Water resources management in the Nile basin: the economic value of cooperation

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ABSTRACT

Since 1999 a multilateral effort termed the Nile Basin Initiative has been underway among the Nile riparians to explore opportunities for maximizing the benefits of the river's waters through cooperative development and management of the basin. However, to date there has been virtually no explicit discussion of the economic value of cooperative water resources development. We believe that a serious discourse among Nile riparians about the economics of Nile cooperation is both inevitable and desirable, and that this discourse will not diminish the importance of environmental, social, or cultural issues that new infrastructure on the Nile will entail. To initiate such a discussion, in this paper we present the results of the first economic model designed to optimize the water resources of the entire Nile basin. Total (potential) annual direct gross economic benefits of Nile water utilization in irrigation and hydroelectric power generation are estimated to be on the order of US$7–11 billion. This does not account for the costs of building or operating the infrastructure.

Key words: water conflicts, Nile basin, cooperation, economic optimization

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Introduction

It is now part of the international water resource community’s lexicon to argue that “water is an economic good”. Though this phrase means different things to different people, it clearly calls for recognition that water has an economic value and that this value must be a central consideration in the management of water resources. Since 1999, a path-breaking multilateral effort termed the Nile Basin Initiative (NBI) has been underway among the Nile riparians to promote cooperation and explore opportunities for maximizing the benefits of the river’s waters through cooperative development and management of the basin system. Yet to date there has been virtually no explicit discussion of the economic value of cooperative water resource development from a basin-wide perspective. We believe that a serious discourse among Nile riparians about the economics of Nile cooperation is both inevitable and desirable (and in no way diminishes the importance of the environmental, social, or cultural issues that new infrastructure development on the Nile will entail). To initiate such a discussion, we present the results of the first economic model designed to optimize the water resources of the entire Nile Basin.

If the countries of the NBI are successful in launching cooperative basin-wide development and management schemes, this will represent a water management enterprise of historic proportions. Although the Nile south of Aswan is currently one of the least developed of the major international rivers of the world, the river system offers numerous opportunities for developments that would facilitate the management of Nile waters. Multipurpose dams on the Blue Nile in Ethiopia and elsewhere in the Blue Nile watershed could, for example, manage the Blue Nile flood and enable water resources managers to mitigate both the considerable inter-year and intra-year variations in the flow of the Blue Nile. The construction of such dams could generate hydropower income for Ethiopia and positive downstream externalities for Sudan and Egypt in terms of drought, flood and sedimentation control. Such control structures could also allow water managers to operate the system in such a way that the total flow of water available to the riparians would increase.

On the White Nile, over-year storage in the Equatorial Lakes (Lake Victoria, Albert and Kyoga) and perhaps small water control structures on the tributaries feeding Lake Victoria, could provide hydropower generation and water supply for the White Nile riparians, especially Uganda, Tanzania and Kenya. A major unanswered question on the White Nile is whether the Jonglei Canal Project will be finished and, if so, what form it will take[1]. Although variations in the flow of the White Nile are far less dramatic than in the Blue Nile, management of these waters would still provide positive downstream externalities in terms of drought, flood and sedimentation control.

For several decades, individual riparians have contemplated a variety of plans for the types of water control infrastructure projects described above (Whittington, 2004). More recently, as part of the NBI, investment planning has begun to be examined from a more cooperative, regional perspective. If cooperative investment projects are agreed and undertaken, the riparians could move closer to achieving system-wide, economically optimal management of the shared resources of the Nile. Whatever set of projects is agreed upon and eventually carried

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[1] The Jonglei Canal was conceived to run through the Sudd wetlands of the White Nile in Southern Sudan in order to conserve some of the estimated 50% of flow reduction attributed to wetlands consumption and evaporation in the marshes each year. [We don’t want to sound as if we think the Sudd water consumption is a deadweight loss] Despite serious environmental concerns, construction of the Canal began in 1978 as a joint Sudanese–Egyptian effort. As a consequence of the security situation in Southern Sudan, the project was suspended in 1984 with 250 km of the proposed 360 km canal completed. Concerns have been raised regarding the social and environmental impact of the Jonglei Canal.

out by the riparians, however, will signal the end of an historic period of Nile investment planning by putting in place the physical infrastructure that will allow the riparians collective control of the flow of Nile waters.

These investments will usher in an era of Nile management in which the waters of the Nile can be delivered wherever and at whatever time the collective political leadership of the riparian countries decides. This new era of Nile water management will not be focused on investment planning and the construction of new projects, but on management questions: deciding how to use the waters of the Nile to maximize their benefits to different users in different riparian countries. The challenge will not be to control the Nile waters, but to determine how they should be managed to ensure their most beneficial use. This new era of Nile water resources management will pose problems quite different from the construction of the engineering works of the first period of Nile water management. Instead of looking for ways to augment supply, water resource managers will need to find ways to use existing supplies more wisely in order to maximize benefits, promote economic growth and alleviate poverty in the Nile Basin[2]. Using the economic optimization model presented in this paper, we look ahead to the challenges of this new era of Nile management. We examine issues that will inevitably arise concerning the economic forces at play in water management decisions and the implications they will have for the economic value of water in the Nile Basin.

This paper is divided into five sections. In the next, second section of the paper we briefly review the concept of the "economic value of water", and make the distinction between the economic value of water to a particular user (user value) and the economic value of water within

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[2] An important corollary question is how to share these benefits among riparian countries in an equitable manner. We intend to examine this question in a future paper.

a river basin system (systems value). We also discuss four economic "pressures" on the economic value of water in the Nile system that arise from a combination of interrelated physical and institutional factors and present some preliminary information on the magnitude of these different influences in the Nile basin.

In the third section we present the economic optimization model developed to analyze the economic benefits of cooperation in the Nile Basin; we also discuss its limitations. The fourth section presents the main results of this model. In the fifth and concluding section of the paper, we summarize our findings and offer some preliminary lessons about the economic value of water in the Nile basin.

Background: two concepts of the "economic value of water" and four economic "pressures" at play in the Nile system

In the context of river basin management, there are two notions of the "economic value of water" that are both conceptually correct and commonly confused (Sadoff, Whittington and Grey, 2002). The first, which we term "user value", is the idea that water has economic value to a particular user at a specific location and point in time, such as a household with a private connection using water for domestic purposes, or a farmer abstracting water for irrigation. The economic user value of water is the amount of money a user will be willing to give up to obtain more water and it will be determined both by the use to which this water will be put and the amount of money the user has. This definition of the economic value of water to a user is not based on some abstract notion that water is intrinsically desirable, but is fundamentally determined by its transaction value in a world of scarcity.

It is difficult to generalize about the economic value of water to different users in different locations because both the intended uses of water and users' incomes differ in different times and locations. Information on the current economic value of water to different types of users in different locations in the Nile basin is not available; it is even harder to estimate what such values will be in the future. However, evidence clearly indicates that municipal and industrial users typically have the highest economic values of water (Briscoe, 1996). The economic value of water in irrigated agriculture is much less. How much a farmer is willing to pay for water for irrigation depends on the crop being cultivated, the amount of rainfall, the prices of agricultural products, the prices of other inputs such as fertilizer and labor and other factors, but it is typically in the range of US$0.01–0.25 per cubic metre. The economic value of water for large-scale irrigation of cereal crops such as wheat or rice is at the low end of this range. The economic value of water for the irrigation of high-value fruits and vegetables is occasionally at the high end of this range, but depends to a large extent on market conditions and transportation costs of delivering produce to market.

The economic value of water to an individual need not, however, depend only on whether an individual actually abstracts water for use in some "economically productive" activity or for final consumption. People may well be willing to exchange scarce resources or money to leave water in its natural state in the environment. In this case water "generates" economic value for people by doing what it is already doing, sustaining natural ecological systems. People may value water in its natural state because this enables them to harvest certain products and wildlife (e.g. fish) from the ecosystem. For example, many people living near the Sudd swamps in Sudan harvest fish and graze their cattle on the grasses sustained by the retreating waters of the annual floods on the White Nile. For them water in the natural environment has economic value, although their willingness to pay for these ecological services must be very low, simply because their incomes are minimal. At the other extreme, some Europeans might be willing to pay substantial amounts of money to maintain the current hydrological regime of the Sudd swamps in order to sustain the migratory bird life that winters there and summers in Europe (Whittington & McClelland, 1992).

Individuals may also be willing to pay to leave Nile water in its natural state, not because they want to fish or preserve bird life that they may some day enjoying seeing, but simply to preserve a natural environment for its own sake, because it is the "right" or moral thing to do. This "existence" or "non-use" value is also a component of the true economic value of water if people are willing to sacrifice (or pay) to preserve water in the natural environment. Individuals who derive economic value from the preservation of Nile water in its natural state might be willing to pay to avoid the flooding of the canyons of the Blue Nile gorge by a series of reservoirs, in part perhaps to preserve the biological diversity and genetic resources that exist in a largely undeveloped natural habitat. The waters of the Nile can thus create economic value to individuals living far outside the boundaries of the watershed. Typically individuals' motivations for preservation would represent a combination of both use and non-use values.

The second notion of the "economic value of water" incorporates the first, but takes a broader, systems perspective. This "systems value" or "shadow value" of water is defined as the total value generated by water within the river system – the sum of all benefits and costs to the riparians as a whole. Rather than asking what the value of water would be to a specific user, we attempt to ascertain the aggregate value of water to all of the inter-related users in the river system. From the systems perspective, we look at how changes in water availability – perhaps caused by changes in the water management strategy for a river basin – would affect all water users and hence the cumulative value of water in the system. The economic value of water from a systems perspective will be different from that of a single user because of the physical interdependencies of water use in a river basin that result in both positive and negative externalities. It is the concept of the economic value of water from a systems perspective that allows us to estimate the economic value of cooperation in an international river basin.

