Gilgel Gibe III Economic, Technical and Engineering Feasibility

Desk Study Report Submitted to the African Development Bank
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Background

This report presents the results of an independent study of the feasibility of completing construction and beginning operations at the Gilgel Gibe III hydro-electric project in Ethiopia's Omo River basin. The Gibe III dam is slated to be 240 meters tall and has a projected generation capacity of 1,870 megawatts of electricity.

While the Nurek Dam in Tajikistan stands 60 meters taller than the planned height of Gibe III, in conducting research for this report, no previous example of any dam of Gibe III's rockfill design with a concrete external liner was found to have been constructed anywhere in the world to the height proposed for Gibe III. A list of other big dam projects is included herein.

This report identifies economic, technical and engineering issues at Gibe III. The report finds six areas in need of additional attention to fully assess the feasibility of Gibe III. In describing those six areas, the report suggests priorities for further research and review.

The report draws on the findings of an earlier review conducted by the same author in support of a workplan created in 2008 for the World Bank as part of a proposal to assess the feasibility of the Bank providing financial assistance to the Gibe III project. Citing a lack of transparency and the absence of a competitive bidding process in the selection of a prime contractor, the World Bank opted not to proceed with a full review of the funding application for Gibe III. A full-scale economic and technical feasibility study was therefore not conducted.

The World Bank's feasibility study would have provided opportunities for site access and record reviews that are beyond the scope of a desk study. It is not known whether any qualified independent review teams have been given adequate access to the Gibe III project site and project records to date.

Construction of the dam has begun with Ethiopian sponsorship and is slated for completion in 2011-2012. Construction is supported in part by the issuance of hard-currency, domestically tax-exempt *Millennium* bonds marketed to the Ethiopian diaspora at a reported maximum 5% rate of interest. The bonds carry the risks of a premature call and uncertain currency repatriation rights. There is no secondary market for Ethiopian bonds. Ethiopia's currency does not trade freely on global markets.

The Millennium bonds have not been found to be marketed with provisions for independent audits of the bond issue or of subsequent fund distributions or bond repayments. To those uncertainties can be added issues regarding currency repatriation (whether repayments will ultimately be made in Ethiopian currency and at artificial exchange rates), taxation, and the interest to be paid in the event of premature repayment (a "call").

This desk study does not include conclusions or recommendations on whether to provide financial support for Gibe III. It does identify economic, technical and engineering issues regarding the feasibility of the Gibe III project—but not environmental issues because the scope of the World Bank's proposed economic and technical assessment did not encompass environmental impacts. **The results of this study can be used to structure additional research and create decision tools for financial institutions, policy makers and bond analysts.**

A summary of findings is presented first, with six categories of issues. Detailed findings are then presented for each category.

Summary of Findings

Permeability:	The structural integrity of dams depends in part on the ability of the dam structure to minimize permeability through the structure itself. Some seepage is inevitable, but permeability risks are compounded by the dam's design and dimensions. Primary permeability is distinguished from more critical issues of secondary permeability, i.e., permeability through joints and cracks in the concrete liner installed on the rockfill dam structure. Secondary permeability rates will govern at Gibe III. The dam will create an artificial lake 150 kilometers long. The lake will retain 11 billion cubic meters of water. That amount of water will exert considerable hydrostatic pressure on the dam structure. If water builds up inside the base of the dam, it will make the facility more unstable and vulnerable to deformation and structural failure during seismic events.
Structural stability:	Structural stability is initially achieved on the basis of the peak strength of the materials used to construct the dam. After the dam and its foundations have settled and experienced one or more seismic events, materials in the dam may shift beyond the capability of peak strength to hold them in place. Once this occurs, the dam begins to rely on residual strength for its structural stability. Volcanic ash has been a problem at other civil engineering projects in the region. If ash or other low-load-bearing soils are present in the dam or its foundations, then the risk of catastrophic failure will be heightened. The Gibe III contractor's prior performance at Gibe II provides cause for concern, thanks to the failure of the original design and construction plan to identify and address the presence of weak soils. The risk of catastrophic failure of the dam at Gibe III is not insignificant.
Shear strength:	Pre-construction measurement and testing of the shear strength of materials to be installed in a dam assists in calculating when and how structural failure or deformation could occur. In assessing Gibe III's engineering designs, it is important to examine how shear strength was measured. Two principal measurement techniques are contrasted

here. Shear-block tests are equated with peak strength. Ring-shear tests can measure both peak strength and residual strength. No evidence was found that appropriate strength testing has been conducted at Gibe III.

