# The relationship between Bio-Physical Factors and Power Generation at Ntaruka, Rwanda and implications for revenue generation

**By**

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## Acronyms

| | | |
|---|---|---|
| ADB | : | African Development Bank |
| CCE | : | Climate Change Explorer |
| CITT | : | Kigali Centre for Innovation and Technology Transfer |
| DRC | : | Democratic Republic of Congo |
| EIA | : | Environment Impact Assessment |
| EWSA | : | Energy Water and Sanitation Authority |
| GEF | : | Global Environment Facility |
| GoR | : | Government of Rwanda |
| GPS | : | Global Power System |
| IFAD | : | International Fund for Agricultural Development |
| IMCE | : | Integrated Management of Critical Ecosystems |
| kWh | : | Kilowatts |
| LHWP | : | Lesotho Highlands Water Project |
| MDGs | : | Millennium Development Goals |
| MINAGRI | : | Ministry of Agriculture |
| MININFRA | : | Ministry of Infrastructure |
| MW | : | Megawatts |
| PEI | : | Poverty Environment Initiative |
| PRB | : | Pangani River Basin |
| REMA | : | Rwanda Environment Management Authority |
| Rwf | : | Rwanda Francs |
| UNEP | : | United Nations Environment Programme |
| USAID | : | United States Agency for International Development |
| USD | : | US Dollar |
| WCD | : | World Commission on Dams |

## EXECUTIVE SUMMARY

This paper was commissioned under the auspices of Poverty-Environmental Initiative (PEI) in Rwanda. It was premised on the energy crisis of 2004, which also coincided with the fall in water levels of L. Bulera that supply water to Ntaruka power station among others. The objective of the study was to contribute to the wider policy dialogue on optimizing the benefits from dam construction, beyond power generation.

The study found that indeed, the fall in the waters of L.Bulera accounted for reduction in power generation. However, it also established that it was not the sole factor. The growth in population in the hinterland of Ntaruka changed land use to a level that Rugezi wetland could not function as it used. There were also policy failures whereby the government opened up the wetland to agriculture without rigorous studies. Critically, and because the country was slow on investing on alternative sources of energy, Ntaruka's capacity to satisfy the growing demand for energy was overstretched.

The year 2004 thus depicted a culmination of past failures. Cumulatively, Electrogaz lost Rwf 17,365 million between 1999 and 2008. Several response measures were adopted after 2004, including load shedding, investment in alternative of thermal energy, tariff revision and rehabilitation of Rugezi ecosystem among others. Some recovery in the water levels and power generation has been registered.

Many lessons have been learnt. Top on the list is that sustainable management of the Rugezi ecosystem can generate benefits not only for power generation but also for other sectors downstream. These include clean water supply, flood control, irrigation, and industrialization to mention but a few. Another lesson is that Electrogaz (now RECO/RWASCO) is starting to appreciate the concept of Payment for Ecosystem Services. It would thus be imperative for policy makers to:

(i) provide enabling legislation so that companies involved in dam construction can also broaden the type of benefits they generate
(ii) provide incentives to companies so that they offer the above benefits, and
(iii) define clear shared roles and responsibilities within the public-private partnerships (PPP) for power generation

## A: Introduction

1. Power generation is associated with several bio-physical impacts both ‘upstream’ and ‘downstream’. The impacts can be positive or negative, and therefore, likely to be translated into private and social benefits, as well as private and social costs. From the planning perspective, the preferred policy choice would be that of optimizing overall impacts. This choice is gaining prominence because the construction of dams have brought fewer benefits than envisaged and have resulted in significant social and environmental costs [WCD, 2000]. As many countries continue to pursue energy development to socio-economic development, their focus is increasingly shifting to optimizing the socio-economic environmental benefits.

2. This report was commissioned under the auspices of Poverty-Environment Initiative (PEI), Rwanda to establish the relationship between the biophysical factors and power generation at Ntaruka on one hand and the revenue generation of the impacts on the other. The motivation is to bring out those issues that should be put on the policy agenda for debate as Rwanda continues to pursue its sustainable development agenda. The study is premised against a background of energy crisis in 2004 when at the same time the water levels of Lake Bulera that supplies Ntaruka Power Station had fallen. One of the question that therefore comes upfront is: **What was the relative significance of water reduction to power generation at Ntaruka in 2004?**

3. Many studies on power generation, pricing, ecosystem degradation and rehabilitation have been made in the past in Rwanda. They have been referred to in several sections in this report. The value addition of this report however, is to look beyond the past and current bio-physical factors that have explained power generation at Ntaruka and provide an integrated and holistic approach that should serve as basis for mobilizing multi-institutional efforts for sustainable energy production and policy dialogue.

4. Policy debate on the above approach is more urgent than before because of evidence on drying water basins in Africa[1], the projected increase in precipitation due to climate change[2] and growing demand for energy to meet varied socio-economic development targets, including the Millennium Development Goals (MDGs). Aware of these factors, the Government of Rwanda (GoR) set itself ambitious targets with regard to the energy sector [Box 1]. Such targets must be backed by major investments in water supply infrastructure, water conservation and protection of the ecosystems.

[1] UNEP [2010] Africa Water Atlas
[2] UNDP: Climate Change Futures; Health, Ecological and Economic Dimensions

**Box 1: Objectives and targets with respect to the energy sector in Rwanda**

- Combine hydraulic potential with the methane gas one in order to satisfy the power demand in all development activities of the country;
- Increase the population access to electricity from 6% to 35;
- Ensure a growth rate in power consumption of 9.6% annually;
- Ensure a rural electrification rate of 30%;
- Reduce the wood portion in the energy balance from 90% to 40%.

