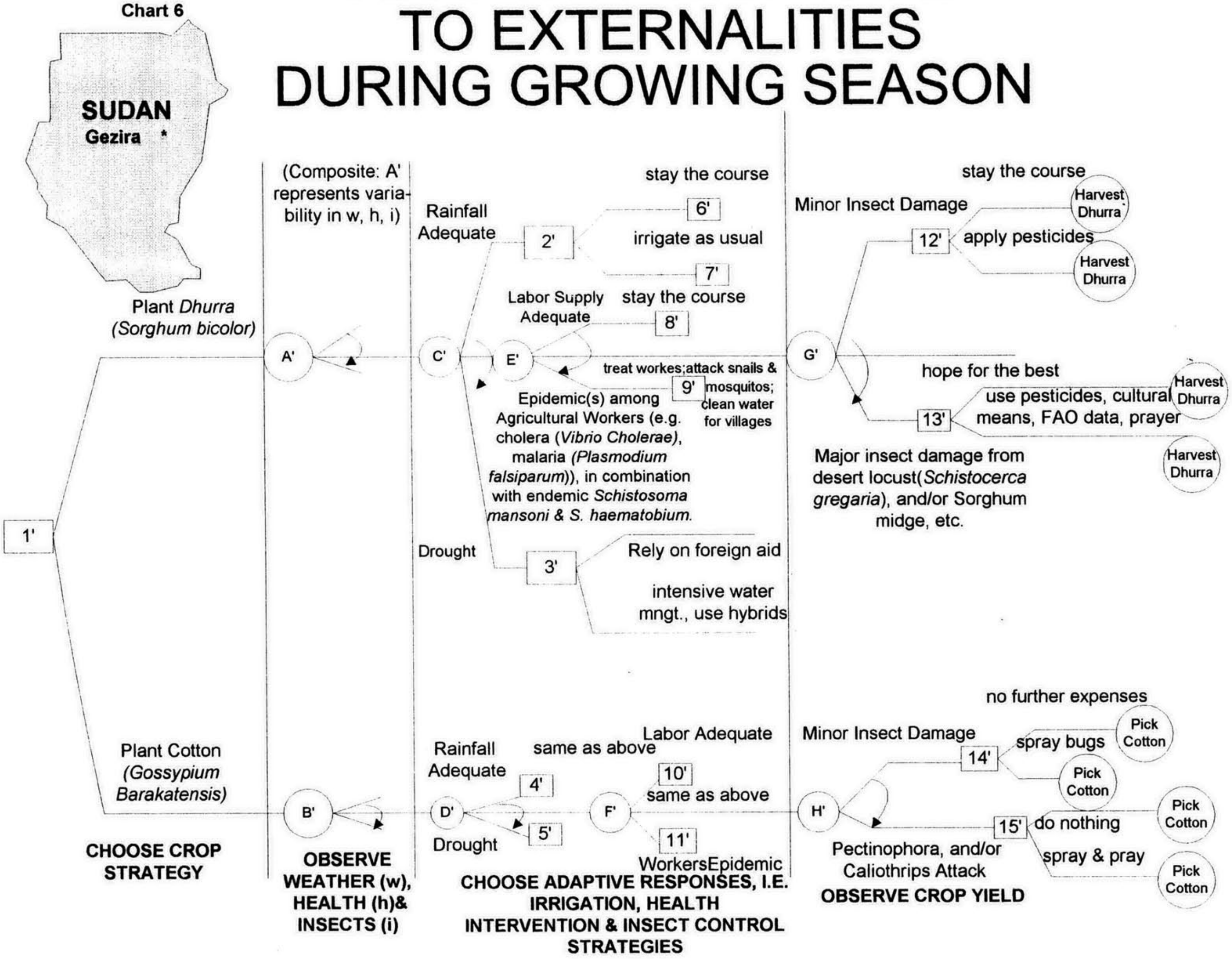
Chart 4D
2000 A.D.
Mid-SEPT.
OCTOBER
NOVEMBER-JANUARY
DEC.-Late MARCH
Pick Long Staple
Water *G. Barakatensis* every 2 wks. unless rain
73B
86
Plant trap crops, e.g. *Hybiscus spp.*(okra, kenaf & kerkede) and Lablab niger (Lubia)
89
Spray for Termites *(Macrotermes thoracalis)*
95
Don't Pick;Pectinophora & Dysdercus infest
No Spray; Risk root boring
96
Same as above
No Traps: Risk flea beetle, Heliothis, Spodoptera & adult whitefly
97
90
Same as above
Moisture Deprivation
Terminator
98
Pick Short/Medium Staple
99
Labor Shortage at Node 95 harvest due to Schistosoma heamatobium. Available labor is picking cultivar. If they finish before time to pick long staple, some % of short staple crop can be salvaged. Otherwise, adaptation requires seeking hired help from outside area.
91
Same as above
Water G. aegypti every 2 wks. unless rain
87
Same as above
100
Same as above
101
77B
92
Same as above
Moisture Deprivation
Terminator
102
Pick Cultivar
103
Don't Pick: Pectinophora & Dysdercus faciatus infest
93
Same as above
104
Same as above
Water cultivar every 2 wks. unless rain
88
Same as above
81B
105
Moisture Deprivation
94
Same as above
Terminator
106