Monitoring and planning: Dam construction involves more than simply moving rocks around. It involves ongoing and diligent construction oversight, materials testing and laboratory analysis. Is independent construction oversight occurring at Gibe III?

- Monitoring devices need to be installed during construction.
- Monitoring and contingency plans need to be developed to detect and respond to seepage, shifting, pressure buildup, deformation, movement of the dam and other scenarios during facility operation.
- Potential facility failure modes need to be identified and surveillance and monitoring systems put into place for each of them.
- Mitigation and emergency response capabilities need to be institutionalized and readied for quick deployment.

Economic feasibility: The economic feasibility of a hydro-electric facility is determined in part by power sale arrangements and the performance of electrical generators. Gibe III's rate structures and performance projections are called into question. Given existing indicators regarding tariff structures in Ethiopia, the electrical power generated at Gibe III could prove to be unaffordable for many of the residential customers for whom the dam is ostensibly being constructed.

Economic externalities: The costs and impacts of building and operating a dam often extend beyond the dam site itself. Negative economic externalities can be created where changes in physical resources occur. At Gibe III, physical changes will extend upstream and downstream. So too will economic impacts, which include disruptions in food production and drinking water access. Despite their significance, these impacts do not appear to have been quantified or adequately considered in assessing the economic and technical feasibility of Gibe III.

Detailed Findings

Permeability

In examining the permeability of the dam structure, two types of permeability need to be distinguished. Primary permeability is the rate at which liquids pass through consolidated soil or other materials. Secondary permeability is the rate at which liquids pass through the voids (and highly permeable material) that may exist between more impermeable, consolidated substances.

In calculating permeability rates, secondary permeability governs the speed at which liquids travel through materials (where secondary permeability exists) such as highly fractured masses of rock.

Published descriptions of Gibe III characterize the dam as a rockfill structure with a concrete exterior liner. Concrete is intended to provide an impermeable barrier, which the dam's rockfill mass itself cannot do because the voids between the rocks are highly permeable.

If properly constructed and maintained, concrete's low primary permeability can allow it to serve as an effective water barrier for long periods of time, especially in small structures protected from extreme temperature differentials. Concrete's primary impermeability is limited by the size of each contiguous concrete mass or slab.

Filler material placed in the joints between slabs is designed to allow concrete to expand and contract without cracking. However, seam fillers are vulnerable to damage and deterioration.

Cracks and other failures within concrete slabs can create voids that allow for high rates of secondary permeability to negate concrete's low primary permeability. In a structure as tall as Gibe III there is a risk that the concrete liner will be damaged by differential settling and other structural shifts within the dam and its foundations. These shifts could be aggravated by risks from:

1. Soils containing volcanic ash present under or adjacent to the dam. A bridge in the region reportedly failed because it had been built over volcanic ash that was not strong enough to support the loads placed upon it.
2. Impurities in the water used to make concrete.
3. Differential compaction and uneven settling of the dam structure.
4. Uneven cooling and contraction of the concrete during construction.
5. Heat expanding the concrete and causing it to crack following construction.
6. Seismic activity, for which southwestern Ethiopia is known. See: http://www.ethiopians.com/earthquake_engineering_resources.htm. The weight of the 11 billion cubic meters of water retained by the dam could trigger seismic events.
7. Excessive moisture inside the base of the dam is liable to make the facility more unstable and vulnerable to liquefaction, deformation and structural failure during seismic events.