The economic value of water in the Nile Basin from this second, systems perspective will be determined by the interactions and magnitude of several different relationships, including the size of the evaporation and seepage losses, the hydroelectric power generation potential at different sites and the magnitude of the agricultural user values in different locations. These factors, coupled with the physical structure of the river basin network, create four principal "economic pressures" that affect how the water resources system should be managed and operated to maximize the system-wide economic benefits. We next discuss these four "economic pressures" and present estimates of some of the data that will determine their relative magnitude in the Nile system. Some of these data depend upon what projects are assumed to be in place and in operation in the Nile Basin, how they are operated and how much water is withdrawn by the riparian countries. For these illustrative calculations, we assume that the water withdrawals are at current levels and that a full set of Nile infrastructure projects is in place (Table 1)[3]. []

Economic pressure no. 1: "Withdraw water for irrigation as far upstream as possible – before you lose it through evaporation and seepage"

As Nile water flows north toward the Mediterranean, much is lost from evaporation and seepage. For each cubic metre of water that leaves Lake Tana in Ethiopia, about 40% is lost by

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[3] This list of infrastructure projects is derived from existing proposals; it is not our recommendation for the "best" set of infrastructure projects for the Nile basin.

the time it reaches the Mediterranean (assuming none is withdrawn for irrigation along the way). In some stretches of the river, evaporation and seepage losses are larger than in other places and in the southern reaches of both the White and Blue Niles rainfall in part compensates for evaporation and seepage losses. Seepage losses in one stretch may enter the groundwater aquifer along the river and contribute to in-stream flows downstream. But from Khartoum north, the Nile flows through severe desert and the net evaporation and seepage losses are substantial.

Figure1 shows the proportion of a cubic metre of water starting at Lake Tana that remains at different points along the Blue and Main Niles. Figure 2 shows similar information for a cubic metre of water starting at Lake Victoria and travelling down the White and Main Niles. The losses experienced include average evaporation from major reservoirs, both existing and proposed. The evaporation losses amount to 1–2% of the flow along each stretch north of Khartoum. Evaporation losses from the Sudd swamps and the Aswan High Dam Reservoir are particularly severe, constituting almost 50% and 15% of the entering flows, respectively.

From an economic perspective, if there were no other countervailing pressures, one would want to withdraw water for consumptive uses such as irrigation and municipal water supply before it flowed downstream, because this strategy would minimize evaporation and seepage losses. In other words, *ceterus paribus*, there is more water to use if it is used upstream rather than downstream, so economic efficiency would dictate that it be used upstream.

Economic pressure no. 2: "Withdraw water for irrigation as far downstream as possible in order to take full advantage of hydroelectric power generation facilities"

Hydropower is a non-consumptive water use and thus it is advantageous from an economic perspective to let each cubic metre flow through as many hydropower generation facilities as possible before it is withdrawn for consumption. This second economic pressure would dictate that, *ceterus paribus*, consumptive uses should occur downstream so that water flows through as many hydropower generation facilities as possible. One of the opportunity costs of withdrawing water upstream is therefore the foregone hydropower generation potential from all hydropower facilities downstream of that consumptive use that could have been obtained if the water had not been withdrawn.

The magnitude of hydropower generation at each point in the system is largely a function of two factors: (1) the quantity of water passing through the turbines and (2) the net head at each hydroelectric power generation site. Figures 3 and 4 show the average annual flows passing through the existing and some potential hydroelectric power facilities on the Blue and main Niles and White and main Niles, respectively. The flow of water passing through the potential hydroelectric power facilities on the Blue Nile increases steadily as the Blue Nile gathers volume, peaking at the Ethiopian–Sudanese border (at the proposed Border Dam). Releases from the Aswan High Dam are higher even after accounting for evaporation and seepage losses because the flow of the White Nile has augmented the flow of the Blue Nile at Khartoum.

Figures 5 and 6 illustrate the average net head at each existing and some potential hydropower facilities along the Blue and main Niles and the White and main Niles, respectively. As shown, the net heads available on the upper reaches of the Blue Nile are much larger than those at sites on the Blue Nile in Sudan or even at the Aswan High Dam Reservoir. The net heads on the upper reaches of the White Nile are also large, but considerably less than on the Blue Nile in Ethiopia.

Figure 7 shows the monetary value created by a cubic metre of water flowing through hydroelectric power turbines at each of the sites along the Blue and main Niles, assuming each kilowatt-hour has an economic value of US$0.08. The economic value of hydropower created per cubic metre is highest upstream on the Blue Nile in Ethiopia owing to the large net heads at Lake Tana and Karadobi. The cumulative value generated by a cubic metre of water flowing downstream in the Blue Nile does not increase much after the Border Dam because the net heads at the subsequent downstream reservoirs (Roseires, Sennar and Aswan High Dam) are not great and substantial evaporation and seepage losses are incurred along the way. Figure 8 shows the cumulative value of the hydropower generated by a cubic metre of water flowing downstream on the Blue and main Niles.

Figures 9 and 10 present the results of similar calculations for the White Nile. Existing studies suggest that there are six potential power station sites between Lake Victoria and Lake Kyoga, with capacity ranging from 150–350 MW. For a cubic metre of water flowing from Lake Victoria, the economic value of hydropower generated at Aswan High Dam only accounts for a small fraction of the total value because of the substantial evaporation and seepage losses in both the Sudd area and the dam itself.

Economic pressure no. 3: "*Store water upstream to reduce evaporation losses"*

Figures 1 and 2 illustrate the importance from a systems perspective of minimizing the economic losses associated with evaporation losses at Aswan. As noted above, one way of doing this is to use water upstream. Another approach is to reduce storage in the Aswan High Dam Reservoir by moving storage upstream into the potential Blue Nile Reservoirs and the Equatorial Lakes. For an equivalent amount of storage, evaporation losses upstream are reduced because (1) volume-to-elevation relationships are more favorable at the upstream reservoir locations and (2) evapotranspiration is lower at the more humid upstream sites (Guariso & Whittington, 1987).

Economic pressure no. 4: *"Withdraw water where its user value is greatest"*

The economic benefits from water use will be greatest when water is used by those who use it most productively, i.e. those with the highest user values. At this time not enough is known about the economic value of water to users to make any definitive statements about where in the Nile Basin user values of water will be highest. However, four relationships will almost certainly hold. First, the initial units of water that a riparian country receives have the potential to be the most valuable. Users will derive more value per unit of water when it is scarce than when it is abundant, because there is generally a limit to the amount of water that will be used in the most highly productive sectors, i.e. household and industrial consumption. Initial units of water should be allocated to their most productive uses, while subsequent units of water should be allocated to uses of decreasing productivity. Riparian countries with little current access to water may still have opportunities to expand high-value uses that have already been fully exploited by countries with abundant supplies.

Second, those countries that have the most economically sound water resource management policies, practices and institutions, will be likely generate the highest user values for water. Countries that are able to devise and implement institutional arrangements to charge water users prices that reflect scarcity values, for example, are much more likely to foster economically efficient water use (and put water to high-value uses) than countries that do not. Thus, the highest user values of water in the Nile Basin will not simply be the result of technological, economic and climatic factors, but also of the water resource policies and practices adopted by the riparian countries themselves. Because policies change, the relative economic value of water to different users in the basin is best viewed as dynamic. As discussed below, this insight is a key to unlocking the economic potential of the Nile’s water resources.

Third, those countries with economically sound water-related sectoral policies will also be more likely to generate higher use values for water. Agricultural policies that promote the production of high value crops and water-efficient farming methods, infrastructure policies that enable market access for high value agricultural products, and industry or service sector policies that encourage high value production with moderate or minimal water requirements will all increase the user value of water in a country.

Fourth, the economic value of leaving water in a free-flowing river to preserve natural ecosystems and to provide recreational opportunities will grow over time. The critical environmental assets at risk from Nile water management are the canyons of the Blue Nile gorge in Ethiopia and the immense freshwater swamps on the White Nile in Sudan. Today the environmental and aesthetic values associated with free-flowing stretches of the Nile will seem of secondary importance to many Nile riparian countries. Yet experience suggests that the economic value of these environmental assets will increase; even today they may have surprisingly high values for ecotourism and debt-for-nature swaps.

Balancing economic pressures in a systems context: the Nile economic optimization model (NEOM)

The Nile economic optimization model (NEOM) provides a framework for integrating hydrological and economic information in order to consider jointly the effects of the four economic pressures described above. It is formulated as a non-linear, constrained optimization problem designed to determine the annual pattern of water use that will maximize the sum of economic benefits from irrigated agriculture and hydropower generation in the Nile basin (i.e. the systems value of water generated from irrigation and hydropower). Figure 11 shows how the Nile system is represented in the NEOM. The water resources network is characterized as a series of nodes and links between these nodes. There are two kinds of nodes in the NEOM: reservoirs and irrigation schemes. The model includes all the existing reservoirs and irrigation schemes in the basin, as well as eight new reservoirs and 13 new irrigation schemes[4]. The links between nodes in the NEOM describe the physical characteristics of the Nile river along different stretches (e.g. the capacity of the channel and the net evaporation and seepage losses along each stretch). The Jonglei Canal is a special type of link because the user can specify whether or not it can be assumed that it will be built and the amount of water it can be assumed to be able to carry.

The mathematical formulation of the NEOM can be expressed as:

$$Maximize \sum_{c} \{ \sum_{i,c} P_w^{i,c} \sum_{t} Q_t^{i,c} + \sum_{i,c} P_e^{i,c} \sum_{t} KWH_t^{i,c} \}$$

Subject to the following constraints:

1. Continuity Constraints for Reservoir Nodes

$$S_{t+1}^{i} = S_{t}^{i} + I_{t}^{i} + (1 - EV_{t}^{j-i})R_{t}^{j} - (e_{t}^{i} - r_{t}^{i})[a^{i} + b^{i}(\frac{S_{t}^{i} + S_{t+1}^{i}}{2})] - Q_{t}^{i,c} - R_{t}^{i}$$

for t = 1,2,3...12

2. Continuity Constraints for Intermediate Nodes

$$(1 - EV_{t}^{j-i})R_{t}^{j} + I_{t}^{i} = R_{t}^{i} + Q_{t}^{i,c}$$

for t = 1,2,3...12 (j indicates nodes immediate before i and can be more than one node)

3. Storage Capacity Constraints for Reservoir Nodes

$$S_{Min}^{i} \le S_{t}^{i} \le S_{Max}^{i}$$

4. Irrigation Water Withdrawal Pattern

$$Q_{t}^{i,c} = Q^{i,c}\delta_{t}^{i}$$

for t = 1,2,3...12

5. HydropowerGeneration Equalities

$$KWH_{t}^{i,c} = \eta\, R_{t}^{i}\, f(S_{t}^{i}, S_{t+1}^{i})\, \varepsilon$$

for t = 1,2,3...12

6. HydropowerGeneration Capacity Constraints

$$KWH_{t}^{i,c} \le CAP^{i,c}$$

for t = 1,2,3...12

7. Non - negativity Constraints

$$S_{t}^{i}, R_{t}^{i}, Q_{t}^{i}, KWH_{t}^{i,c} \ge 0$$

for all the decision variables and for t = 1,2,3...12

where

$P_w^{i,c}$ = the economic value of water for irrigation at site *i* for country *c* (in US\$/m^3),

$Q_t^{i,c}$ = the quantity of water withdrawal for irrigation at site *i* for country *c* in month *t*,

$P_e^{i,c}$ = the electricity price at site *i* for country *c* (in US\$/kWh),

$KWH_t^{i,c}$ = the hydropower generated at site *i* for country *c* in month *t*,

S_t^i = reservoir storage for reservoir *i* in month *t*,

I_t^i = the inflow to site *i* in month *t*,

R_t^i = the release (or the outflow) from site *i* in month *t*,

EV_t^{j-i} = the percentage of evaporation loss for water flowing from site *j*, where *j* indicates immediate nodes before site *i* and can be more than one, to site *I*,

e_t^i = the evaporation rate at site *i* in month *t*,

r_t^i = the addition to flow at site *i* in month *t* owing from rainfall,

a^i and b^i = the constant and the slope of the area storage relation of the reservoir, respectively,

S_{Min}^i and S_{Max}^i = the minimum and maximum storage for any reservoir at site *I*,

$Q^{i,c}$ = the irrigation withdrawal for irrigation site *i* in October,

δ_t^i = the coefficients of irrigation withdrawal for site *i* in month *t* in relation to irrigation withdrawal for site *i* in October,

η = unit conversion constant,

$f(S_t^i, S_{t+1}^i)$ = function determining average productive head,

ε = hydropower efficiency and

$CAP^{i,c}$ = the maximum hydropower that can be generated at site *i* in month *t*.

