PROPOSAL COVER SHEET, REQUIRED DECLARATIONS, AND BUDGET SUMMARY FORM

Proposal Cover Sheet

NASA Research Announcement 00-OES-08

Research Area: Land-Cover, Land-Use Changes (LCLUC)

Title: **Assessment, Monitoring, and Modeling of LCLUC and Their Impacts on Groundwater Resources, Ecosystems, and Carbon Cycling in Saharan Africa:**
A Case Study, SW Egypt

Principal Investigator: Mohamed Sultan

Department: Geology

Institution: Research Foundation of SUNY on behalf of the University at Buffalo

Street/PO Box: The UB Commons, Suite 211, 520 Lee Entrance
City: Amherst
State: NY Zip: 14228
Country: USA Congressional District: 27
e-mail: misultan@geology.buffalo.edu
Telephone: 716-645-6800 ext. Fax: 716-645-3999

Co-Investigator(s):

Neil Sturchio	University of Illinois sturchio@uic.edu	Earth & Environmental Sciences 845 West Taylor Street Chicago, IL 60607-7059 Phone: 312-355-1182
Eugene Yan	Argonne National Laboratory eyan@anl.gov	9700 South Cass Avenue Argonne, IL 60439 Phone: 630-252-6322
R. Michael Miller	Argonne National Laboratory rmmiller@anl.gov	9700 South Cass Avenue Argonne, IL 60439 Phone: 630-252-3395
Julie D. Jastrow	Argonne National Laboratory jdjastrow@anl.gov	9700 South Cass Avenue Argonne, IL 60439 Phone: 630-252-3226

Budget Year 2: $170,333 Year 3: $166,598 Total: $336,931

N.B.: First year was conducted at Argonne National Lab where the PI worked before moving to Univ. at Buffalo (Budget for first year was: $181,406)

Abstract

We are developing and applying an integrated systems approach that involves the analysis of temporal remote sensing data, geochemical and ecological analyses, and hydrologic modeling to assess, monitor, and model the recent and future impacts of changes in the landscape and land cover associated with major agricultural development projects in Saharan Africa. These development projects are affecting the water resources of the underlying groundwater aquifers and the existing fresh water ecosystems, as well as producing new carbon sinks. Southwest Egypt was chosen as a test site, because Egypt's landscape and its climatic and hydrologic settings resemble those in neighboring Saharan countries, where aggressive land use development projects are also under way. We are monitoring and modeling the hydrologic impacts of the development of Lake Nasser behind the Aswan High Dam that raised groundwater tables of the Nubian aquifer in the vicinity of the lake by over 40 m. Similarly, we are investigating the hydrologic impacts caused by the creation of four adjoining lakes to the west of Lake Nasser as lake levels peaked (1990 to present) and overflowed into the Tushka spillway. We are also monitoring the agricultural expansion and quantifying the amounts of carbon being sequestered in surface and subsurface sources in these new agricultural communities as they develop.

Keywords

(1) Research fields: Hydrogeology; carbon sequestration; change detection
(2) Geographic area: Desert-arid; north Africa
(3) Remote sensing: Landsat; VIS, near-IR
(4) Methods/scales: GIS; regional scale; time series analysis

Questions, goals, approaches

The questions that we are trying to answer are:

1. What are the changes of land use and land cover in SW Egypt since the erection of the Aswan High Dam?
    a. What are the changes in the areal extent of the lake Nasser since the erection of the Aswan High Dam?
    b. What are the changes in the areal extent of the adjoining lakes since the peak floods in 1999?
    c. Where did agricultural expansion activities occur?

2. What are the consequences of these LCLUC?
    a. What are the hydrologic impacts of the development of Lake Nasser and adjoining lakes (west of the lake) and agricultural expansion activities in SW Egypt on the Nubian aquifer water level and water quality?
    b. What are the hydrologic impacts of the agricultural expansion (e.g. Tushka canal, East Uweinat) projects on the Nubian aquifer water level and water quality?
    c. To what extent, and what are the mechanisms by which, carbon is being sequestered through reclamation of desert lands?

Proportion of themes covered by the project:

1. Social Science activities (10%)
2. Water (groundwater flow and surface runoff modeling and geochemistry) (40%)
3. Mapping/monitoring LCLUC (25%)
4. Carbon (carbon sequestration)(25%)

What has been accomplished in the second year?