***Source: GoR [2000]Vision 2020***

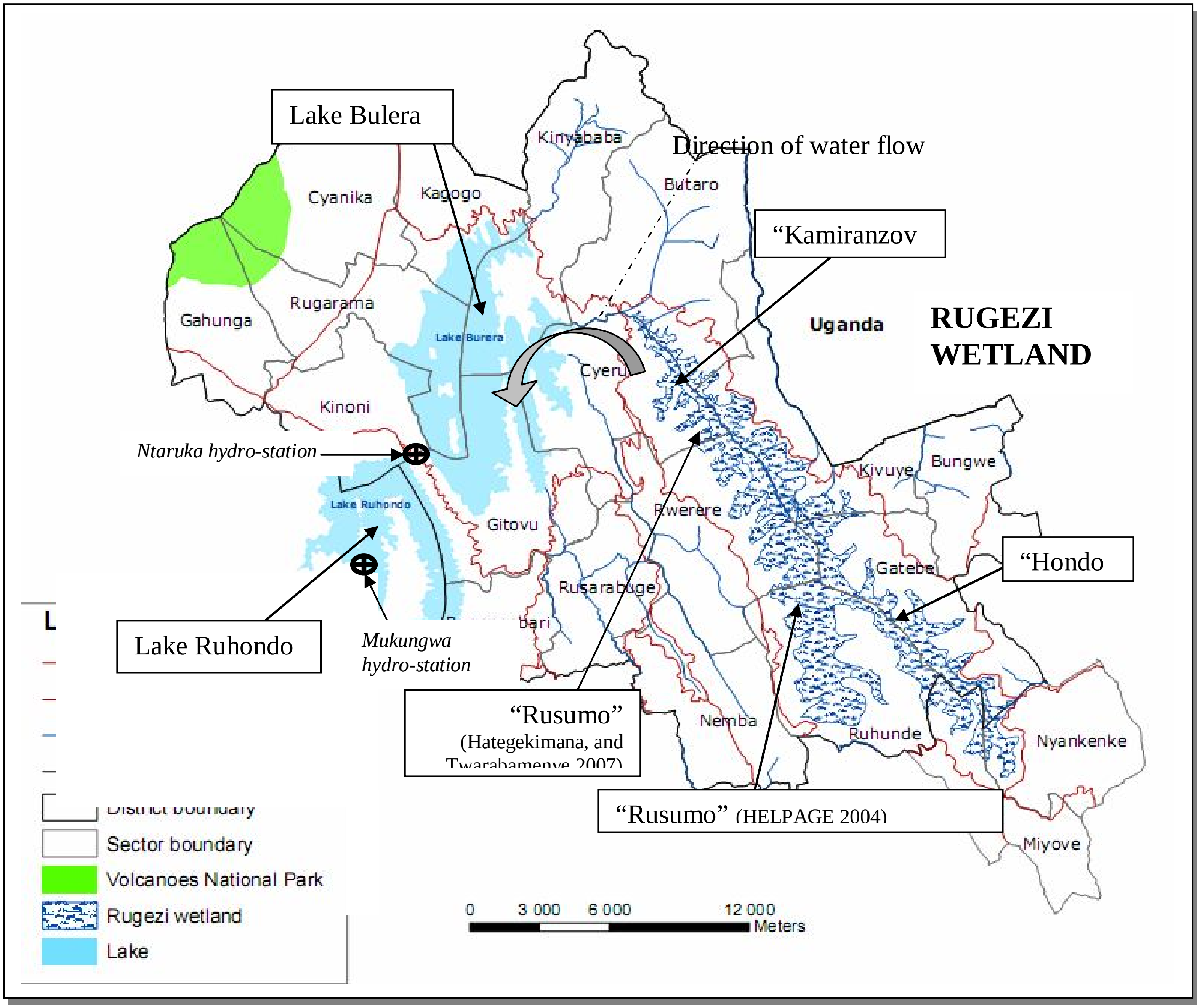
5. Ntaruka which is the subject of this study is located in Rugezi watershed. In that watershed is the Rugezi wetland. The watershed supplies Rwanda with 90% of its total electricity through two main hydropower stations, the Ntaruka and Mukungwa stations[3] (see Figure 1). Ntaruka power station lies at the outlet of L.Bulera, on which it is immediately dependent for water supply. Water through it enters L.Ruhondo, and at its outlet, there is yet another power station, Mukungwa power station. According to some studies, Rusomo's outflow determines 50% of the inflow into L.Bulera. Lake Bulera occupies 5280 hectares, with a maximum depth of 174 meters, and Lake Ruhondo occupies 2610 hectares, with a maximum depth of 68 meters [Hategekimana and Twarabamenye, 2007]. Ntaruka was designed with the capacity of 11.25 MW while Mukungwa was designed with the capacity of 12.5MW. Malfunction of either station or both is bound to be heavily publicized because the two stations accounted for 90% of energy supplies in 2004.

6. The total flows from the Rugezi wetlands also have international importance for the Nile River Basin. The Nile River Basin claims 67% of Rwanda's national territory and drains 90% of its national waters through the Nyabarongo and Akagera Rivers. Water flows out of Rwanda into Lake Victoria and contributes roughly 8-10% to the White Nile waters. The Rugezi wetlands became part of the Ramsar Convention in 2001, officially designating it as a wetland of international importance.

7. Figure 2 presents the relationship between water level in L.Bulera and power generation at Ntaruka from 1998 to 2004 when the power crisis was at its peak. The Ntaruka dam was designed with the understanding that the maximum and minimum water loading of L.Bulera would be 1864m and1859m respectively. In order to maintain the safety of the dam, the water would be spilled over if it exceeded the maximum limit. At the time of this study, it was reported that the average for the year 2010 was 1862m.