The model uses a time increment of one month and solves for values of the decision variables S_t^i (reservoir storage), R_t^i (release for outflow), $Q_t^{i,c}$ (withdrawal for irrigation), $f(S_t^i, S_{t+1}^i)$ (average productive head) and $KWH_t^{i,c}$ (amount of electricity generated) for a single year to determine the combination of monthly releases from a specified set of Nile hydropower generation facilities and the monthly abstractions at specified sets of irrigation schemes that will generate the greatest annual economic benefits to the riparian countries as a whole. The constraints require continuity at different nodes, storage capacity constraints, irrigation water withdrawal patterns, hydropower generation equalities, hydropower generation capacity constraints and non-negative constraints.

This basic model formulation was first proposed by Thomas & Revelle (1966) for studying the operation of the Aswan High Dam. It was later extended by Guariso & Whittington (1987) to include reservoirs on the Ethiopia portion of the Blue Nile. The model presented above is the first time the formulation has been used to characterize the entire Nile Basin. The model is quickly solved on a personal computer using GAMS software.

The model can be used to evaluate the economic implications of different combinations of proposed Nile water control infrastructure that have been proposed by the riparian countries (Fig. 11). The user can specify the total amount of water available over the course of the model year (i.e. whether the water resources managers are attempting to operate the control structures during an average, high or low hydrological year). The user of the model can also constrain the optimization to ensure specific levels of water flow or withdrawals, for example, to meet basic needs, priorities or obligations at any point in the river system. Municipal and industrial water withdrawals can be specified for each riparian country and the model can be constrained so that these demands are always met. Environmental goals can also be incorporated in NEOM as constraints on system management. For example, minimum flows through the Sudd swamps can be required. NEOM can be used to examine the implications of not flooding portions of the Blue Nile gorge, or requiring minimum flows along different stretches of the river. The user can also prohibit the construction of specific environmentally sensitive projects.

NEOM does not explicitly include the economic benefits of flood control. In the future, if most of the proposed control infrastructure is built, operating the Nile system to maximize the economic benefits from irrigation and hydropower generation should in fact solve flooding problems on the Blue and main Niles. The economic benefits of flood control are thus relevant for investment planning purposes in terms of ensuring that the economic benefits of proposed dams justify their costs. Once these control structures are completed, however, operating the system to achieve hydropower and irrigation objectives will indirectly ensure that flood damage is minimized because the seasonal variability of the Nile flow will be smoothed. The proposed reservoirs will be likely to be sufficiently large to store substantial amounts of the water from high floods for use during periods of low floods, mitigating the effects of floods and, to some extent, droughts.

There are numerous other limitations of this model formulation. For example, neither water quality considerations nor sediment transport is incorporated, nor are groundwater flows incorporated explicitly in the model. The NEOM is deterministic and assumes that the managers of the system know the pattern of inflows throughout the basin over the coming year. Moreover, this is an annual model and does not address the complexity of over-year storage issues.

Most importantly, the capital costs of the infrastructure development projects are not included. There are two contexts in which this admittedly extreme assumption might be relevant.

The first is if international donors provided grant financing to build the proposed Nile infrastructure projects. Second, after such infrastructure is built, the capital represents sunk costs and from both an economic and social perspective should be operated to maximize economic benefits. Nevertheless, it is important to emphasize that the results presented in this paper should not be viewed as an *ex ante* economic justification for the construction of infrastructure projects in the Nile basin.

We have confronted numerous data deficiencies and were forced to make many simplifications to formulate and solve this economic optimization model for the Nile Basin. However, from an economic perspective, the main problem is the lack of information on the demand functions for irrigation water in the different riparian countries. This is not a problem that will be solved easily or quickly because these user values of water are simply unknown today in the Nile Basin. It is also important to emphasize that such economic user values of water are not static. They will change over time in response to infrastructure investments and technological and climatic factors, as well as macroeconomic and sector policies in the riparian countries.

To address this uncertainty in the user values of water in irrigated agriculture, our data analysis consisted of three steps. First, we have assumed an economic value of water in agriculture and a value of hydropower that are generally consistent with international experience (US\$0.05/m^3 in irrigated agriculture and US\$0.08/kW-h) in well-run irrigation schemes and power systems. We have assumed that these user values are the same in all riparian countries in the Nile basin and that they are constant regardless of the amount of water withdrawn in a particular country (i.e. for this step of the analysis we have assumed perfectly horizontal demand curves for water in agriculture and hydropower.) We then used the NEOM to examine several scenarios with different assumptions about the water control projects in place in the basin and the locations and amounts of water withdrawals. Water withdrawals for several of the scenarios were constrained so that fixed amounts were withdrawn by each riparian, while water withdrawals in the final model run were unconstrained so that the model could determine where and how much water should be withdrawn to maximize total economic benefits (systems values). We then compared (a) the scenarios in which the results were constrained by fixed water withdrawals, to (b) the scenario in which water withdrawals were unconstrained (i.e. in which water was free to be allocated to the highest value uses). This approach allowed us to examine the economic implications of different patterns of water withdrawal for irrigation.

Second, we conducted sensitivity analysis by varying the user value of water in irrigated agriculture. We evaluated how the economic value of cooperation would change for different user values of water for irrigation, still maintaining the assumption that the user value for the water in irrigation would be the same across different riparian countries.

Third, we relaxed the assumption that different riparian countries had the same user value of water in irrigation and allowed this value to differ across countries. Starting from the baseline case for which the user value of water in irrigation was assumed to be US\$0.05/m^3 for both upstream and downstream riparian countries, we evaluated four cases for which a group of countries (upstream or downstream riparian countries) would have high or low user value of water for irrigation while the user value of water in irrigation for the rest of the riparian countries (downstream or upstream riparian countries) remains at US\$ 0.05/m^3: (1) high user value for water in irrigation for upstream riparian countries (Ethiopia and Equatorial states), (2) low value for upstream riparian countries, (3) high value for downstream riparian countries (Sudan and Egypt) and (4) low value for downstream riparian countries.

The next section of this paper presents the results of the analyses for each of these three steps for dealing with the uncertainty in user values.

Results

In order to determine the economic value of cooperation, we first calculate the total economic benefits under two cases: the *status quo* conditions and full cooperation. Under the *status quo* situation, no proposed infrastructure is built and irrigation water is allocated to individual riparian countries in approximately the current allocation pattern. We define "cooperative full development" as the state of the world in which all proposed infrastructure projects (i.e. Blue Nile reservoirs, wetland conservation projects and White Nile power projects currently under consideration by the riparians) will be completed and operated to optimize the total economic benefits for the whole basin. We judge that it would be impossible to build the full set of Nile infrastructure projects under discussion and to operate them to maximize economic benefits without full cooperation among the riparians. On the other hand, the Nile riparians could cooperate fully in the construction and operation of a lesser number of infrastructure projects; we term this state of the world "cooperative partial development". On the other hand, a smaller number of infrastructure projects might result from less than full cooperation, that is, coalitions among some subset of Nile riparians.

Table 2 presents the comparison between the *status quo* and cooperative full development (assuming the value water for irrigation is US\$0.05/m^3 and the value for hydropower is \$0.08/kW-h). The difference between the total economic benefits between the *status quo* and cooperative full development can be interpreted as the economic value of cooperation[5]. Table 2

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[5] Some specific characteristics of these investment projects justify our use of the term "economic value of cooperation" here. The idea of building these investment projects is not new; in fact many projects discussed here

shows that the economic value of cooperation is US$4.94 billion ($10^9$) annually, more than the total economic benefits realized at present for the *status quo* conditions for the whole basin. In terms of the average economic value per cubic metre, the economic value of water will increase from 0.04 per m^3 (including both irrigation and hydropower benefits) to 0.09 per m^3 due to cooperative full development.

While cooperative full development in the Nile basin would create significant economic benefits compared to the *status quo*, this is only one of many possible scenarios for the future Nile development. We thus consider four additional scenarios in our analysis. These scenarios are defined based on the status of capital investment projects that are completed. A brief description for each scenario is given in Table 3, including the *status quo* (Scenario 1) and cooperative full development (Scenario 6). Scenarios 2 to 5 represent situations in which only some of the currently proposed infrastructure projects are completed. These may be envisaged as partial cooperation solutions, or alternatively as steps on the path to full cooperation (where investment is constrained by either a lack of capital for investment or a lack of political agreement about which projects to construct). Scenario 2 represents the partial cooperative development of hydropower potential in the Blue Nile (only Lake Tana, Mobil Dam and Border Dam are assumed to be built). Scenario 3 represents the full development on the Blue Nile (all five proposed dams in Ethiopia are assumed to be built) and Scenario 4 represents the full development on the Blue Nile plus the completion of the wetland projects on the White Nile.

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are little different from the Century Storage Project proposed by H.E. Hurst more than half a century ago. The primary reason for lack of progress in putting these investment projects in place has been lack of cooperation among the Nile riparian countries. Some countries where it is proposed that these projects be built have not had the financial means to take on these investment projects on their own and owing to the potential objection of downstream countries, the financing of these projects has been complicated. [Such a situation is likely to continue unless the Nile riparian countries can agree to cooperative schemes that will allow riparians jointly to harness the potential of these investment projects, either individuals or through joint partnership arrangements.