Detailed engineering reviews of the site's geology and the dam's design and construction should assess the risks to the concrete liner failing and reducing the structural integrity to the rockfill structure. A dam failure will not necessarily result in the complete release of all impounded water. Risks of failure at Gibe III need to be considered in the context of the dam's slope and scale. At 240 meters in height, Gibe III will exceed the height of these existing dams:

- The Three Gorges Dam in China, at 101 meters in height
- Cahora Bassa Dam, Zambezi River, Mozambique, 171 meters
- Hoover Dam in the United States, 221 meters
- Guri Dam or Central Hidroeléctrica Simón Bolívar in Venezuela, 162 meters
- Itaipu Dam on the border between Brazil and Paraguay, 196 meters
- Grand Coulee Dam in the United States, 168 meters

Structural stability

The stability of the dam depends on the strength of materials at their weakest points, which is often found where materials join together, such as rocks-to-rocks or concrete on top of rocks. Calculations of sheer strength would or should have served as a basis for determining the dam's dimensions. An outside engineering review needs to examine how those calculations were made and how the sheer strength of the dam was modeled under static loading and different (and repeated) seismic events.

Two types of sheer strength can be distinguished:

- Peak strength
- Residual strength

When you dislodge a rock and begin to move it, peak strength is the energy needed to start the rock moving. Once the rock has begun to move, residual strength may be all that is needed to keep the rock moving.

As the dam weighs down soils within and beneath the structure or is jolted by seismic events, peak strength could be exceeded in portions of the facility. This will leave the structure's integrity reliant on residual strength.

Given the nature of the local soils, voids present within the rockfill structure, repeated seismic activity in the area and pressures exerted by the mass of water that will build up behind the dam, an engineering study needs to assess the consequences of peak strength being exceeded during the dam's lifecycle and then how the dam structure could react under different scenarios.

The Gibe III prime contractor's level of previous experience with dam projects the size of Gibe III, and the contractor's inclination to perform pre-construction engineering studies (as evidenced by the interruption of work at Gibe II due to a failure to adequately perform pre-construction geological testing) underscores the importance of examining whether and how residual strength was measured and factored into the Gibe III design.

Measurement of shear strength

The strength of two materials where they come together can be measured using sheer block tests and ring sheer tests.

Sheer blocks:	A sheer block test places a sample on a block and pushes it laterally over another sample. While sheer blocks can be used to measure peak strength, the fact that fresh, untouched base material is constantly being encountered on the lower portion of the test unit's slip surface makes sheer block tests unsuitable for assessing the residual strength of slip surfaces because they consistently over-state calculations of residual strength.
Ring sheer:	A ring sheer test has the upper test substance rotated over the base substance in a circular, ring-like motion that enables both test surfaces to achieve full contact before residual strength is determined. Ring sheer tests can provide accurate data on

both peak strength (at the beginning of a test sequence) and residual strength—once peak strength has been exceeded.

An independent engineering assessment should examine how sheer strength was measured at Gibe III and seek to assess the extent to which the design will remain stable once peak strength has been exceeded.

Monitoring and planning

Monitoring and contingency planning is important in all phases of a dam's lifecycle. It is critical during construction.

The adequacy of oversight of the construction process needs to be evaluated as part of an independent engineering and technical study. The oversight capabilities and practices of the Ethiopian Electric Power Corporation (EEPCo) and government regulatory agencies in Ethiopia to oversee the design and construction of the Gibe dams should be evaluated. Technical expertise (supported by adequate oversight procedures, training, laboratory analysis capabilities and resources for onsite monitoring) are needed to ensure that proper engineering practices were followed by Salini Costruttori, the prime contractor at Gibe III and the previous two Gibe hydroelectric projects.

Sound engineering and construction practices can be employed to reduce structural risks at big dam projects but not eliminate them. Hence the need for monitoring and contingency planning.

Monitoring plans at Gibe III need to be reviewed for adequacy in detecting and responding to seepage, movement of the dam structure, excessive pressure on the dam structure and other indications of failure. Proper placement of instrumentation needs to be planned prior to facility construction and subject to independent outside review. During construction, the following should be installed:

- Observation wells and piezometers
- Plumb lines
- Load cells
- Strain gauges

A list of potential problems with the facility needs to be developed and contingency plans readied, tested and institutionalized for each potential problem. Potential failure modes need to be identified, with monitoring and response plans organized for each failure scenario identified. Mitigation and emergency response capabilities need to be built up, monitored and kept ready for launch. Contingency planning needs to be extended to potentially impacted areas downstream, paid for by the dam operator.