[3] Uwizeye, Jean Claude and Anne Hammill. (Februrary 2007) op cit.; CITT/KIST. Energy Baseline. UNEP-GEF Pilot Project on Reducing the Vulnerability of the Energy Sector to the Impacts of Climate Change in Rwanda. Project Report. Kigali, Rwanda. August 26, 2006.

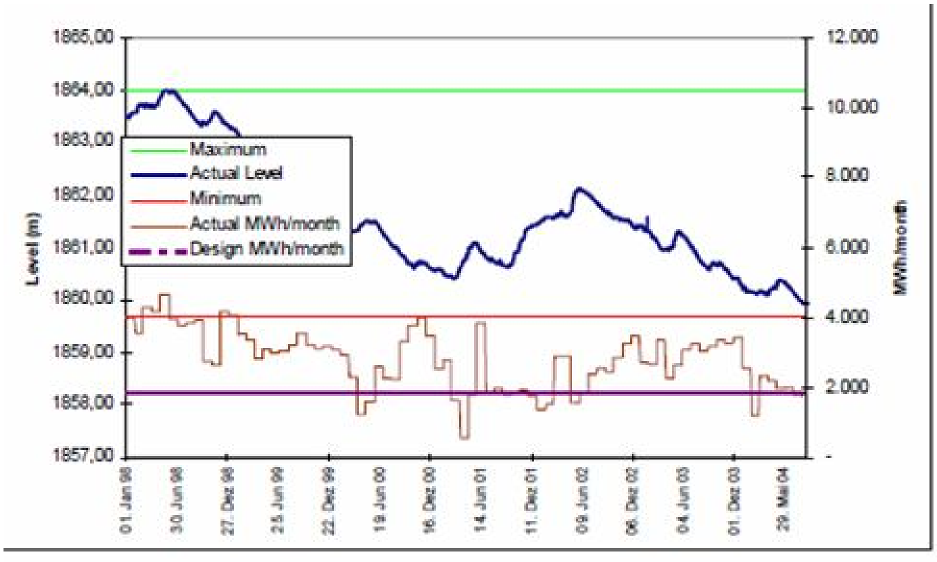
**Figure 1: Location of Ntaruka in Rugezi Watershed**




***Source: Elizabeth Willets [2008]***

8. Ntaruka was commissioned with two 3.75 MW units in 1958 and another 3.75 MW unit was added in 1962. In total therefore, it has installed capacity of 11.25MW. Between 1998 and 2004, the lake had fallen by 4 metres. The power generation declined more or less in tandem with the fall in water levels (Figure 2). In that period, the actual power generated was far below the installed capacity. This paper sought to investigate the relevance of water levels to power generation on one hand and the other factors on the other, with a view of documenting a plausible policy position.

**Figure 2: Relationship between L. Bulera level and power generation at Ntaruka**




***Source: ELECTROGAZ [2004]***

9. With the above in perspective, the study sought evidence to satisfy the following objectives:

   (i) to describe the biophysical factors pertinent to Ntaruka's hydro-power station
   (ii) to describe plausible causes of water reduction at Ntaruka in 2004 and their bearing on power generation and energy costs
   (iii) to describe other factors relevant to understanding of Ntaruka's performance
   (iv) to identify policy measures and instruments for sustaining power generation at Ntaruka now and in the future

10. Owing to the short duration of the study[4], evidence in this report is based on existing literature and documentation, and selective interviews (Annex 1).

## B: Analytical model for describing the bio-physical factors pertinent to power generation at Ntaruka

11. In this section, a model to describe the complex bio-physical interrelationships and their bearing on accounting for water for power generation at Ntaruka is presented. It is a rainfall-runoff model called WATBAL (Yates,1997).It was derived from a best case of Environmental Impact Assessment (EIA) in the region (Figure 3)[5]. The model is popular in planning for energy generation because it simulates changes in soil moisture and runoff.

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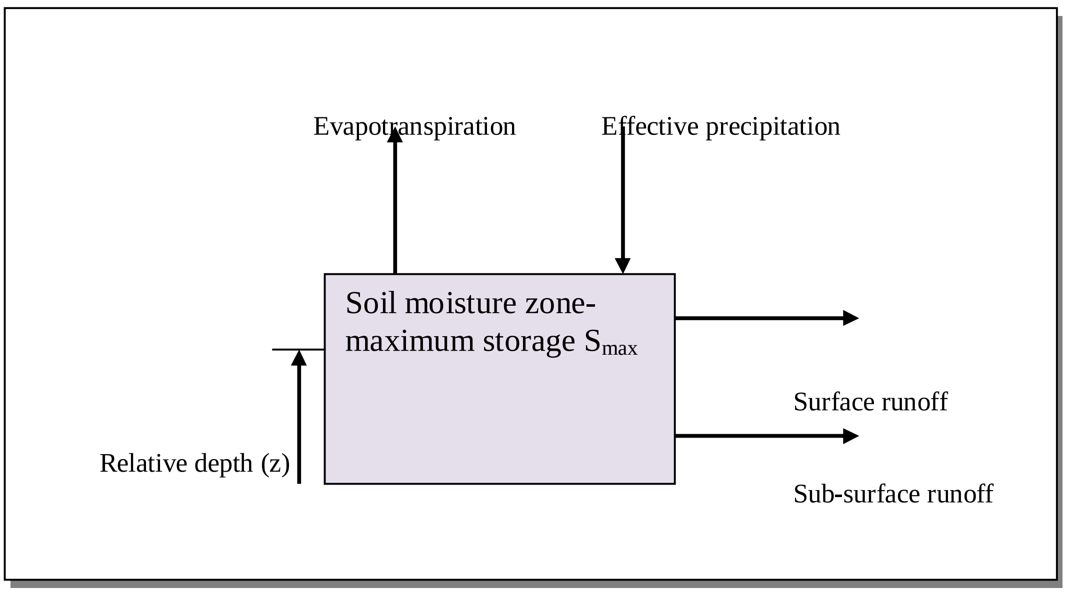
[4] Only 6 days were allocated to this analytical study
[5] Nile Basin Initiative [2007]: Strategic/Sectoral, Social and Environmental Assessment of Power Development Options in The Nile Equatorial Lakes Region

12. It comprises two elements. The first is a water balance component that describes water movement into and out of a conceptualized basin like Lake Bulera (Figure 1).