Scenario 5 represents the full development in the White Nile (demolition of Jebel Aulia dam and the construction of the While Nile reservoirs and power stations and wetland projects) plus partial development on the Blue Nile (only Lake Tana, Mobil Dam and Border Dam are assumed to be built).

For each scenario of these six scenarios, we consider two cases: (1) fixed amounts of water withdrawals for individual riparian countries and (2) no constraints on water withdrawals in a particular country. Two factors are taken into consideration in establishing water withdrawal constraints in our analysis. The first is current use patterns which reflect the 1959 Nile Waters Agreement between Egypt and Sudan. The second is the aspiration of the upstream riparian countries to utilize Nile water for development of irrigation schemes. We assume that Ethiopia would eventually utilize 10 billion m^3 of water from the Nile basin for irrigation purposes (Whittington *et al*., 1994) and that the equatorial states would use at least 2 billion m^3 of water annually.

It is, in fact, impossible to know what water withdrawal targets would “satisfy” all riparian countries and moreover it must be assumed that desired withdrawals will change over time. The specific water withdrawal constraints used in these analyses are thus somewhat arbitrary and are used only for purposes of illustration. Our main objective is to demonstrate that imposing water withdrawal targets can be quite costly from an economic perspective.

The economic value of cooperation on the Blue Nile can be seen by comparing Scenarios 2 and 3 with Scenario 1 (*status quo*). Under the scenario of limited infrastructure development on the Blue Nile, the annual economic value of cooperation is between US$1.15 billion and US$1.97 billion (Tables 4 and 5), depending on whether or not the water withdrawal targets are imposed. In the case where all Blue Nile development projects are built (Scenario 3), such benefits increase to between US$2.76 billion and US$3.63 billion annually. The economic value of cooperation on the Blue Nile derives mainly from two sources: (1) economic benefits from additional hydropower production from Blue Nile hydropower stations and (2) water savings from shifting storage from the Aswan High Dam Reservoir to these Blue Nile reservoirs. The sizable difference in economic benefits between the case for which water withdrawal targets are imposed and the case for which such constraints are removed indicates that imposing water withdrawal targets is not efficient from an economic perspective. Under our assumptions, about US$800 million would be lost annually if these water withdrawal targets were imposed.

The economic benefits of wetland projects are shown in Scenario 4[6]. If no water withdrawal constraints are imposed, the incremental benefits of adding the wetland project to the infrastructure system, given the assumed values for irrigation (US$ 0.05/m^3) and hydropower (US$0.08/kW-h), are quite small (about US$100 million annually). The marginal benefits of the wetland project, however, increase dramatically when water withdrawal targets are imposed (Table 4). Without the water savings from the wetland project, it is impossible to meet the water withdrawal targets for upstream riparian countries while not compromising the irrigation water withdrawal targets of Sudan and Egypt.

Tables 4 and 5 also show the economic value of cooperation on the White Nile. The difference between the Scenario 2 and Scenario 5 is that in the latter the White Nile power stations are added (along with the wetland project). Without the White Nile power stations, the NEOM suggests that water from Lake Victoria basin can be best utilized by the equatorial states, even if the wetland project is completed (Scenario 4). With the White Nile power stations, the

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[6] By wetland projects, we refer here to the Jonglei and the Machar Marshes projects, which could be operated to preserve the majority of the current wetlands.

model allocates most of the White Nile flows from Lake Victoria to the downstream countries. The hydropower power facilities along the White Nile effectively tip the balance in favor of downstream users. Egypt is thus a major beneficiary of the construction of the White Nile power stations because once water passes through the White Nile power stations, the NEOM indicates that the best strategy is for it to continue on to the Aswan High Dam Reservoir in order to capture the hydropower and irrigation benefits in Egypt. From the Egyptian perspective, a strategy for alleviating concerns over potential irrigation withdrawals in the equatorial states might thus be to assist these countries in the expansion of their hydropower facilities.

Figure 12 shows how the total economic benefits would increase when the level of cooperation (infrastructure development) increases. The level of cooperation can be interpreted as either (a) more riparian countries are brought into cooperative development schemes, or (b) more capital investment projects are added to the system, or (c) both. The effects of imposing country-level water withdrawal constraints are also shown in Fig. 12. Except for the case of full cooperation, imposing water withdrawal constraints will significantly reduce the economic benefits of cooperation. In fact, the economic savings in removing water withdrawal constraints for the case of full cooperation in the Blue Nile exceeds the marginal benefits of building a wetland project – even without taking into consideration the capital costs and negative environmental impact associated with the wetland project.

Tables 6 and 7 present the results from the sensitivity analyses, varying the value of irrigation water. If the economic value of water for irrigation is reduced to US\$0.02/m^3, the NEOM allocates all of the irrigation water to Egypt because it is preferable to withdraw irrigation water after the hydropower benefits of release from the Aswan High Dam are realized instead of irrigating upstream and losing out on these hydropower benefits. The second economic pressure – “withdraw water for irrigation as far downstream as possible” – has clearly dictated the model results here. The model allocates more water to Sudan as the economic value of water for irrigation increases. When the economic value of water for irrigation increases to US$0.08/m^3, it is better to withdraw water before the Aswan High Dam because the gains of additional hydropower generated at Aswan High Dam cannot offset the losses from evaporation.

Table 6 also shows that, if the value of water for irrigation is the same across different riparian countries, it is not justified from the systems point of view to allocate any water for upstream riparian countries for irrigation purposes within the range of economic value of irrigation water assumed for this sensitivity analysis (US$ 0.02/m^3 to US$ 0.08/m^3). The model would allocate water to upstream riparian countries if the economic value of water for irrigation in these countries is much higher than that in the downstream riparian countries (Table 7). The fourth economic pressure – “Withdraw water where its user value is greatest” – prevails only when the difference in user values is very large. An interesting finding is that the economic value of cooperation is surprisingly robust to the variations in the user value of water for irrigation. The economic value of cooperation fluctuates in a relatively narrow range (from US$ 4.7 billion to US$ 5.5 billion annually) when the value of water for irrigation in various riparian countries changes from $US 0.02/m^3 to $US 0.08/m^3. These results suggest that the managers of an integrated Nile system could adapt to different economic values of water for irrigation by putting more or less emphasis on hydropower generation. For example, more electricity will be generated if the value of water for irrigation is relatively low and emphasis will be shifted to reduce evaporation losses. In addition, much of the value of cooperation is from the hydropower generation associated with the assumed infrastructure projects in the Blue Nile and White Niles.

Thus the bulk of the value for cooperation will not change if the economic value for hydropower is assumed to be fixed.

Discussion

Table 8 summarizes 13 key results of the model analyses. Total (potential) annual direct gross economic benefits of Nile water utilization in irrigation and hydroelectric power generation are on the order of US$7–11 billion. Again, this does not account for the costs of building or operating the infrastructure and thus may strike some observers as a relatively small number. However, for policymakers in countries with gross domestic products per capita of less than US$300, it is likely to appear quite large. Moreover, there is a strong likelihood that the global community will pay for much of the financial costs of this infrastructure, so that the direct economic benefits could be largely captured by the people in the Nile Basin (Song & Whittington, 2004). Finally, it is anticipated that these cooperative investments will yield significant indirect benefits and leverage opportunities "beyond the river" for greater regional integration and cooperation (Sadoff and Grey, 2002).

In most scenarios the total direct economic benefits are generated "relatively" evenly in Ethiopia, Sudan, Egypt and the Equatorial States. This result is likely to surprise many policymakers and analysts in the Nile basin, who often fear that benefits will accrue unequally among the riparian countries. How these benefits are shared will need to be determined by negotiation[7]. However, the economically efficient location of water use can be strongly affected by which Nile riparian countries have the best set of macroeconomic and sector policies in place.

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[7] Hydropower facilities could be owned and operated by consortia of riparian countries as is currently the case in the Senegal River Basin. –[This probably isn't ready for primetime.] Other potential negotiated benefit sharing arrangements could involve government or private sector riparian power purchase arrangements, power interconnection infrastructure and wheeling arrangements, agricultural investment by riparian private sector entities across the basin, or the bundling of other apparently unrelated investments such as rail or telecom interconnections (Waterbury & Whittington, 1998; Waterbury, 2002).

Macroeconomic and sector policies will be primary determinants of the value of water in irrigation and the value of kilowatt hours of electricity. Inter-country power grids will enable electricity producers to obtain maximum prices, increasing the value of water in hydropower generation. These results are again likely to surprise many people in the basin, who often expect such natural advantages as soil type and precipitation to dominate policy variables.

Although total economic benefits would be generated relatively equally in Egypt, Sudan, Ethiopia and the Equatorial States, the composition of the benefits differs by county. If large-scale infrastructure development in the Nile basin is undertaken, the majority of the economic benefits from hydroelectric power generation will be generated in Ethiopia and to a lesser extent in Uganda. Power interconnections will increase the magnitude of these benefits. On the other hand, the majority of the irrigation benefits are generated in Sudan and Egypt. If the economic value of water in irrigation were the same in Ethiopia, Uganda, Egypt and Sudan, from a system-wide perspective the economically efficient management solution would be to use water for irrigation in downstream riparian countries. But low crop water requirements in the Ethiopian highlands may increase the economic value of water in irrigation.

If the economic value of water in irrigation is the same throughout the Nile basin, the model does not promote water use for irrigation in the highlands region of Ethiopia. This is because it wants to capture the hydroelectric power generation along the Blue Nile gorge. Abstracting irrigation water in the Ethiopian highlands upstream of the proposed Blue Nile reservoirs results in significant losses in hydroelectric power generation. The more economically valuable a kilowatt-hour of electricity from hydropower, the higher the economic penalty of withdrawing water for irrigation in the Ethiopian highlands and the greater the system-wide benefits of downstream riparians using water for irrigation purposes downstream of power generation. This “within-country” tradeoff between hydropower generation and irrigation is not limited to Ethiopia. Uganda, Sudan and Egypt also confront this tradeoff.

The economic benefits of irrigation to Ethiopia are likely to be greater near the border with Sudan, in the west of the country, because such water supplies have already generated substantial hydropower benefits. Once water flows through the Ethiopian highlands and the hydroelectric power potential there is captured, it does not matter much whether the water is withdrawn for irrigation in Sudan, Egypt, or the lowlands of Ethiopia (except that the model does not want to withdraw water directly above hydropower facilities).