In our two-year proposal that was submitted from UB, we have combined the tasks that were to be accomplished during the second and third years. These were:

Task 1: Establish a GIS that incorporates co-registered temporal TM, MSS, and elevation data, along with geologic, hydrogeologic, and soil maps for the study area.

Task 2: Develop a calibrated two-dimensional transient flow model for the study area that predicts groundwater levels in the area and surroundings for various scenarios involving agricultural development, extraction of groundwater, and recharge of the aquifer from the lakes (Nasser and Tushka spillway) and by pumping.

Task 3: Develop a calibrated carbon cycle model for the area, built on information extracted from the detected LCLUC throughout the past 35 yr and carbon pools in the study area.

Achievements:

Status of Task 1:

We have developed a GIS which incorporates all of the data sets used in this project. Data are compiled in ARCGIS in digital format. Data in this GIS includes:
:
Digital image data of:
Corona KH-4A data from 1967 (14 strips)
Landsat TM from 1980s (mosaic + individual scenes)
Landsat MSS from 1972
MODIS from 2000-2003
ASTER from 2002
SIR-C from 1994
Space Station Handheld photography 1998
Gemini Handheld photography 1964

High resolution color scans of:
British Topographic Maps from 1954
1:500,000 Hydrologic Maps
1:500,000, and 1:2,000,000 Geologic Maps
Sudan Geological Map 1:2,000,000 Scale

Digital forms of:
1-km digital elevation model
90-m level 1 DTED
30-m ASTER generated DEM around Tushka Lakes and west

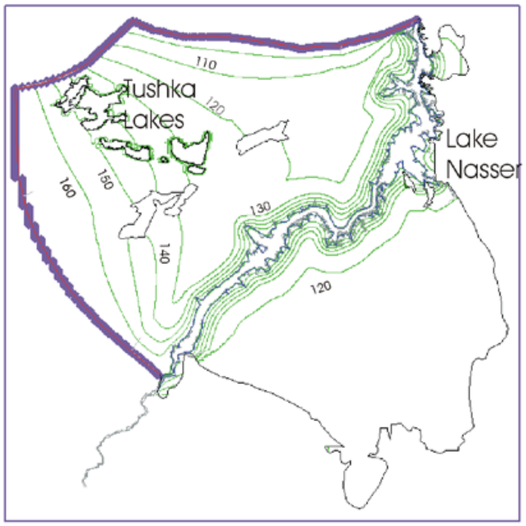
Digitized:
Well Locations
Groundwater head contours
Bedrock Surface Contours
Fault locations

Groundwater Analysis
Soil Analysis

Lake level elevations vs. time
Areal extent of lakes in multiple years

In addition, we have made a significant amount of this data available through our website (http://isis.geology.buffalo.edu/website/Egypt4). Data is made available through our ARCIMS server, which allows users to view and query the data. Some data has redistribution restrictions (e.g. 90m DTED data), and is either not made available, or only made available as a processed image.

Status of Task 2:

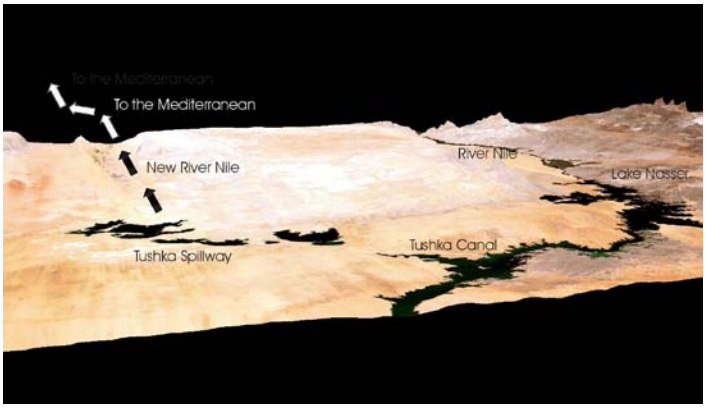


The progress in the second year builds on our findings in the first year as follows: our work during the first year led to the construction and validation of an integrated hydrology model over a subset of the study area. The area was limited to a portion of the western margin of Lake Nasser. We estimated a net recharge along the western margin of the lake throughout the past 30 yr at 5.3×10^{10} m^3 and projected net recharge of 1.5×10^{10} m^3 for the next 50 yr (Kim and Sultan, 2002). Whether these estimates are valid for the entire Lake is a subject that needed further investigations. We addressed this topic in the second year by extending our groundwater flow model to incorporate the entire Lake and surroundings, including the area of the newly formed Tushka Lakes (Figure 1). The initial conditions for the earlier model were set to those observed at the year 1970. The new model was extended to the earlier stages of lake development (1965).

Our preliminary model predicted that recharge of the Nubian aquifer from the lake will continue, but at a much slower rate than during the previous 30-yr period. Some forty years after the construction of the Dam, the lake levels have peaked and the Lake Nasser reservoir has approached its maximum storage capacity in the past few years. Consequently, the depressions to the west in the southern Western Desert of Egypt have been only recently used as a natural flood diversion basin to reduce possible downstream damage to the Nile valley. Fig. 2 shows the progressive encroachment of water onto these depressions with time giving rise to a number of lakes, the Tushka lakes. The recharge from the lakes was ignored in our earlier model. It is incorporated in our new model.

January 1999 December 1999 October 2000 March 2002 January 2003

One issue that was addressed in the second year is whether the continued apparent decrease in recharge to the Nubian aquifer from the lake could eventually lead to overflowing of the flood diversion depressions and to potential development of another route for the River Nile, perhaps even flooding the proximal agricultural areas in the depressions. In other words, what is the likely route the water will take if left to flood the lands in the vicinity. This apparent pattern of continued decrease in recharge and increase in surface water accumulation in Lake Nasser with time has apparently not been considered in the ongoing national plans to develop SW Egypt. Costly (~US$ 2 billion) plans are underway to construct the Tushka Canal that is intended to divert $5.0 \times 10^9 m^3/yr$ of excess Lake Nasser water to reclaim deserts west of the lake. Ironically, during the past three years, the rise in Lake Nasser water levels caused the lake waters to overflow the natural diversion spillway, develop three major lakes and channel lake waters some 100km across the adjacent desert land west of the lake. In other words, the spillway is apparently accomplishing what the Tushka Canal is intended to do; it is channeling Lake Nasser water to the deserts, west of the lake. Thus, our work in the second year, has social implications because it bears on the following questions: (1) Are there are less costly alternatives to the Tushka project if we let nature take its course and perhaps give it a helping hand, (2) What are the risks facing the population and agricultural developments in the lowlands as river Nile water spilling off Lake Nasser continues to encroach onto the lowlands?

