Proposal Cover Sheet

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Proposal No.

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**

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Budget

Year 1: $181,406 Year 2: $170,333 Year 3: $166,598 Total: $518,337

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 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 agricultural development of desert lands?

Proportion of themes covered by the project:

1. Social Science activities (0%)
2. Water (groundwater flow modeling and geochemistry) (50%)
3. Mapping/monitoring LCLUC (25%)
4. Carbon (carbon sequestration)(25%)

What has been accomplished in the first year?

We have accomplished all the milestones listed in the proposal for the first year (1,2,3,5,6 listed below). In addition, we have accomplished in part one of the tasks (4) planned for years 2 and 3.

1. We compiled, digitized, and co-registered Landsat TM (1980s), MSS (1970s) , SIR-C, DTED, geologic maps (1:500,000), water table elevation (1970-2000), Lake Nasser surface water elevation (1970-2000) for the study area.

2. We monitored the changes in the area occupied by Lake Nasser from 1970 to 2000 using digital terrain elevation data (DTED) and measured lake levels (160 –180m) throughout this time span. This method was successful in the south where the lake surface water elevation (163m) extracted from the DTED is close to the lowest measured lake levels (160 m). Figure 1 is a TM color composite (bands 1,4,7) over the southern margins of Lake Nasser with an overlay of DTED-derived elevation contours that show the areal extent of the lake at surface water elevations of 163m (blue), 173m (yellow) and 182m (red). This method was not as successful in the northern parts where the DTED-derived surface water lake level (173 m) enabled only the mapping of the areal extent of the lake at surface water elevations above 173 m. This issue is being resolved by using temporal (ranging from early 1960s, before the lake was filled, through year 2000) Landsat TM, MSS, ASTER, and CORONA data sets acquired over the problematic northern areas.

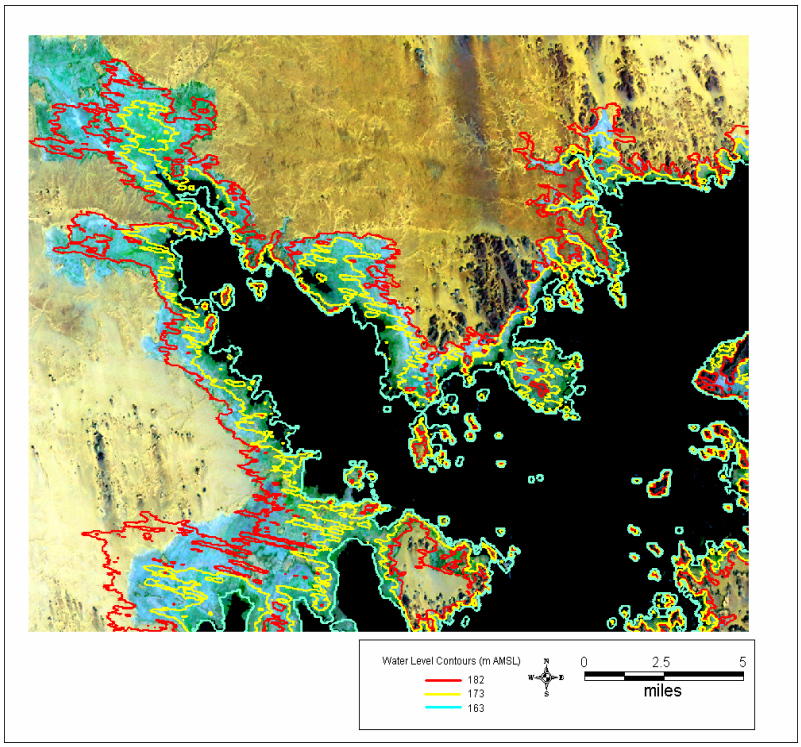

Fig. 1 Color composite from Landsat TM bands 1,4,7 acquired (1984) over the southern portions of Lake Nasser with an overlay of DTED-derived elevation contours that show the areal extent of the lake at surface water elevation of 168m. Also shown is an overlay of the areal extent of the lake at surface water elevation of 163m (blue), 173m (yellow) and 182m (red) that was inferred from DTED data. Areas in blue were flooded prior to 1984.