Finally, most of the projects on each Nile riparian country’s drawing boards have been designed only from the perspective of a single riparian country, not from a basin-wide perspective. A suboptimal outcome of the NBI would be if the result of the riparians’ negotiations was that every riparian got their “own” unilaterally-designed projects approved. This could lead to conflicts down the road over the operation of the infrastructure because there are simply too many projects on the drawing boards for them all to make economic sense. Furthermore such unilaterally designed projects will fail to capture the greater gains afforded by system-wide management and development.

Whatever the eventual level of infrastructure development in the Nile basin, the NBI has set in motion an historic shift from unilateral investment planning to a focus on cooperative system-wide development and management of Nile waters. This new perspective should enable the riparians better to sustain the ecosystem and generate greater economic benefits for all people in the Nile basin. The direct economic value of cooperation will be substantial and if cooperation on the Nile can be achieved, it will catalyze other development gains throughout the region.

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The research in this paper builds on knowledge accumulated over years of study of Nile water management issues and the work of many other Nile scholars. The authors are particularly indebted to John Waterbury, Guariso Guariso, Kingsley E. Haynes, J.A. Allan, Aris Georgakakos and Ariel Dinar for their contributions to this field and to our editor, Jerry Delli Priscoli, for his many helpful suggestions.

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Fig. 1. Evaluation and seepage losses: the Blue and main Nile.

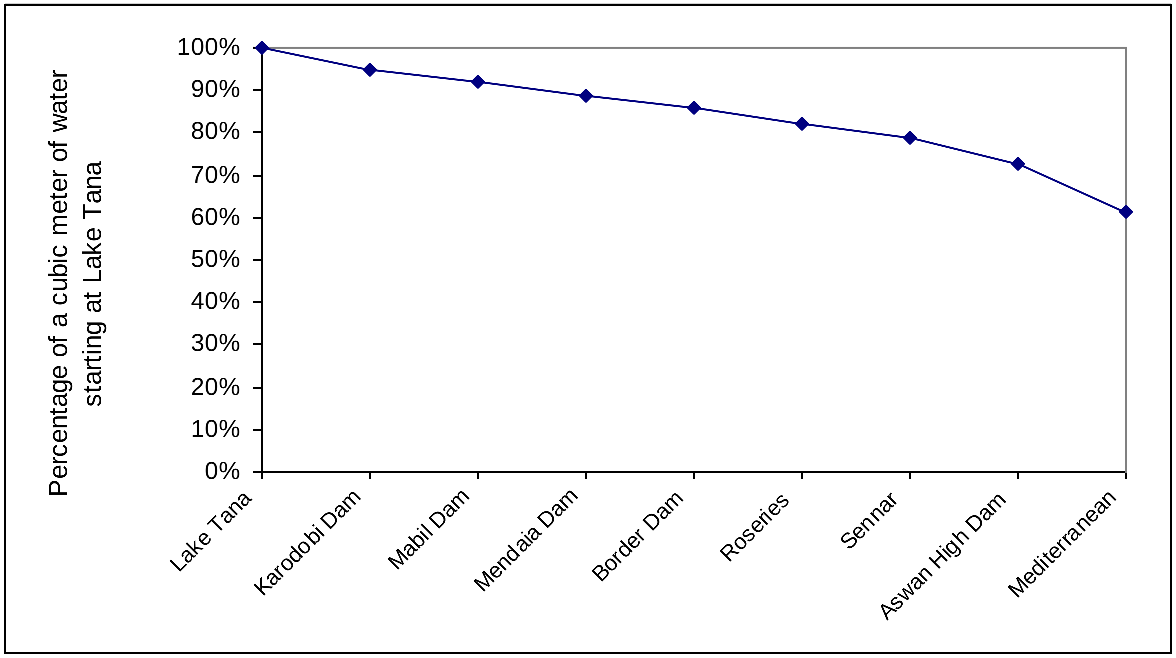

Fig. 2. Evaluation and seepage losses: the White and main Nile.

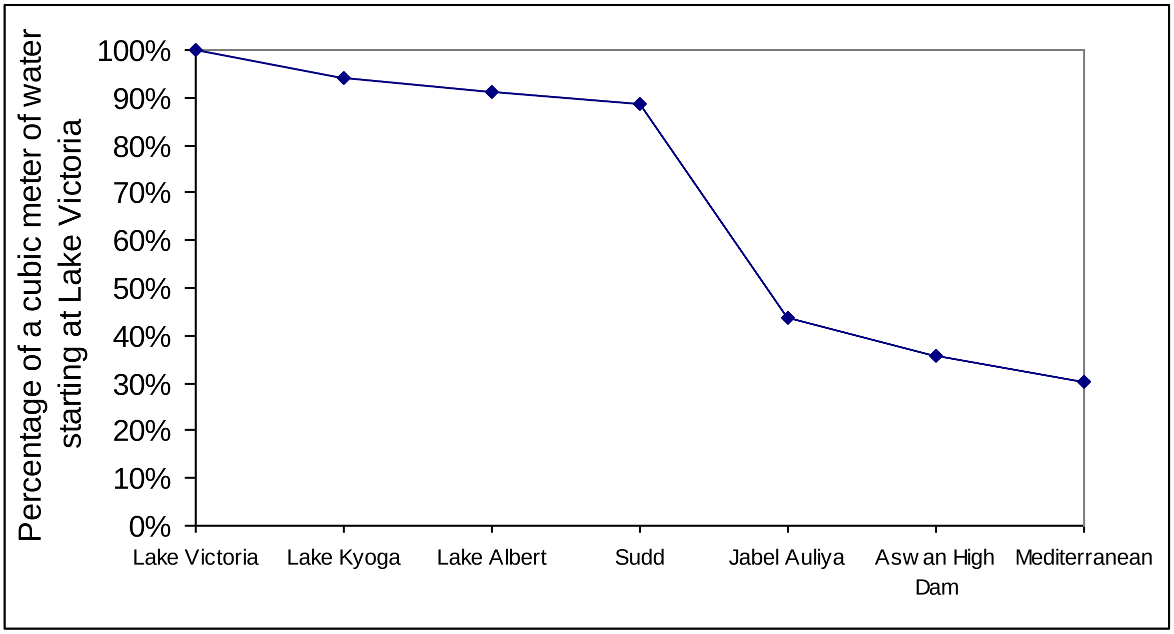

Fig. 3. Average annual flows: the Blue and main Nile. MCM = million cubic metres.

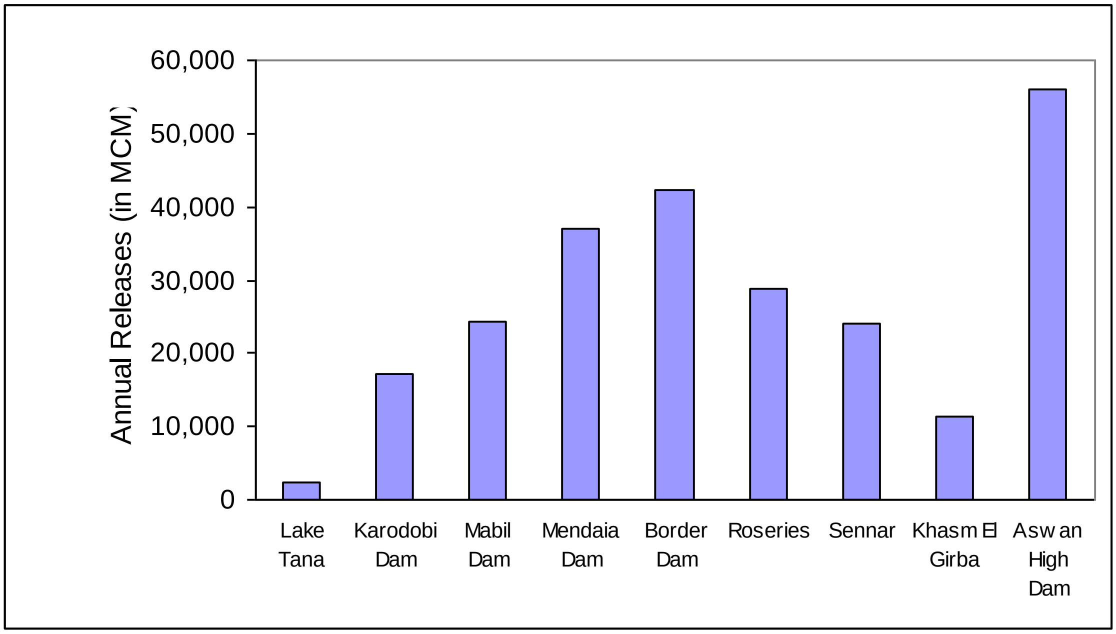

Fig. 4. Average annual flows: the While and main Nile. MCM = million cubic metres.

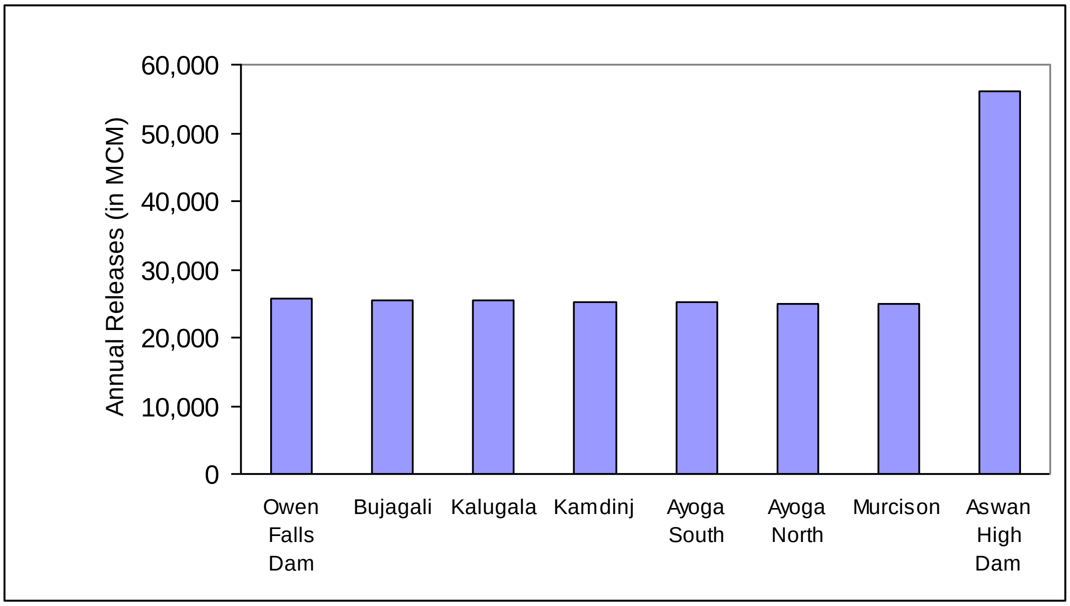

Fig. 5. Average net head: the Blue and main Nile.