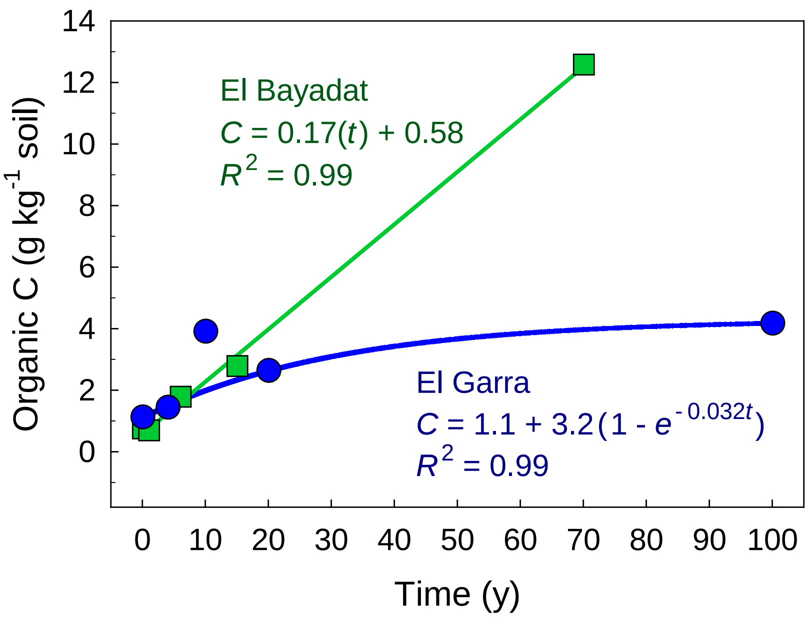


During the second year we developed and calibrated regional groundwater and surface water flow models (1) to examine the validity of our preliminary findings over the entire lake and its surroundings, (2) to analyze the interaction between surface water and groundwater in the study area, and (3) to evaluate and quantify the impact of a decreasing recharge rate on the lake's water level and on the surface water diversion scenarios in the surrounding area. The models were constrained by observations (e.g., lithologic, physical, elevation) extracted from remote sensing datasets and by inferences made from geochemical data for groundwater and surface water samples. The groundwater model was calibrated against near-lake and near-spillway head data; the surface water flow model was calibrated against the stages of spillways and spillway lakes.

The surface runoff model was used to simulate the most likely route that Lake Nasser water will take as it encroaches on the proximal lowlands. An essential data set that is needed for this exercise is digital topography with high spatial resolution. Using multiple view angle ASTER data, we generated digital elevation data for this area at a spatial resolution of 30m.

Status of Task 3

Analyses of soil organic C (carbonate free) for sites representing a range of times in irrigated agriculture suggest that organic C can accumulate in some fine-textured, irrigated desert soils over time.



At two sites, we sampled a chronosequence composed of five fields ranging in time under irrigated agriculture from 0 to over 65 years. Samples were also collected at four other sites at which only two or three fields representing different lengths of time under irrigated agriculture were available. Soil samples were collected from the surface 15 cm of field furrows. Total C and N levels in the soil were measured with a LECO CN-2000 elemental analyzer. Because large amounts of carbonates were present in most of the soils, inorganic C was determined separately by measuring pressure changes in a closed system with a pressure transducer following treatment of the samples with 30 g L^{-1} $FeCl_2$ solution in 6 M HCl (Wagner et al., 1998). Organic C was determined by the difference between total C and inorganic C.

Soil organic C and total N increased with time in irrigated agriculture across the two five-field chronosequences, but changes in organic C and total N over time at the other four sites were more difficult to evaluate because of the lower number of fields sampled (Table 1). Al Thowra showed a fairly substantial increase in organic C and total N between 3 and 35 years but the 10-year-old site had the lowest site values. The negative value for organic C at the Well 4 site reflects differences in measurement error between our determinations of total and inorganic C and suggests little real change in organic C has occurred in 2 years, particularly since total N did not increase. While a slight loss of organic C and total N apparently occurred between 15 and 40 years at W. El Mayhoub, major losses appeared to occur between 50 and 300 years at El Malkiah. In fact, the loss at El Malkiah is so dramatic that it suggests the sample labels may have been accidentally reversed.

The number of sites available at El Bayadat and El Garra, however, allow for more reliable evaluations of C and N accumulation in irrigated, fine-textured desert soils. At El Garra, organic C appears to have reached an equilibrium level and the change over time can be described with a simple exponential model often used in chronosequence studies (Fig. 3). The model curve presented in Fig. 3 assumes that the 10-year-old field is an outlier and fits the data for the other four fields extremely well. This model predicts that the equilibrium organic C concentration is 4.3 g C kg^{-1} soil and that the mean residence time (MRT) of organic C at this site is 31 years. The model also indicates that 50% of equilibrium C was reached after 22 years and 95% was achieved after 94 years. If, in fact, the 10-year-old field is not an outlier, the model fit is not nearly as good ($R^2 = 0.71$), the MRT is only 10 years, and 95% of equilibrium is reached after just 29 years. At El Bayadat, in contrast to El Garra, organic C is still accumulating at a linear rate – with no indication of what the equilibrium concentration will be or when it will be reached (Fig. 3). Although initial organic C concentrations were lower at El Bayadat, the rate of organic C accumulation is much faster (0.17 g C kg^{-1} soil y^{-1}) than at El Garra (average of 0.07 g C kg^{-1} soil y^{-1} during the initial 22 years).