13. The second is the calculation of potential evapotranspiration, which, in the gridded version of the model, is computed using the Blaney-Criddle Method. The simplified representation of soil moisture dynamics is known to adequately represent runoff changes due to climate fluctuations (Yates and Strzepek, 1994; Yates, 1997).

14. According to the model, water enters the soil moisture store through precipitation and is removed either by evapotranspiration, surface runoff, or sub-surface runoff. The water balance component of the model comprises three parameters related to (1) surface runoff, (2) subsurface runoff, and (3) maximum catchment water-holding capacity.

**Figure 3: Simplified version of the WATBAL Model that is used to compute gridded runoff**




15. The monthly soil moisture balance is written as:

$$CS_{max}\frac{dz}{dt} = P_{eff}(t) - Rs(z,P,t) - R_{ss}(z,t) - Ev(z,Pet,t)$$

where: Peff = effective precipitation (length/time)
Rs = surface runoff (length/time)
z = relative storage (length) ($0 \le z \le 1$)
P = precipitation (length/time)
Rss = sub-surface runoff (length/time)
Ev = evapotranspiration (length/time)
Pet = potential evapotranspiration (length/time)
CSmax = maximum catchment storage (length)

16. In WATBAL, the relative importance of water storage on the hydrological regime of a cell is expressed as:

$$CS_{max} = S_{max}\, x\, AWC_{mult}$$

where: $S_{max}$ = maximum water holding capacity of the soil (mm)
$AWC_{mult}$ = maximum rooting depth (m)

17. $S_{max}$ is expressed as millimeter of water stored per meter depth of soil and is dependent primarily on the type of soils in the cell. $AWC_{mult}$ is dependent on the type of vegetation and hence is primarily a function of land-use within the cell. The model thus provided basis for describing land use changes in Rugezi hinterland. The storage variable, z, is given as the relative storage state and is a value between 0 and 1. Consequently, when $CS_{max}$ is multiplied by z, it gives the volume of water stored in the cell at any given time. The model has served as basis for searching for data to describe the bio-physical factors that can plausibly be associated with the energy crisis in Rwanda in 2004.

**C: The relationship between water supply and sustainable power generation**

18. A hydro power scheme requires both water flow and a drop in height (referred to as a head) to produce useful power. It is a power conservation system, absorbing power in the form of head and flow, and delivering power in the form of electricity or mechanical shaft power. Practically, no power conservation system can deliver as much useful power as it absorbs. Some power is lost by the system itself in the form of friction, heating, noise etc.Net power generation from a hydro power unit could be obtained from the following equation:

$$Pnet = hgross * Q * g * eo$$

Where

Pnet = Net power generated from the unit in kW
hgross = Gross water head in meter
Q = Discharge in m3/sec
eo = System efficiency
g = gravitation force in m/sec2

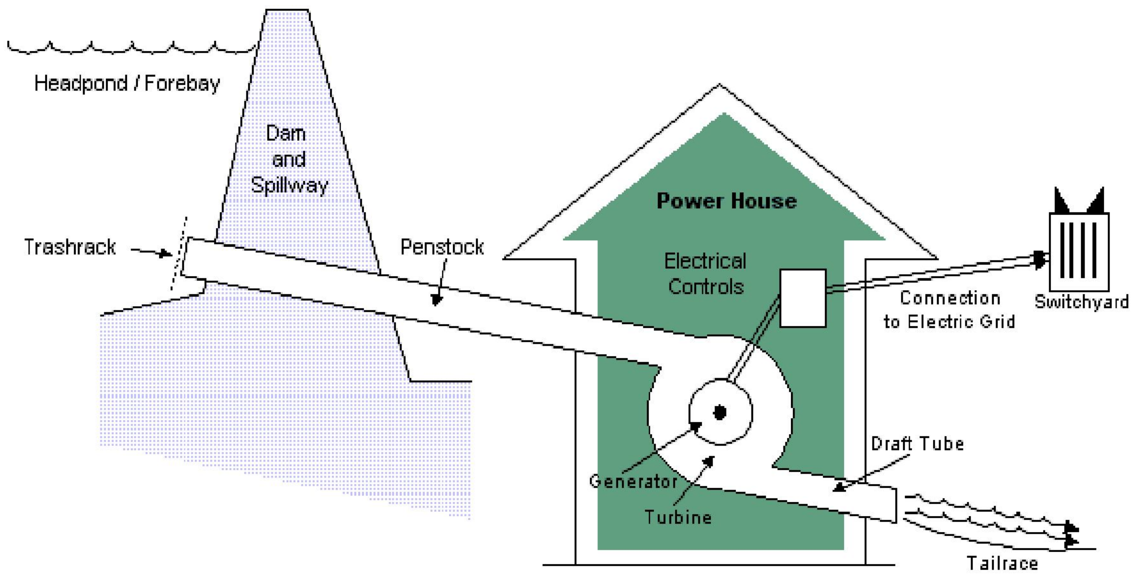
19. All in all, the above are the factors that determine the capacity of a dam. A typical hydro power has about 50% power loss, out of which about 5% losses in Channel, 10% loss in Penstock, 20% loss in turbine, 15% loss in Generator, 4% losses in step-up/down transformers loss and 10% Transmission losses[6]. The amount of power that can be produced at a hydroelectric site is a function of the available head and flow.