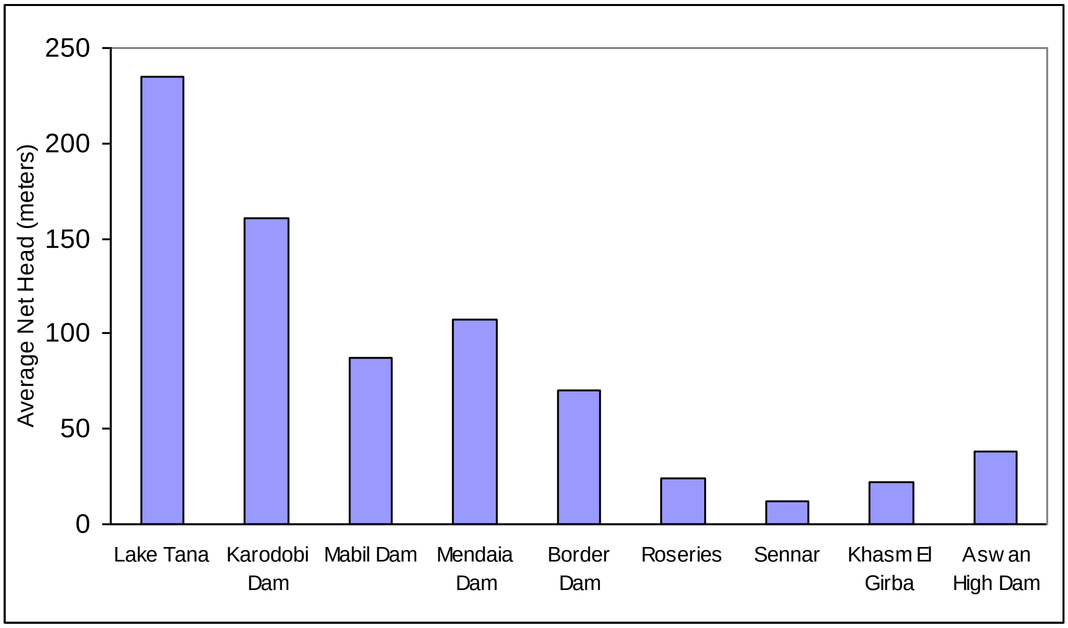

Fig. 6. Average net head: the White and main Nile.

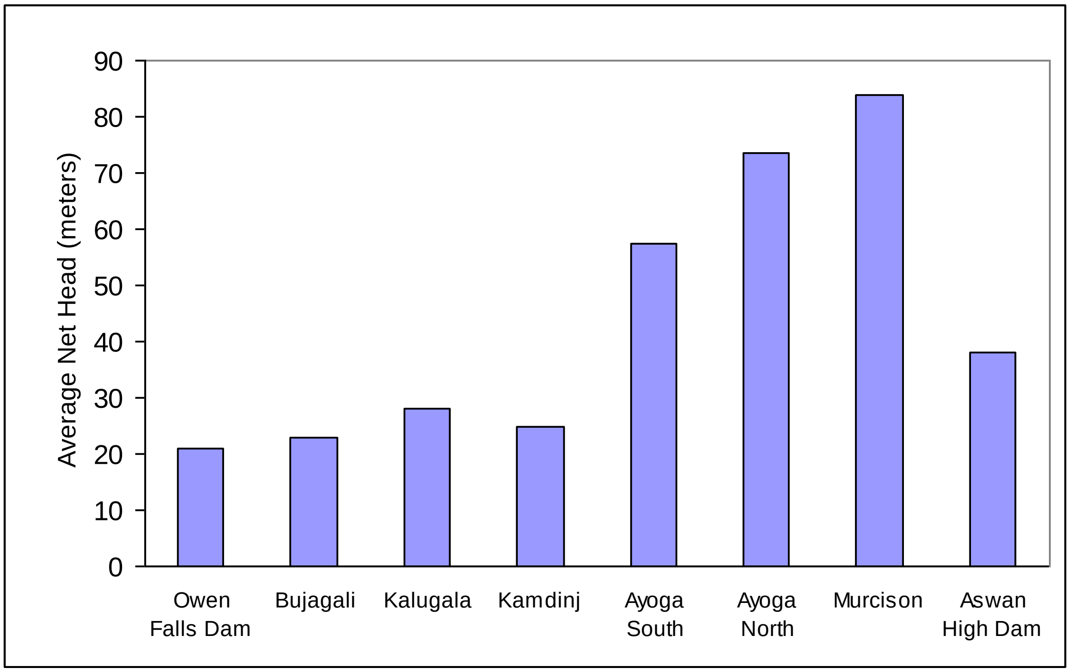

Fig. 7. Economic value of hydropower generated by a cubic metre of water flowing through the Blue and main Nile.

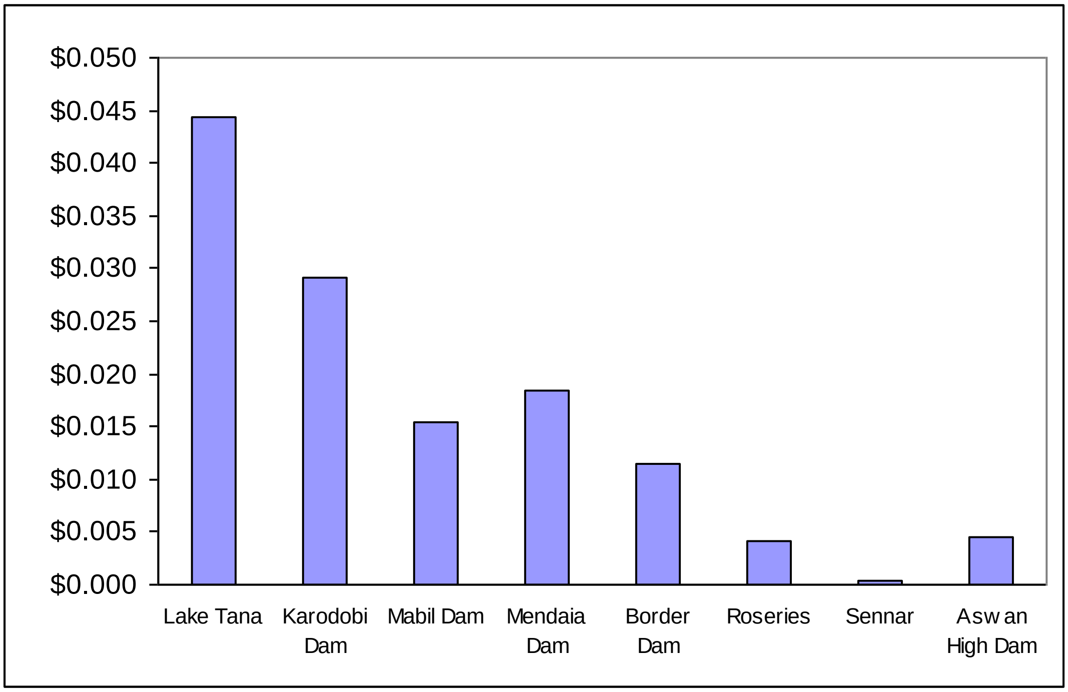

Fig. 8. Cumulative economic value of hydropower generated by a cubic metre of water flowing through the Blue and main Nile.

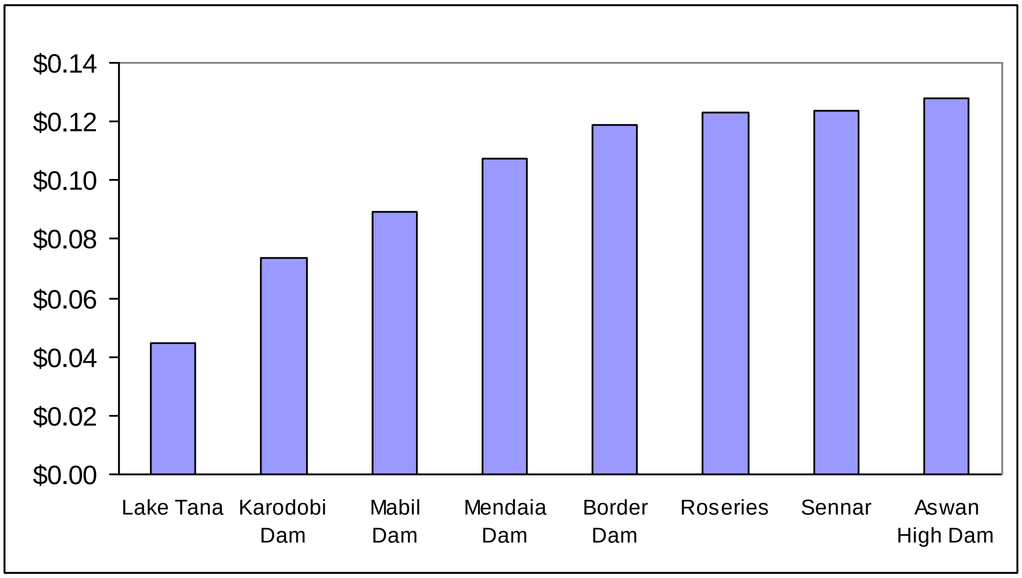

Fig. 9. Economic value of hydropower generated by a cubic metre of water flowing through the While and main Nile.