We are currently seeking to determine why the soils at El Bayadat have accumulated almost four times as much organic C as the El Garra soils and are still apparently accruing C while the El Garra soils have reached an equilibrium level. Several potential explanations are being investigated. First, at El Bayadat, the farmers amend the soils with local variegated shale, which weathers over time and likely increases the clay content of the soils. We are in the process of doing grain size analysis to determine soil particle size distributions and x-ray diffraction to determine clay mineralogy for the two chronosequences to determine the effects of shale amendment on soil clay content. The amounts and mineralogy of clays play a critical role in the physical and chemical protection of organic matter from decomposition. Secondly, although N follows similar accrual patterns over time to that of organic C at each site, the C:N ratio is consistently much lower at El Garra (9.5 ± 0.4) than at El Bayadat (12.5 ± 0.4). Any number of factors (e.g., fertilization rates, cropping differences, differences in atmospheric deposition) could be the cause of this difference, but whatever the reason, it is possible that N is more limiting at El Bayadat, which could have significant effects on decomposition rates. Thus, we are also investigating potential differences in management or cropping practices including the amounts of plant inputs to soil, fertilizer inputs, tillage practices, and crop rotations. In addition, we will fractionate the soil into particulate organic matter and silt- and clay-sized organomineral associations to determine whether the forms of C being accumulated differ across the chronosequences or between sites.

Table 1. Soil carbon and nitrogen concentrations and C:N ratios for sampled irrigated agriculture chronosequences in Egypt.

Site	Field age (y)	Total C (g C kg^{-1} soil)	Inorganic C (g C kg^{-1} soil)	Organic C (g C kg^{-1} soil)	Total N (g N kg^{-1} soil)	C:N Ratio[a]
El Bayadat	0	1.86	1.10	0.8	0.06	13.1
	1	2.35	1.65	0.7	0.05	13.9
	6	8.63	6.84	1.8	0.15	11.6
	15	9.66	6.87	2.8	0.23	12.1
	70	12.60	0.02	12.6	1.07	11.8
El Garra	0	28.79	27.66	1.1	0.12	9.7
	4	12.99	11.54	1.4	0.16	9.0
	10	15.05	11.14	3.9	0.36	10.9
	20	14.75	12.11	2.6	0.31	8.6
	100	14.28	10.11	4.2	0.46	9.1
Al Thowra	3	14.78	11.35	3.4	0.30	11.3
	10	6.96	5.48	1.5	0.22	6.7
	35	13.06	7.68	5.4	0.52	10.4
Well4	0	11.51	12.13	-0.6	0.47	-1.3
	2	11.32	9.51	1.8	0.24	7.5
W. El Mayhoub	15	19.16	11.47	7.7	0.77	10.0
	40	13.59	6.88	6.7	0.71	9.5
El Malkiah	50	16.96	7.77	9.2	0.78	11.7
	300	8.18	7.57	0.6	0.08	7.3

[a] C:N ratio calculated with organic C.

New findings

Egypt has committed enormous resources (~$3 billion) to construct the Tushka Canal in SW Egypt, but our satellite based observations and models have shown that billions of dollars worth of future water management projects could be saved if nature is left to take its course there. Despite the enormous cost and the lack of international funding, Egypt embarked on construction of the Tushka Canal to reclaim desert land in SW Egypt by pumping water from Lake Nasser. Now, a lack of funds has put the second and third stages of the Tushka Canal on hold. The Tushka Canal will take water from Lake Nasser and pump it up a cliff to cultivate about half a million acres that were formerly part of the Western Desert. It takes an enormous amount of energy to pump the water uphill. Our investigations have shown that an alternative method accomplishes the same goals, cultivating the same area, but lets nature do it instead, without big energy-consuming pumping stations. A "second River Nile" is in the making, as Lake Nasser water continues to encroach on the surrounding areas turning desert land to arable lands. That is because as time progresses, the bottom of an artificial lake becomes more sealed. This process will continue, essentially creating spillways for the water from Lake Nasser to follow, running from depression to depression across portions of the Western Desert. It took forty years for this process to create five major new lakes to the west of Lake Nasser. These lakes are extensive, covering an area approximately one-fifth the size of the massive Lake Nasser. That flow is so significant that, given time (hundreds of years), it could potentially create a second River Nile, running west of and parallel to the Nile Valley. In the meantime, lands surrounding the inundated areas could be cultivated.