Periodic reviews need to be initiated of actions taken to reduce the likelihood and consequences of dam failure. Reviews should include:

- Facility designs
- Design and placement of monitoring systems
- Data collection and analysis procedures

- Dam operation procedures
- Risk-reduction measures
- Structural remediation capabilities
- Contingency plans and capabilities
- Downstream impact reduction
- Communication capabilities and procedures

Economic feasibility

The economic feasibility of the Gibe III project is an open question that would need to take into account the rate structures for selling power generated from the facility and the service agreement with the dam operator.

Global climate change and diminished water supplies are reducing power generated at hydro-electric facilities elsewhere in the world and appear likely to do so at Gibe III.

Liability exposure and allocation in the event of unanticipated outcomes at the Gibe projects needs to be clarified and examined. Unanticipated events could interfere with loan repayments and the supply of electricity to residential consumers in the franchise areas served by the Gibe hydro-electric projects.

Tariff structures for selling electricity from the Gibe projects and the service agreements with the electrical utility and the contractors engaged in the Gibe projects need to be examined to assess whether and how investors and bond holders can be repaid under a variety of performance scenarios. Rate structures and service agreements need to be examined to determine whether they are equitable, reasonable, and conform to general principles of fairness, soundness and best utility-rate-practices. The viability, independence and fairness of systems for resolving tariff disputes should also be examined.

National and local governments (and many international organizations) lack the expertise and resources to conduct rate studies and to adequately and fairly respond to subsequent rate disputes and rate appeals. These institutional and systemic shortcomings have led to unexpected economic burdens from utility projects in many areas of the world, including Western countries where such expertise is more readily available.

Tariff systems commonly operate outside of normal government channels for taxation and appropriation. Their frequent lack of transparency and their ability to generate significant recurrent revenues makes utility franchises an attractive vehicle for private enrichment at public expense. The larger the infrastructure project, the greater the opportunities for kick-backs and diversion of funds away from purposes that are used and useful to rate payers. Even where instances of outright fraud and corruption are low, poor decisions in utility infrastructure planning and financing can exercise profound, long term negative economic effects.

EEPCo's existing tariff and electrical distribution policies are reputed to favor large industrial and commercial users over residential consumers. Cross subsidization of industrial and commercial users by residential customers, who pay disproportionally higher rates for the same amount of electricity, can unreasonably benefit industrial and commercial users, while under serving residential consumers whose lack of access to electricity originally served to justify public investments in the Gibe dam projects.

The affordability and equitability of electrical tariffs can be reduced in the event that generation capacity falters due to unplanned events such as water shortages and maintenance problems. It is not known whether or how power sale agreements may favor specific customers or classes of customers in the event of generation shortfalls or cost increases involving the Gibe projects. While wholesale customers may be provided with guaranteed supplies of power at relatively low cost, it is possible that EEPCo's rate structures could allocate responsibility for cost increases and generation shortfalls to categories of rate payers least able to afford it.

Contract terms, oversight arrangements and tariff-dispute-resolution systems may neither allow nor encourage adequate control of costs once Gibe III becomes operational. Contract terms and oversight arrangements may allow costs to be passed on for expenses that are not used or useful to some classes of rate payers, thereby violating central principles of equity and fairness in utility rate systems. **Electrical power from Gibe III could be unaffordable to substantial numbers of residential customers for whom the dam project is ostensibly being built.** Residential customers appear likely to subsidize the electricity used by commercial and industrial customers.

Considerable attention needs to be devoted to assessing the financial aspects of the Gibe III project and the institutional factors surrounding tariff-system administration. When neglected, the financial terms and conditions of electrical projects can exercise long-term negative effects on some economic sectors, interfere with debt servicing and divert resources away from productive purposes. The allocation of liabilities at Gibe III deserves attention in light of the nature and extent of the risks inherent in the Gibe III project and the manner in which risks have been monitored and controlled to date.

The need for a new approach to risk management at EEPCo is underscored by the fact that research activities to support the preparation of this report were repeatedly hindered by EEPCo's website. EEPCo's main website www.eepco.gov.et was found to be propagating 'Silent love China' computer attacks that attempt to install Trojan software on visitors' computers and steal passwords. It is recommended that www.eepco.gov.et not be visited until corrective actions have been taken.

Security breaches within EEPCo's computer systems need to be investigated and corrected immediately, with enhanced security monitoring and response capabilities instituted and maintained. Independent outside auditing of EEPCo's computer security practices should also be instituted and maintained.