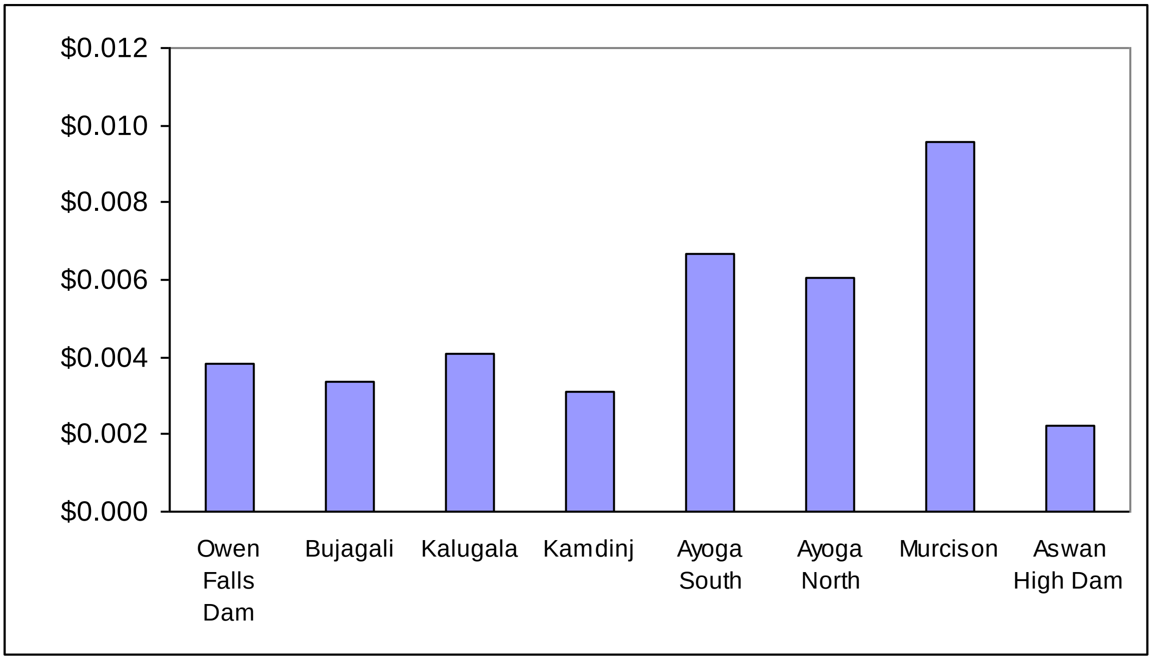

Fig. 10. Cumulative economic value of hydropower generated by a cubic metre of water flowing through the White and main Nile.

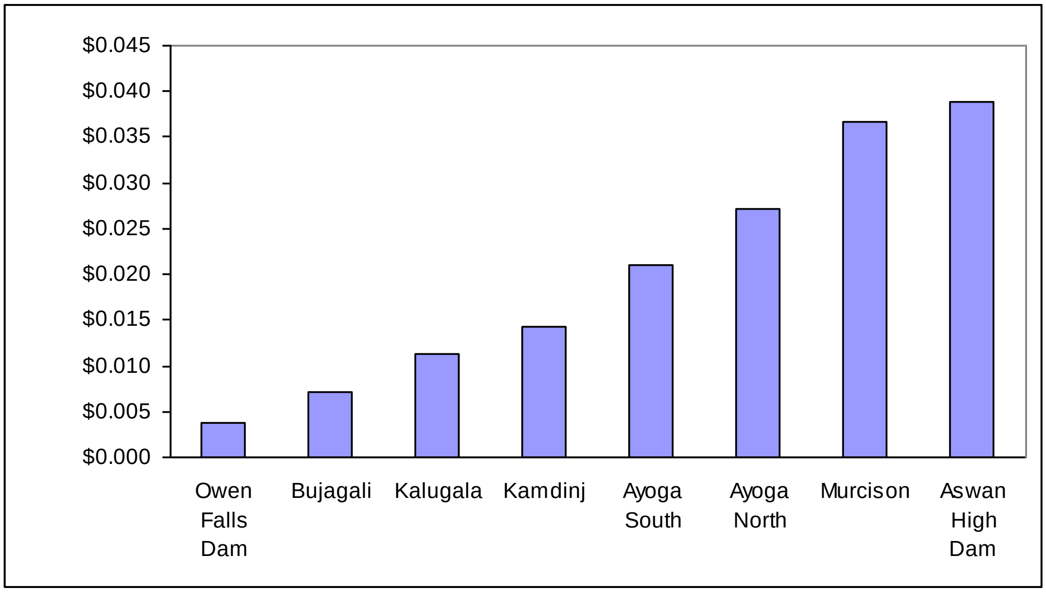

Fig. 11. Schematic diagram of the Nile Basin.

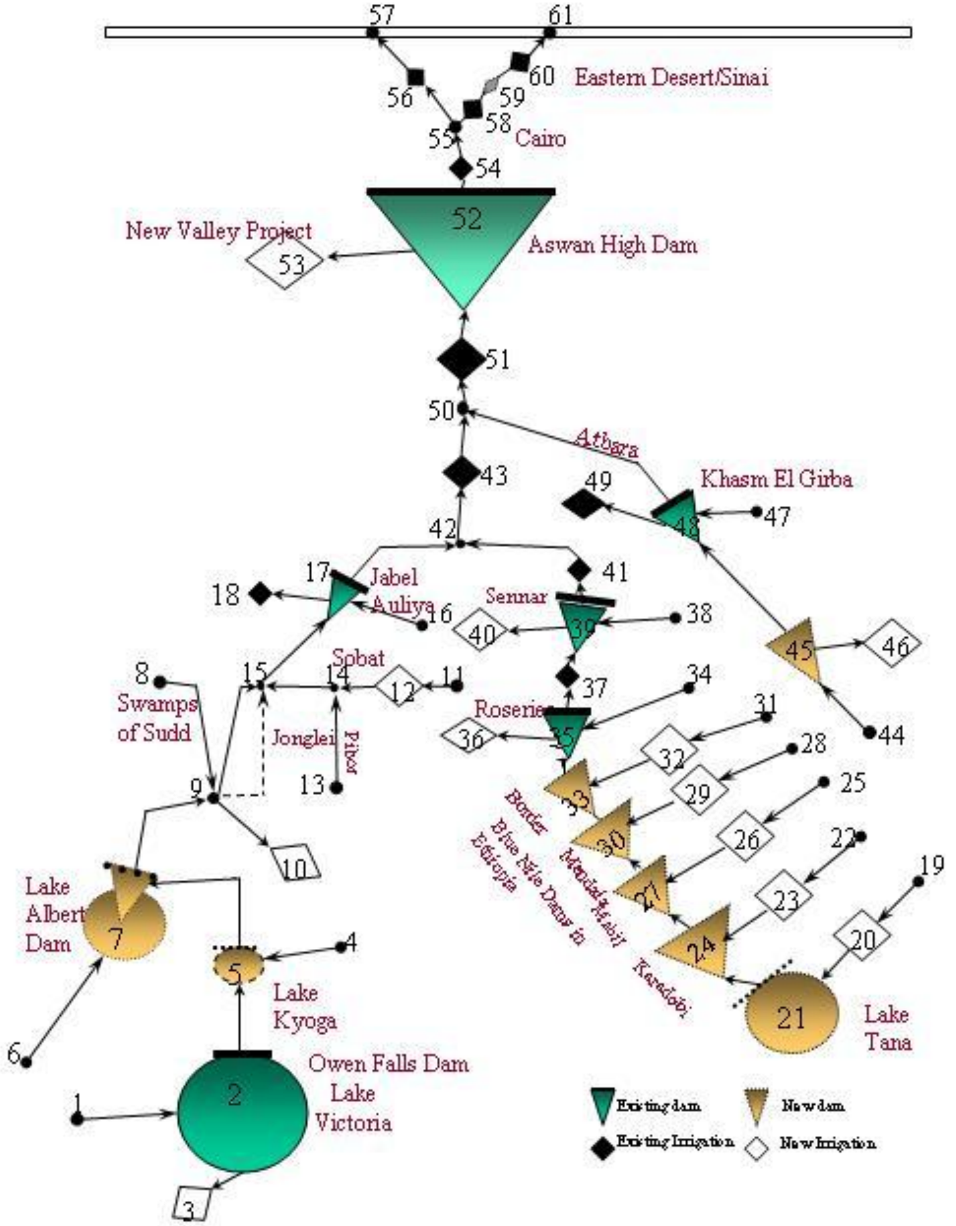

Fig. 12. Economic value of cooperation under different scenarios: constrained vs. unconstrained.

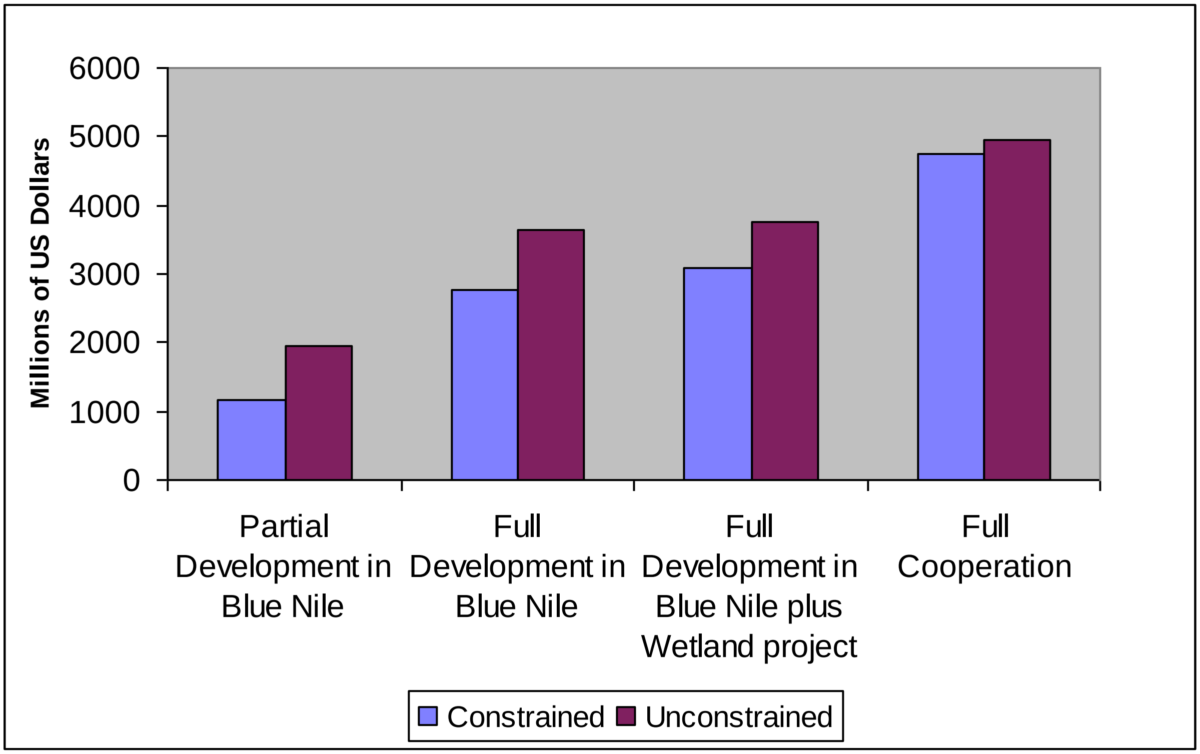

Table 1. Potential development projects in the Nile Basin.