3. To determine the hydrologic impacts of lake changes on the Nubian aquifer water level in the study area, we ascertained the state of the system in terms of (a) chemical and isotopic compositions of surface water and groundwater and (b) hydraulic parameters such as the elevations of the Lake Nasser surface water table surface throughout the past 30 years. Three groups of groundwater samples were collected for isotopic (O, H) and geochemical analyses (anions, cations): samples that were collected along the Lakeshore, in the proximity of the lake, and at a distance from the Lake (Fig. 2).

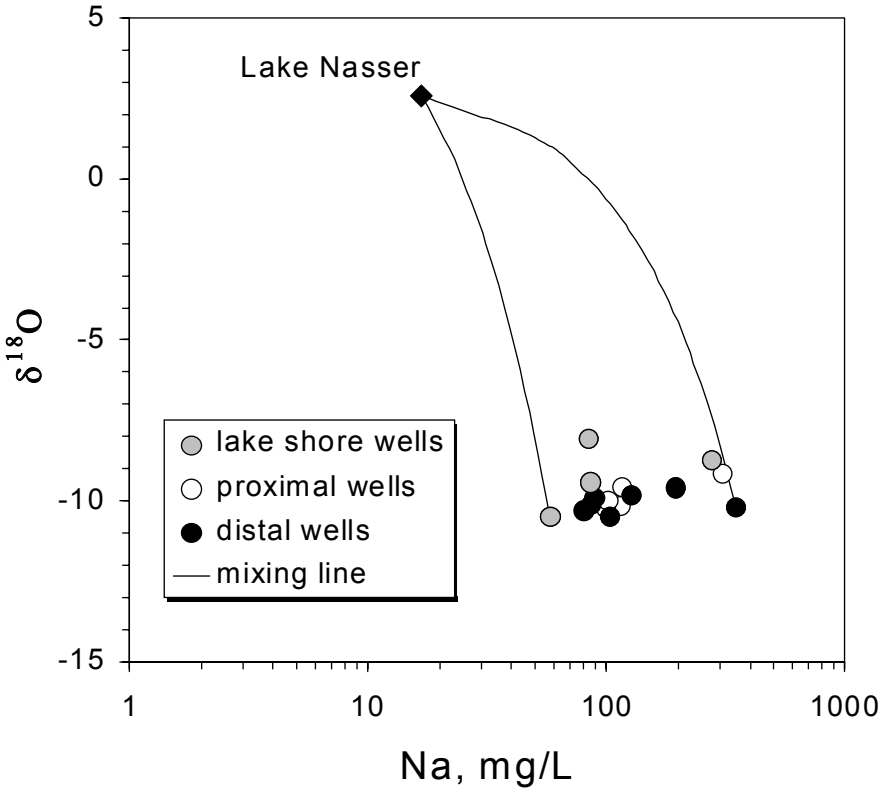

Fig. 2. Showing $\delta^{18}O$ values (‰) vs. Na concentrations (mg/L) for Lake Nasser water and ground waters in the area. Also shown are mixing trajectories for mixing of Lake Nasser water with ground water. Evidence for Lake Nasser infiltration into ground water is strongest in lakeshore wells, based on their relatively high $\delta^{18}O$ values.

4. The constraints provided by the geochemical and isotopic data together with relevant hydraulic parameters were used to complete the development of a two-dimensional unconfined-aquifer groundwater flow model for the SW parts of the lake and adjoining areas to the west where extensive agricultural projects (Tushka project will reclaim 0.5×10^6 acres of desert lands). Relevant hydrologic data are being collected to extend the model to incorporate the entire lake and all the agricultural development projects in the area.

5. To investigate the factors controlling carbon sequestration in reclaimed desert lands, we collected a suite of samples from reclaimed lands that vary in their geologic settings and reclamation ages. These are being subjected to process/mechanistic-based soil fractionation scheme to quantify the development of microaggregate structure and of protected C pools.

6. Two field trips were conducted. One to collect soil samples from reclaimed deserts of varying geologic settings and ages and another for collecting groundwater and surface water samples for geochemical and isotopic analyses.