6 According to Renewable Energy Information Network, Bangladesh

20. A conservative, "rule-of-thumb" relationship is that power is equal to seven times the product of the flow (Q-m3/s) and gross head (H-m) at the site i.e., (P-kW =7QH). The hydro turbine size depends primarily on the flow of water it has to accommodate.

21. Figure 4 below shows a typical arrangement at Ntaruka. A reverse pump is used. After the construction, the dam has to be maintained to keep its operating efficiency. This could also imply keeping the water holding reserve void of sedimentation. By implication, part of the operating costs should be costs of environmental mitigation.

**Figure 4: Small hydro system schematic**




22. Rwanda's mountainous terrain and abundant rainfall (1,250-1,500 mm/year), should in theory offer great potential for generation of electricity by small hydroelectric generating stations in the numerous, steep, fast-flowing rivers and streams. However, according to the Department of Energy, these sites appear costly to develop and maintain because of the small capacity and the topography, which prevent the construction of reservoirs to store water from the high flow seasons for use during the dry seasons. So, water becomes used more or less following the rains. That makes Rwanda's hydropower situation precautious.

23. Further, Rwanda has to learn that dams whether small or big are increasingly being challenged to have a more holistic view than mere power generation. This is mainly because of increasing water demand and greater awareness of environmental concerns and social responsibilities. In turn, and as evidenced in the later section, this has increased the complexity of dam planning, operation and sharing of benefits. It is thus no longer fashionable to approve dam operation on the basis of economic criteria alone. It is therefore no wonder that in its report, the World Commission on Dams (WCD) called for a more equitable distribution of the benefits to be gained from large dams and proposed the inclusion of all identified stakeholders in the planning and management of water resources stored in reservoirs (WCD, 2000).

24. In order to achieve equitable distribution of benefits from dams, policy decisions for dam operations must take into account the interests of water users upstream and downstream of the dam. They must also give consideration to political, organizational, social and environmental factors. That makes a shift from the hitherto emphasis on biophysical constraints to power generation. Accordingly, it became an integral part of this study to establish Rwanda's readiness to take that holistic approach to management of dams that hithero were mainly concerned with power generation.

**D: Past and current context of Ntaruka in power generation**

25. Rwanda depends to more than 95% on hydroelectric generation. About 45% of national consumption in 2003 were covered by the two national power stations Mukungwa and Ntaruka that made up for 83% of the total installed ELECTROGAZ capacity of 28.56MW. The two stations lie in a sequence on the same system of lakes and thus are strongly interdependent. By implication, anything going wrong at any of the stations or both was bound to be greatly felt and publicized.

26. Built by the Belgians during colonialism, the Ntaruka station contains three turbines that require a flow rate of 12 cubic metres per second for the station to achieve its full capacity of 11.25 MW. However, the Rusumo tributary which links the Rugezi Wetlands to Lake Bulera has a flow rate of only 2 cubic metres per second during the rainy season. As such, should the station be operated at its full potential, it has the potential to directly contribute to a decline of the water level in Lake Bulera (CITT, 2006). Another question that comes to mind is: "**Was it the degradation of Rugezi wetland and hinterland that caused the power crisis at Ntaruka or was it the overstretching the capacity of Ntaruka to generate power**?

27. A review of literature and information gathered from interviews suggest several causes, including the two above. However, the literature has tended to mainly focus on the degradation. The latest one is quoted below:

> *"Ntaruka's reduced electricity generation was attributed to a significant drop in the depth of Lake Bulera, which acts as the station's reservoir. This decline in water levels in turn was precipitated by a combination of factors, including: poor management of the upstream Rugezi Wetlands, the headwaters of the watershed; degradation of the surrounding Rugezi-Bulera-Ruhondo watershed due to human activity; poor maintenance of the station; and reduced precipitation in prior years. At the time, concern was expressed that this reduction in precipitation might foreshadow the future impact of climate change in Rwanda[7]".*

28. Earlier, Kigali Centre for Innovation and Technology Transfer (CITT) listed more or less similar causes being responsible for reductions in Rugezi's hydro-potential[8]. They are:

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[7] Hove, Hilary, Jo-Ellen Parry, and Nelson Lujara. "World Resources Report Case Study. Maintenance of Hydropower Potential in Rwanda Through Ecosystem Restoration." World Resources Report, Washington DC. http://www.worldresourcesreport.org

(i) increases in energy demand, largely in urban areas
(ii) reduced flow of tributaries to and water levels of Lake Bulera and Lake Ruhondo
(iii) insufficient rainfall and drought
(iv) poor land practices
(v) inadequate servicing and maintenance of stations, and the age of stations
(vi) increases in agro-processing (principally coffee, tea, wheat, pyrethrum, maize)

29. It is evident that the 2004 energy crisis brought into focus the degradation of Rugezi wetland. Information from scientific report done by RRAM, pointed out that this degradation was noticed to have occurred gradually by different anthropogenic activities led by different stakeholders (government projects, authorities and population). The message from the report is that 2004 was the epitome of the accumulated negative impacts in Ntaruka's hinterland.

30. The anthropogenic causes of the degradation of the Rugezi Marsh are first, traceable to the demographic pressure and characteristics. It is reported that between 1978 and 2000, the population in the catchment increased from 295,021 to 517,715 inhabitants with approximately 75. 5 % increase over a period of 24 years. The population density grew from 337 to 577 inhab/$km^2$.The family farm size shrunk from1.4 to 0.6 hectares. In response, the population started to cultivate on hilly slopes and to reclaim the wetland. In turn, there was an increase of the runoff and an accentuation of the erosion (Ngenzi, 1995).Lack of water and soil control measures aggravated the problem of soil erosion and water run-off. The materials transported from hillsides made up of silt, fine sands, gravels and sometimes by big blocks created the area of deposition everywhere in the wetland. That reduced strongly the filtering and recharging capacity of the Rugezi wetland.