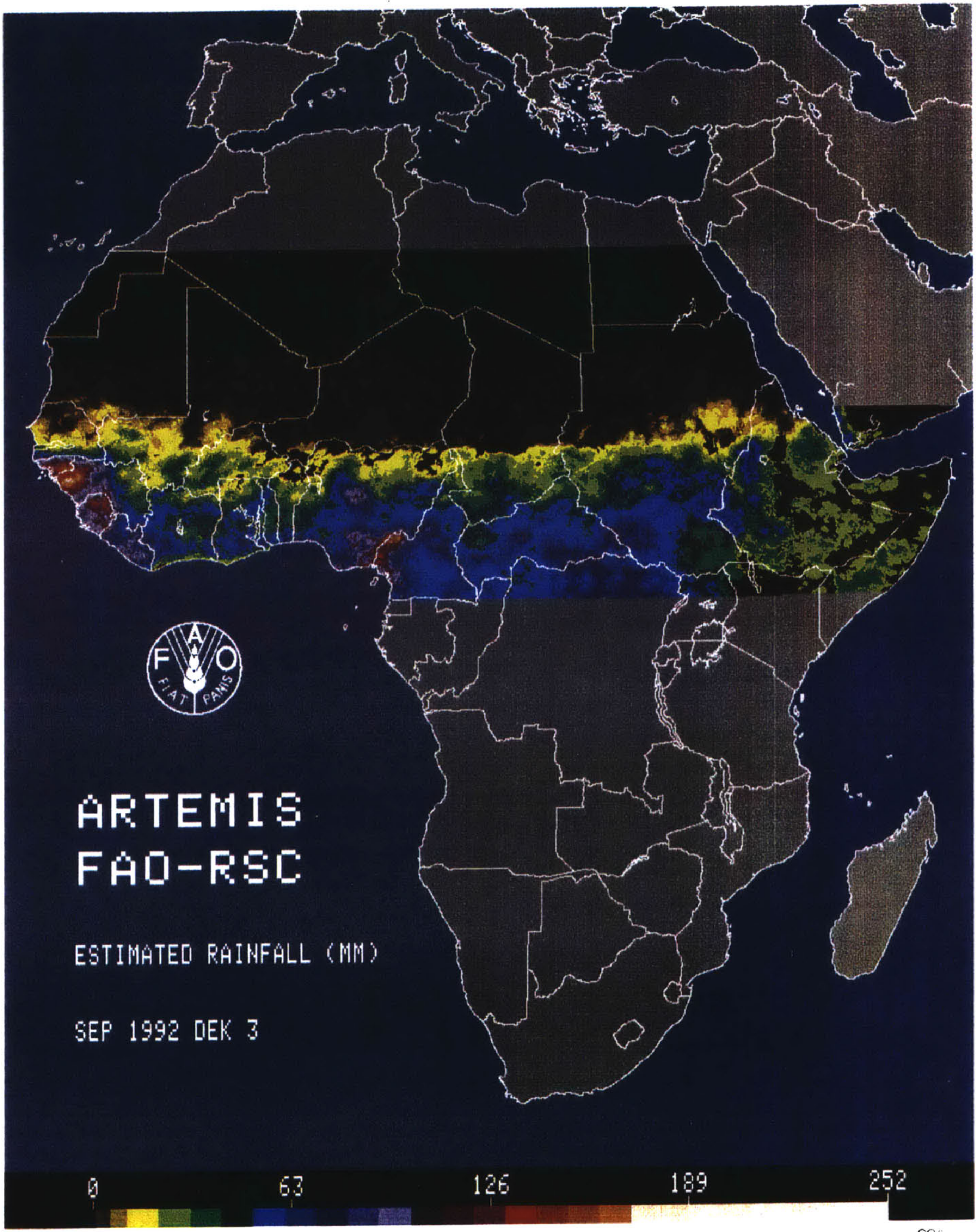
Chart 5

SCHISTOSOMIASIS INTERVENTION DECISIONS
(Schistoma mansoni; S .haematobium)



ADAPTIVE RESPONSE TO EXTERNALITIES DURING GROWING SEASON




FAO
FIAT PANIS
ARTEMIS
FAO-RSC
ESTIMATED RAINFALL (MM)
SEP 1992 DEK 3
0
63
126
189
252