New findings

The investigation of the effects of the new irrigation land development on the Nubian aquifer indicated that many of the proposed irrigation areas, especially those with small aquifer thickness, would become fully saturated with introduced water, resulting in potential flooding and salinization. It is noteworthy to mention that similar adverse effects resulted from the construction of the Aswan High Dam, where the general rise in ground water table levels that accompanied the construction of the Dam led to salinization of vast areas of agricultural lands in northern Delta. Measures have to be taken to avoid the recurrence of these adverse effects in SW Egypt as Egypt proceeds with the implementation of the Tushka project. These findings have scientific as well as economic and social impacts. Egypt has allocated large investments (an estimated 4 billion dollars) to the project and plans are underway to relocate large segments of its population to SW Egypt.

New potential

1. We developed an integrated hydrology model that accounts for LCLUC (inferred from remote sensing data) and for the constraints on groundwater sources (inferred from geochemical and isotopic data).
2. The distinct isotopic composition of Lake Nasser ($\delta D = +20.4‰$, $\delta^{18}O = +2.6‰$) relative to that of the underlying Nubian aquifer ground waters ($\delta D \sim -80‰$, $\delta 18O \sim -10‰$) allows precise estimation of the mixing ratio of these two waters. A diagram showing $\delta^{18}O$ vs. Na concentration illustrates the evidence for mixing of Lake Nasser water with ground waters in the vicinity of the lake (Figure 2). The evidence for mixing is strongest in the wells along the shore of Lake Nasser, less strong in proximal wells along the path of the Tushka canal and in distal wells. In one of the wells along the lakeshore, we estimate that about 18% of its waters came from Lake Nasser and 82% from the Nubian aquifer groundwater. These observations are consistent with our ground water flow model, that predicts that the advance of the recharge front from the lake did not exceed 20 Km during the past three decades. (Kim and Sultan, 2002).

3. The constraints provided by the geochemical and isotopic data together with relevant hydraulic parameters were used to complete the development of a two-dimensional unconfined-aquifer groundwater flow model for the SW parts of the lake and adjoining areas to the west. The model, constrained by regional-scale groundwater flow and near-lake head data, was successfully calibrated to temporal-observation heads from 1970 to 2000 that reflect variations in lake levels. Predictive analyses for the subsequent 50-yr period were conducted by employing the calibrated model. Simulations of long-term effects, beyond year 2000, of Lake Nasser on recharge and temporal groundwater head show that recharge from the lake will continue at a much slower rate than during the 30-yr period of 1970-2000 (with approximately 86% reduction in 30-yr recharge). The

modest projected pumping and injection activities in the study area are not expected to cause major deviation in the overall head distribution compared to the base case scenario. Implications for similar (adopting an integrated science approach) applications elsewhere are clear.

New Products

Construction of a series of co-registered images (Landsat TM, MSS, and CORONA) that show the LCLUC over the Lake is underway.

Conclusions

Work during the first year led to the completion and validation of an integrated hydrology model over a subset of the study area. The validated model was used to predict long-term effects, beyond year 2000, of Lake Nasser on recharge and temporal groundwater head. We find that recharge from the lake will continue at a much slower rate than during the 30-yr period of 1970-2000. The modest projected pumping and injection activities in the study area are not expected to cause major deviation in the overall head distribution. The recharge resulting from the new irrigation land development could potentially lead to flooding and/or salinization. To the best of our knowledge, our results (Kim and Sultan, 2002) represent the only published work on the hydrologic impacts on the Tushka Canal project, a project regarded by many as being of the same scale as the Aswan High Dam project.

The developed model serves as a significant step towards the establishment of a comprehensive ground water flow model over the entire Lake Nasser, and the adjoining lands. Analysis of a carefully selected suite of soil samples is underway to understand how different land use practices and geologic settings influence the accumulation of total soil Carbon. The reaction of infiltrating Lake Nasser water into the aquifer will tend to drive chemical reactions that may affect porosity, permeability, and water quality in the aquifer because it will be out of equilibrium with the aquifer rocks. These reactions will be modeled using the Geochemist's Workbench reaction path code and validated by comparison with measurable chemical and isotopic quantities in the waters. This modeling will be done during the next year of this project.

Publications

Kim, J., and Sultan, M. 2002, Assessment of the long-term hydrologic impacts of Lake Nasser and related irrigation projects in southwestern Egypt, Journal of Hydrology, v. 262, p 68-83.