From the outside, it is now known whether EEPCo has been breached by deliberate acts of espionage by government agencies within the Peoples' Republic of China or by Chinese criminal groups. The nature of the breach at EEPCo, which purposely avoids infecting PRC government websites, suggests the former.

Given their commercial interests at stake in Ethiopia, one would have expected that the Italian government and Salini would have defended their interests and sought to prevent Chinese interference at EEPCo, regardless of whether security breaches stemmed from PRC government agencies or private parties. Actual responsibility for defending EEPCo's interests rests with EEPCo itself, notwithstanding EEPCo's inability or unwillingness to do so.

Economic externalities

In addition to the aforementioned economic considerations regarding Gibe III, the following negative externalities appear as costs to populations who will bear disproportionately negative economic and quality-of-life impacts as a result of Gibe III.

Economic losses are likely to be experienced from increases in disease caused by the dam's impacts on the physical environment. Specifically:

- Increases in schistosomiasis (also known as bilharzia or snail fever) are expected upstream of the dam. According to the United States Centers for Disease Control and Prevention:

  > Children who are repeatedly infected can develop anemia, malnutrition, and learning difficulties. After years of infection, the parasite can also damage the liver, intestines, lungs, and bladder. Rarely, eggs are found in the brain or spinal cord and can cause seizures, paralysis, or spinal cord inflammation.
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  > Symptoms of schistosomiasis are caused by the body's reaction to the eggs produced by worms, not by the worms themselves.

- Malaria rates are likely increase around the artificial lake, especially among children, as indicated by a study of malaria rates at Gibe I completed in 2008. Gibe III's impact on malaria rates downstream should also be examined.

Downstream economic losses do not appear to have been adequately examined in the host nation's planning activities and reviews of the dam conducted to date. In order to meet electricity sales targets, water withholdings in excess of publicly announced levels may occur.

Impacts from evapotranspiration, evaporation and ground water recharge from the artificial lake created by Gibe III have not been found to be adequately recognized in the official plans for Gibe III. These water losses will expand the need for additional water withholdings from the Omo River and will inevitably lead to decreases in water released downstream.

Loss of water in the Omo River basin will translate into reduced flows into Lake Turkana, shrinking the size of the lake and altering the lake's chemistry. Lake Turkana is a high desert lake largely located in Kenya. The lake is the destination of the Omo River. The lake is a source of potable water and food (from fishing). It reportedly provides support for 300,000 people, many of whom have no viable economic alternatives.

Lake Turkana is already stressed. The lake has been receding and becoming more alkaline, which threatens to make its water undrinkable. Resources for securing alternate potable water supplies have not been identified. Gibe III would contribute additional stress and lower economic outputs from the lake and the Omo River basin.

"Stopping the periodic inundations that replenish floodplains in the R Omo and its delta region will have a direct effect on several commercial [fish] species that depend on those areas as nurseries," said Dr. Peter B. Bayley, Department of Fisheries & Wildlife, Oregon State University, who has conducted research on fisheries in the Omo River basin.

Eliminating periodic inundations in the Omo River basin will disrupt food supplies for downstream communities that have developed sophisticated agricultural practices that depend on existing water supplies and flow cycles. Disruptions in food supplies do not appear to have been fully taken into account in planning for the dam, nor have adequate mitigation measures reportedly begun to be implemented downstream. Changes in water supplies will accelerate resource competitions among tribes downstream and could lead to armed conflicts.

Adversely impacted individuals and localities do not appear to have been granted adequate legal standing and enabling resources that would allow them to participate at key junctures of the dam's permitting, licensing and funding processes. Nor does the existing permitting and licensing process appear to have been conducted independently from the process of pro-actively arranging for the Gibe III project to be implemented.

A lack of independent outside participation in planning, regulatory and technical matters has deprived all three Gibe hydro-electric projects of valuable inputs that would have reduced risks for project sponsors, investors and electrical rate payers.

As demonstrated by the failure of Gibe II to be implemented as planned, the lack of independent oversight and meaningful stakeholder participation has contributed to cost over runs, project delays and wasted allocations of public resources. In the case of Gibe III, the stakes are higher, notably in regard to engineering and financial risks and impacts on populations whose survival depends on maintaining access to existing natural resources.

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