31. The Rugezi wetland is situated in the region of high mountains where the risks of erosion and flood are very high. On the hillsides, soil loss due to erosion is estimated to 13.7 t / ha a year (RRAM, 1987). This erosion is associated, either with the fragility of the arable layer of soil developed from quartzite and schistous soils or with the absence of soil conservation techniques. The sedimentation affected the functionality of the wetland. The capacity could therefore have been reduced.

32. It is also reported that the marsh of Kamiranzovu was drained in 1980s to provide for agriculture and as a consequence the original capacity of the wetland for storage and purification of the water has never been fully regained. Today, the Kamiranzovu inflow in the Rusumo stream is insignificant and its water became very strongly loaded with sediments. [Hategekimana and Twarabamenye,2007]

33. The above reclamation was driven by the marshlands reclamation policy developed in 1960s.The idea started with the project of Hydro-agricultural development of Rugezi Marsh. From that idea was born the development of Kamiranzovu arm as pilot project supported by Japanese International Cooperation agency (JICA). This development consisted in the digging of the principal canal and lateral ones in order to drain the plenty of water in the marsh towards Rusumo stream, outlet of the whole marsh. Thereafter, the reclaimed parts of the wetland were allocated to neighbouring communities for the cultivation of green beans and ramie which were considered as commercial crops in the region. Unfortunately, the project failed due to the low yield of those cash crops .The suitability of the ecological conditions for these crops had not been studied. In response, the population took on to growing other crops, notably Irish

Potatoes, maize and sorghums. Another weakness is that the property rights and rules for accessing the marsh were not defined, a factor that drives over-use of the marsh by competing users.

34. The Southeast zones was degraded from 1960-1983, due to the dynamiting effect of the rock wall to create Fels outlet, which sent the water to tea plantation project in Mulindi. As result, the water level fell rapidly and the whole part was reclaimed for agriculture (RRAM, I998). The outlet was later dammed; consequently the water level got raised. The zone have been restored. The restoration reached not only the rewetting but also created the water bodies. The water is now at 0.50m above the soils level. Activities like transportation in canoes and fishing have resumed.

35. In 2000 a follow-up project to the above called the Buberuka Rural Spaces Management funded by International Fund for Agricultural Development (IFAD) began. It involved reclamation of the two arms of the marshes ( Musenyi and Nyamwijima) for the cultivation of the potato and the corn. This consisted of digging of a relatively wide and deep central channel to drain the water. The effect of this development was the break of the hydrological balance by lowering the water table. The watershed has also been infested by water hyacinth and other aquatic weeds that increased turbidity and caused water loss through evapotranspiration (CITT, 2006).

36. In the same year of 2000, there was yet another intervention by the then ELECRTOGAZ which deteriorated the already precarious situation of the swamp .It was the drainage of the wetland to provide water for running the three turbines at Ntaruka. The level of the Lake Bulera had dropped down by more than 4 m. These works led to the increase of 0.5 m in width and 1.5 m, in depth of the stream bed .They also consisted in the destruction of the riverside vegetation (Hategekimana, 2005).Collectively, these works contributed to the increase in velocity and runoff. Consequently, the tension of the water, that is the capacity of retention and the suction by which the water is retained by the pores structure, was broken.

37. There is no doubt that the above described activities and events interfered with the sustainable functioning of Rugezi wetland and subsequently on the water levels of L.Bulera.

38. Another cause of Rugezi's degradation was policy failures. Since independence period, the Ministry of Agriculture and Livestock (MINAGRI) had the objective to drain wetlands to avail land as response to demographic pressure and food security (Hategekimana, 2005). In that period, there was no policy framework to sustain the hydrological and ecological functionality of wetlands. The term *marsh drainage* prevailed until it became replaced by marsh development. The era of marsh development saw the introduction of water regulation structures to avoid the drying up of soils which had been observed during implementation of *marshes drainage* scheme.

39. In 2001, thanks to African Development Bank (ADB) funds, the MINAGRI developed a master plan of marshlands development, soil conservation and watersheds protection. This scheme led to wetland classification in accordance with their hydrological aspects, their

level of degradation and recommended the conservation of highland wetlands as integral part in water resources management (MINAGRI, 2001).

40. Like any wetland, Rugezi wetland acts as a sponge releasing water gradually and thus supporting power generation but also minimizing the risks of flooding downstream. The water balance in that wetland has been studied [Sylvère Hategekimana, Emmanuel Twarabamenye]. Using the Taxeront Berkallof formulas (Baccar, 2001) they were able to assess empirically the storage function of Rugezi marsh. Their findings are summarized in Table 1.

**Table 1: Storage function of Rugezi marsh**

| Inflow from direct precipitations $Mm^3$ | Runoff from catchment $Mm^3$ | Evapotranspiration in $Mm^3$ | Outflow at Rusumo in $Mm^3$ | Storage in $Mm^3$ |
|---|---|---|---|---|
| +36,4 | +98,7 | -54,8 | -37,3 | +43 |

***Source: Slyvere, Emmanuel Twarabamenye [2005]***

41. However, the concern is that loss of water due to precipitation is likely to increase because of projected increase of average maximum monthly temperature of around 1.5 to 2.7$^{o}$C up to 2030, and 1.7 to 2.7$^{o}$C for 2046-2065. These estimates based on the Climate Change Explorer (CCE) data have been made by Stockholm Environment in "Economics of Climate Change in Rwanda". Even though there is still uncertainty about climate change impacts at national level, past evidence suggests that the EA region as a whole is subject to periodic extremes with serious floods on one hand, and drought on the other. Flooding would lead to siltation of the power dam, in turn, that could lower the water head for power generation and increased costs of silt removal.