New potential

1. The Nubian aquifer underlying the Western Desert has been recharged in previous wet climatic periods. In other words, the water extracted from this aquifer is fossil water and thus this source is a non-renewable water resource. The encroachment of the Nile River water onto the depressions of the Western Desert will provide a mechanism for recharging the aquifer. Investigations like the ones conducted here will provide the predictive tools to identify the areas of recharge and to determine the magnitude of recharge. This could eventually lead to sustainable agricultural development of large sectors of the Western Desert.

2. We do not quite understand why El Bayadat area is sequestering C at a faster rate than the other locations. Understanding the cause(s) for the enhanced carbon sequestration in El Bayadat, and investigating the feasibility of replicating these factors in other areas could potentially be a worthwhile exercise given the rising interest in identifying cost-effective carbon sequestration procedures and mechanisms.

New Products

Refer to products displayed on our web-based GIS (http://isis.geology.buffalo.edu/website/Egypt4) and listed under section titled "status of Task 1".

Conclusions

Work during the second year led to the following:

(1) Development of a GIS that incorporated the raw and processed data
(2) Generation of digital topographic data of high spatial resolution (30 m) for large sections of the Western Desert. The latter was used to construct and validate a surface runoff model that simulates the encroachment of the rising Lake Nasser surface water levels onto the proximal depressions. The models are being used to examine potential routes for the excess River Nile

water as it encroaches onto depressions in the Western Desert. Outputs of this model (e.g., transmission losses) were used as inputs to the groundwater flow models

(3) Construction and validation of an integrated groundwater flow model covering the entire Lake Nasser and surroundings including the Tushka Canal lakes. The model was calibrated (1965-2000) against temporal head and is being used to predict long-term effects, beyond the year 2000, of Lake Nasser on recharge and temporal groundwater head. Such a model provides valuable constraints on the recharge rates from Lake Nasser and from the Tushka lakes and could potentially be used to test various water management schemes.

(4) Further development of a chemical and isotopic baseline data set for groundwater in the Nubian aquifer of southwestern Egypt. Analyses of stable Cl isotope ratios and ^{36}Cl in groundwater samples from near Lake Nasser and the Toshka Canal were completed and compared with such data for groundwaters in distant oases to provide an indication of chloride source and long-term recharge rate for the Nubian aquifer waters. These data were acquired for end-member water types including deep Nubian aquifer water, shallow Nubian aquifer water, and near-surface modern alluvial aquifer water; the data indicate possible effects of induced recharge of recycled irrigation waters in reclaimed agricultural lands and will be useful to evaluate future effects of land-cover and land-use changes in this area.

Publications

Sultan, M., El Alfy, Z., Becker, R., Milewski, A., Bufano, E. 2003, A Web-Based GIS for Egypt's Geologic Datasets, Geological Society of America Abstracts with Programs, Seattle Nov 2-5.

Yan, Eugene, Ballerstein, E., Sultan, M., and Becker, R. 2003, Hydrologic Impacts of Lake Nasser and the newly developed Tushka Lakes on the Nubian Groundwater System in Southwestern Desert of Egypt, Geological Society of America Abstracts with Programs, Seattle Nov 2-5.

Patterson L. J., Sturchio N. C., Sultan M. I., Lu Z.-T., Purtschert R., Lehmann B. E., Lorenzo R., El Alfy Z., El Kaliouby B., Dawood Y., and Abdallah A. M. A., Chlorine isotopes, chloride sources, and residence times of groundwaters in the Nubian Aquifer, Egypt" Geological Society of America Abstracts with Programs, Seattle Nov 2-5.

Sturchio, N.C., Sultan, M. Lu, Z.T., DU, X., Lu, Z.T., Du, X., Lehmann, B. E., Purtschert, R., Lorenzo, R., El Alfy, Z., and El-Kaliouby,B. 2002, Residence time of the Nubian aquifer water, Western Desert, Egypt, Goldschmidt conference Abstracts with programs.

Sultan, M, Becker, R, Jastrow, J D, Miller, R M, Kim, J, El Alfy, Z, 2003, Land Cover and Land Use Changes and their Impacts on groundwater resources and carbon cycling in SW Egypt, EOS Transactions, American Geophysical Union, vol. 83, p. 47.