Project	Hydropower production (installed capacity in MW)	Water savings (in billion m^3)
Blue Nile		
Blue Nile storage projects (Lake Tana, Karodobi Dam, Mabil Dam, Mendaia Dam and Border Dam)	5700 MW	4
White and main Nile		
Wetland projects (Jonglei I and II, Machar Marshes and Gahzal projects)	–	11
Demolition of Jebel Aulia dam	–	3
White Nile reservoirs (Lake Albert and Lake Kioga)	–	–
White Nile hydropower stations (Owen Falls Dam, Bujagali, Kalugala, Kamdinj, Ayoga South, Ajoga North and Murcison)	2300 MW	–

Table 2. Economic value of cooperation: *status quo* versus full cooperation.

	Status quo	Full cooperation	Economic value of cooperation
	Total economic value (millions of US$)		
Ethiopia	50	3010	
Sudan	723	513	
Egypt	3204	4313	
Others	186	1272	
Total	4164	9107	4943

Table 3. Description of scenarios.

	Blue Nile projects	Wetland projects (Jonglei, Machar, Ghazal)	White Nile projects (White Nile reservoirs and power stations and demolition of Jebel Aulia dam)
Scenario 1: *status quo*	No	No	No
Scenario 2	LakeTana/Mabil/Border	No	No
Scenario 3	Full development	No	No
Scenario 4	Full development	Yes	No
Scenario 5	LakeTana/Mabil/Border	Yes	Yes
Scenario 6: full cooperation	Full development	Yes	Yes

Table 4. Scenario analysis: economic value of cooperation with water withdrawal constraints.

	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**
Water Allocation (BCM)						
Ethiopia	1.00	10.00	10.00	10.00	10.00	10.00
Sudan	12.00	15.00	15.00	17.00	17.00	17.00
Egypt	54.00	45.00	45.00	53.00	54.75	54.60
Others	2.00	2.00	2.00	2.00	2.00	2.00
Total	69.00	72.00	72.00	82.00	83.75	83.60
Hydropower Generated (GWH)						
Ethiopia	0	14,948	35,299	35,129	14,812	35,399
Sudan	1,543	1,572	1,902	1,990	2,382	2,448
Egypt	6,303	3,951	3,345	1,327	5,788	5,761
Others	1,074	963	963	860	15,533	15,533
Total	8,920	21,434	41,509	39,307	38,514	59,141
Total Economic Value (Millions of US$)						
Ethiopia	$50	$1,696	$3,324	$3,310	$1,685	$3,332
Sudan	$723	$876	$902	$1,009	$1,041	$1,046
Egypt	$3,204	$2,566	$2,518	$2,756	$3,201	$3,191
Others	$186	$177	$177	$169	$1,343	$1,343
Total	$4,164	$5,315	$6,921	$7,245	$7,269	$8,911
Economic Value of Cooperation (Millions of US$)		**$1,151**	**$2,757**	**$3,081**	**$3,105**	**$4,748**

Table 5. Scenario analysis: economic value of cooperation without water withdrawal constraints.

	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**
Water Allocation (BCM)						
Ethiopia	1.00	0.00	0.00	0.00	0.00	0.00
Sudan	12.00	22.67	30.01	30.01	3.85	6.34
Egypt	54.00	38.27	31.90	33.85	76.11	73.91
Others	2.00	23.77	23.77	23.77	0.00	0.00
Total	69.00	84.71	85.68	87.63	79.97	80.26
Hydropower Generated (GWH)						
Ethiopia	0	16,814	37,687	37,687	16,813	37,619
Sudan	1,543	2,457	2,457	2,457	2,448	2,448
Egypt	6,303	4,250	3,596	3,789	7,957	7,714
Others	1,074	156	156	156	15,895	15,895
Total	8,920	23,677	43,896	44,089	43,113	63,676
Total Economic Value (Millions of US$)						
Ethiopia	$50	$1,345	$3,015	$3,015	$1,345	$3,010
Sudan	$723	$1,330	$1,697	$1,697	$388	$513
Egypt	$3,204	$2,253	$1,883	$1,996	$4,442	$4,313
Others	$186	$1,201	$1,201	$1,201	$1,272	$1,272
Total	$4,164	$6,130	$7,796	$7,908	$7,447	$9,107
Economic Value of Cooperation (Millions of US$)		**$1,966**	**$3,632**	**$3,745**	**$3,284**	**$4,943**

Table 6. Sensitivity analyses for variation in economic value of water for irrigation (assuming the value for irrigation is the same across different riparian countries).

	Low value of water for irrigation: US$ 0.02/m^3		**Median value of water for irrigation: US$ 0.05/m^3**		**High value of water for irrigation: US $0.08/m^3**	
	Status quo	Full cooperation	Status quo	Full cooperation	Status quo	Full cooperation
Water Allocation (BCM)						
Ethiopia	1	0	1	0	1	0
Sudan	12	0	12	6	12	71
Egypt	54	69	54	74	54	17
Others	2	0	2	0	2	0
Total	69	69	69	80	69	88
Hydropower Generated (GWH)						
Ethiopia	0	37,687	0	37,619	0	37,568
Sudan	1,543	2,467	1,543	2,448	1,543	2,422
Egypt	6,303	12,559	6,303	7,714	6,303	2,134
Others	1,074	15,895	1,074	15,895	1,074	15,895
Total	8,920	68,608	8,920	63,676	8,920	58,019
Total Economic Value (Millions of US$)						
Ethiopia	$20	$3,015	$50	$3,010	$80	$3,005
Sudan	$363	$197	$723	$513	$1,083	$5,858
Egypt	$1,584	$2,382	$3,204	$4,313	$4,824	$1,532
Others	$126	$1,272	$186	$1,272	$246	$1,272
Total	$2,094	$6,866	$4,164	$9,107	$6,234	$11,666
Economic Value of Cooperation (Millions of US$)		$4,773		$4,943		$5,433

Table 7. Sensitivity analyses for variation in economic value of water for irrigation (assuming the value for irrigation can differ across riparian countries).

	Low value of water for irrigation for upstream riparian countries: US$ 0.02/m^3		**High value of water for irrigation for upstream riparian countries: US$ 0.08/m^3**		**Low value of water for irrigation for downstream riparian countries: US$ 0.02/m^3**		**High value of water for irrigation for downstream riparian countries: US$ 0.08/m^3**	
	Status quo	Full cooperation	Status quo	Full cooperation	Status quo	Full cooperation	Status quo	Full cooperation
Water Allocation (BCM)								
Ethiopia	1	0	1	38	1	36	1	0
Sudan	12	6	12	4	12	0	12	71
Egypt	54	74	54	38	54	43	54	17
Others	2	0	2	8	2	6	2	0
Total	69	80	69	87	69	85	69	88
Hydropower Generated (GWH)								
Ethiopia	0	37,687	0	29,435	0	29,863	0	37,630
Sudan	1,543	2,448	1,543	758	1,543	889	1,543	2,418
Egypt	6,303	7,709	6,303	4,220	6,303	4,984	6,303	2,134
Others	1,074	15,895	1,074	13,969	1,074	14,643	1,074	15,895
Total	8,920	63,738	8,920	48,383	8,920	50,379	8,920	58,078
Total Economic Value (Millions of US$)								
Ethiopia	$20	$3,015	$80	$5,357	$50	$4,193	$50	$3,010
Sudan	$723	$515	$723	$253	$363	$71	$1,083	$5,857
Egypt	$3,204	$4,311	$3,204	$2,243	$1,584	$1,260	$4,824	$1,531
Others	$126	$1,272	$246	$1,746	$186	$1,474	$186	$1,272
Total	$4,074	$9,112	$4,254	$9,599	$2,184	$6,997	$6,144	$11,670
Economic Value of Cooperation (Millions of US$)		$5,039		$5,346		$4,814		$5,526

Table 8. Summary of model results: thirteen observations.

No.	NEOM results/observations
1	Total (potential) annual direct economic benefits of Nile water utilization in irrigation and hydroelectric power generation are on the order of US$7–11 billion (this does not account for the costs of building or operating the infrastructure).
2	In most scenarios, total direct economic benefits are generated “relatively” evenly in Ethiopia, Sudan, Egypt and the Equatorial States. How these benefits are shared will need to be determined by negotiation.
3	The economically efficient location of water use will primarily depend on which Nile riparian countries have the best set of macroeconomic and sector policies in place.
4	Macroeconomic and sector policies will be primary determinants of the value of water in irrigation and, to a lesser extent, the value of kilowatt hours of electricity. Inter-country power grids will enable electricity producers to obtain maximum prices, increasing the value of water in hydropower generation.
5	With large-scale infrastructure development, the majority of the economic benefits from hydroelectric power generation are generated in Ethiopia and to a lesser extent in Uganda; power interconnections will increase these benefits.
6	With large-scale infrastructure development, the majority of the irrigation benefits are generated in Sudan and Egypt.
7	If the economic value of water in irrigation were the same in Ethiopia, Uganda, Egypt and Sudan, from a system-wide perspective the economically efficient management solution would be to use water for irrigation in downstream riparian countries. But low

crop water requirements in the Ethiopian highlands may increase the economic value of water in irrigation.

8 Abstracting irrigation water in the Ethiopian highlands upstream of the proposed Blue Nile reservoirs results in significant losses in hydroelectric power generation. The model does not promote water use for irrigation in the highlands region of Ethiopia if the value of water in irrigation is the same throughout the Nile basin (but this may not be the case). This is because it wants to capture the hydroelectric power generation along the Blue Nile gorge.

9 The economic benefits of irrigation to Ethiopia are likely to be greater near the border with Sudan, in the west of the country, because such water supplies have already generated substantial hydropower benefits.

10 The within-country tradeoff between hydropower generation and irrigation is not limited to Ethiopia. Uganda, Sudan and Egypt also confront this tradeoff.

11 The more economically valuable is a kilowatt-hour of electricity from hydropower, the higher the economic penalty of withdrawing water for irrigation in the Ethiopian highlands and the greater the system-wide benefits of downstream riparians using water for irrigation purposes downstream of power generation.

12 Once you get water through the Ethiopian highlands and capture the hydroelectric power potential there, it does not matter much whether you use the water for irrigation in Sudan, Egypt, or the lowlands of Ethiopia (except you do not want to withdraw water directly above hydropower facilities).

13 Most of the projects on each country’s drawing boards have been designed from the

country’s perspective only, not from a basin-wide perspective. A suboptimal outcome of the Nile Basin Initiative would be if the result of the riparians’ negotiations was that every riparian got their “own” unilaterally designed projects approved. This could lead to conflicts down the road over the operation of the infrastructure. There are too many projects on the drawing board for them all to make economic sense. Furthermore such unilaterally designed projects will fail to capture the greater gains afforded by system-wide management and development.