42. Owing to the multiplicity of possible factors at different times and locations as described, it becomes very complicated to establish proportionality of various contributions to the fall in water level at L.Bulera. Such an exercise was way beyond the scope of this study. The situation becomes even more complicated when the water that would be available for power generation becomes competed for with water loss due to evatransipiration and climatic change impacts. The main implication therefore is that it is no longer tenable to plan for power generation from purely an economic angle. The social and environmental issues are as important. However, one other question under this study was set thus: "**Was the fall in water level at L.Bulera specific or spread in other countries**? This question was set as a control.

43. First and foremost, it was found that the 2004 episode at L.Bulera was not the first of its kind. For several years prior to completion of the interconnection with DRC, ELECTROGAZ experienced severe difficulties with their diesel generating stations and as a result drew about 43 GWh annually out of Lake Bulera (reservoir for Ntaruka station) more than twice the average availability of about 20 GWh per annum. Consequently, it is reported that the waters of Lake Bulera fell by about 1m between 1962 and 1973 and by about 3m between 1973 and 1987, and the level of Lake Ruhondo, which supplies the

Mukungwa plant fell by 0.4 meter between 1983 and 1988 (UNDP/World Bank, 1991). Similar water level problems at Lake Kivu were reported[9].

44. Secondly, the story of water declines between 2004 and 2005 is neither peculiar to Ntaruka nor L.Kivu in Rwanda. Many other lakes in the East African region faced similar events, a situation that suggests that there was a much greater phenomenon than that experienced in Rwanda. That phenomenon is climate change induced precipitation. Of course one can also argue that the problem of falling water of L.Bulera could have been exerbered by poor local environmental management over time.

45. The Pangani Fall Redevelopment (Hydropower) Project which is in Pangani River Basin (PRB) in Tanzania has experienced years of declining discharges of the Pangani River, which has caused lower production (electricity) figures. Many streams and valleys that contained water before are now dry and contain water only during the rainy season. It is reported that the Nyumba ya Mungu Reservoir and Power Station experienced during the 2005 the lowest water level ever[10]. **Accordingly,** hydropower from the Great Ruaha and Pangani River Sytems which was until 2001 contributing about 97.5% of the energy needs in the country's national grid system had dropped to 50% by 2005 and to 30% by mid 2006.

46. Likewise in Uganda, the optimum levels of hydropower output at Nalubale and Kiira 380 MW hydropower dam complex at the mouth of L.Victoria reduced from an average of 270 MW in 2002 to around 120 MW during August 2006, a drop of 30%. Lake Tana faced similar patterns. According to African Lakes Atlas, many lakes and water basins have lost their water holding capacities due to multiple factors [UNEP, 2006]

47. Beyond the degradation of the wetland and climate change induced precipitation, there were other factors. ELECTROGAZ highlighted two additional factors: lack of investment and increasing demand for power. Due to lack of investment over the past 20 years (between 1984 and 2004) and strongly growing demand, in 2004 Rwanda faced a capacity deficit of 80–90GWh per annum that relates to a shortfall of 9.5–10.5MW of generation capacity continuously. Allowing for a load factor of 80%, the shortage in physical plant capacity was approximately 12–13MW. Over the past, the emerging capacity deficit has been masked by overuse of hydro-resources and imports above contracted levels. Ntaruka and Mukungwa power stations have on average been used for 140-150% above their designed capability over the past seven years before 2004, while imports were 17.5% above the contracted levels [Hategekimana, Twarabamenye, 2005].

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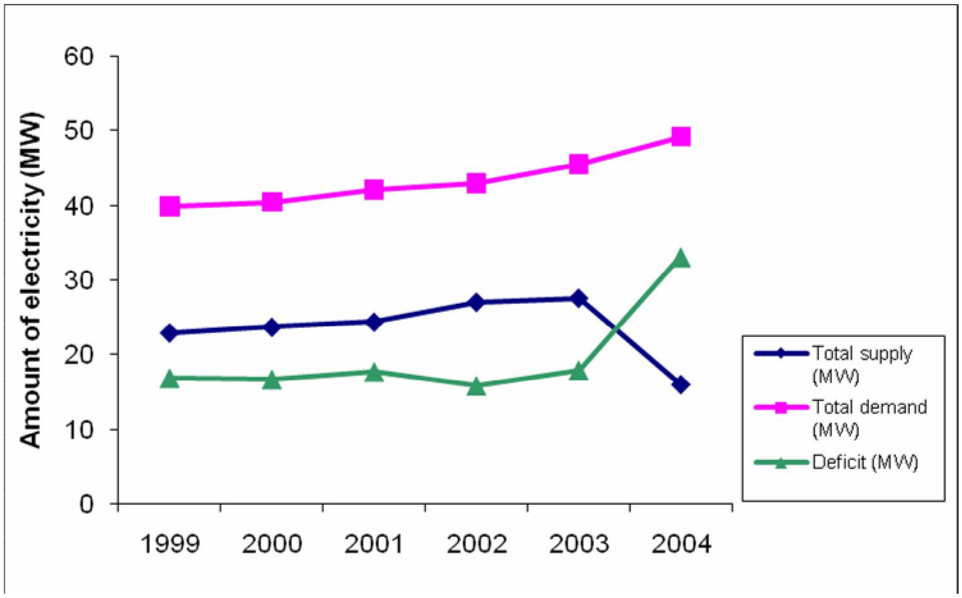
[9] ELECTROGAZ REQUEST FOR BUDGET SUPPORT 2005-2007

[10] Kimwaga, R.J. and Nkandi, S. [2007] Evaluation of the Suitability of Pangani Falls Redevelopment (Hydro Power) Project in Pangani River Basin, Tanzania: An IWRM Approach

48. The above statement was verified by the relationship between demand and supply of electricity between 1998 and 2004 in Figure 5. The evidence clearly points to the fact that ELECTROGAZ was under temptation to meet the energy demands of a growing economy. It is also reported that many energy consumers had faulty installations. A recent technical audit on the 161 largest customers that account for half of Rwandans electricity consumption has identified approximately 15 GWh per year (7-8% of ELECTROGAZ revenues) of losses from faulty technical installations.

**Figure 5: Demand, Supply and deficit for energy in Rwanda, 1999-2004**




***Source:* Rusuhuzwa Kigabo and Gatarayiha [2005]**

**E: Response measures to the Ntaruka energy crisis**

49. The energy crisis at Ntaruka stimulated several responses, some of which will remain beneficial to the country for years to come. The five response measures discussed here are: loadshedding, investment in alternatives, particularly the thermal power, integrating vulnerability and climate change impacts at Ntaruka and finally, rehabilitation of the Rugezi ecosystem.

- **Load shedding**

50. The above response measure was inevitable because the demand for energy continually exceeded the supply (see Figure 5). Due to the drop in national and imported supply, in August 2004, 40% of Rwandan's total electricity demand and half of peak demand had to be shed, i.e could not be served. In many areas outside Kigali and some parts of Kigali, only half of the total demand can be covered.

51. Technical measures were taken by the ELECTROGAZ operator, Lahmeyer International in order to refine load shedding to secure supply to priority installations such as hospitals, water pumping stations and other essential customers. An information campaign was initiated by ELECTROGAZ in order to inform the public and motivate for rational use of energy. ELECTROGAZ too engaged in loss reduction in order to increase available supply.

- **Investment in alternative of thermal energy**

52. Due to the need for a quick solution, the management of ELECTROGAZ (Laymeyer International) identified switching to diesel generators as being the quickest option for the short term solution to supplement hydropower units and alleviate the crisis. Six diesel generating units totaling 12.5 MW were purchased from the European market with funds from the Dutch Embassy in Rwanda. These generators were brought from Messers Global Power System (GPS) a Belgian-German company in May 2004, were tested in the Netherlands before they were transported into Rwanda to be connected to the existing electricity grid.

53. As highlighted by the Director General of ELECTROGAZ during the inaugural ceremony on June 21st, 2005, these units costs huge amounts, about 4,313,727 euros that Rwanda got thanks to the cooperation with the Dutch Embassy. As the Director General said at the inaugural ceremony, those generators are so powerful that they can turn 24 hours a day for a full year. But it is clear that the cost are very high and the company seemingly could not afford it.

54. According to ELECTROGAZ, the hourly diesel consumption of these machines was 800 litres, which is 19,200 litres of diesel per day; and following petrol prices the daily consumption of the Diesel generating units was between Rwf 8 -10 million per day[11]. By 2005, the ELECTROGAZ management found an additional option and hired generators from Agreco, a US thermal energy provider company, but the venture has increased the cost of production considerably, rising from around 10million Rwf (around Rwf 300 million per month) to Rwf 560 million (one million USD) per month. Following the cost recovery practice (purchase of the machines to generate electricity and the cost of operating them) a new tariff had forcible to come up. The donors had advised the government to reduce on subsidies.

- **Tariff revisions**

55. The government response of commissioning thermal energy greatly increased the cost of producing energy. Following the cost recovery practice (purchase of the engines to generate electricity and the cost of operating them), a new tariff had forcibly to come up in 2005. Even before 2005, the tariff had been increased to cover ELECTROGAZ operations at a time when the energy was declining. The trends in the electricity tariff are given in Table 2.

[11] The updates from media interviews with the ELECTROGAZ management reveal that the company is spending up to 560 million Rwf (one million USD) per month simply on the Diesel used to run the generators.

**Table 2: Electricity tariffs from 1998 - 2011**

| Electricity | Unit | ‘98 | ‘99 | ‘00 | ‘01 | ‘02 | ‘03 | ‘04 | ‘05 | ‘06 | ‘07 | ‘08 | ‘09 | ‘10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Industry | Rwf/ | 42 | 42 | 42 | 42 | 42 | 42 | 42 | 42 | 105 | 105 | 105 | 105 | 105 | 105 |
| Household | kWh | 42 | 42 | 42 | 42 | 42 | 42 | 42 | 42 | 105 | 105 | 105 | 105 | 105 | 105 |
| Public service | | 52.2 | 52.2 | 52.2 | 52.2 | 52.2 | 52.2 | 52.2 | 52.2 | 112 | 112 | 112 | 112 | 112 | 112 |

56. Countries determine the tariff bill according to several factors. Typically, a consumer bill may include one, two or sometimes three elements- a fixed minimum charge (customer related costs), a kilowatt charge related to the capacity (capacity charge), and a kilowatt-hour charge based on consumption (energy charge). However, in Rwanda, several factors have influenced the setting of the tariff. To note is that between 1992 and 2005, Rwanda charged a flat tariff for all consumers despite the different costs of service for different load levels. That was not equitable, so eventually it changed in 2006 as shown in Table 2. There was an increase of tariff from 42Rwf per kWh to 105 Rwf per kWh. According to USAID [2005], the increase was based more on the erosion of the currency (through inflation) rather than any cost-based analysis.

57. In 2005, ELECTROGAZ adopted a more technical approach to tariff calculation and setting. Simply, the approach was meant to help it make a margin after making investment, operating and non-operating expenses, taxes and after accounting for losses (Table 3). The recommendations were implemented in 2006 (Table 2). Even then, the government continued to subsidise consumers.

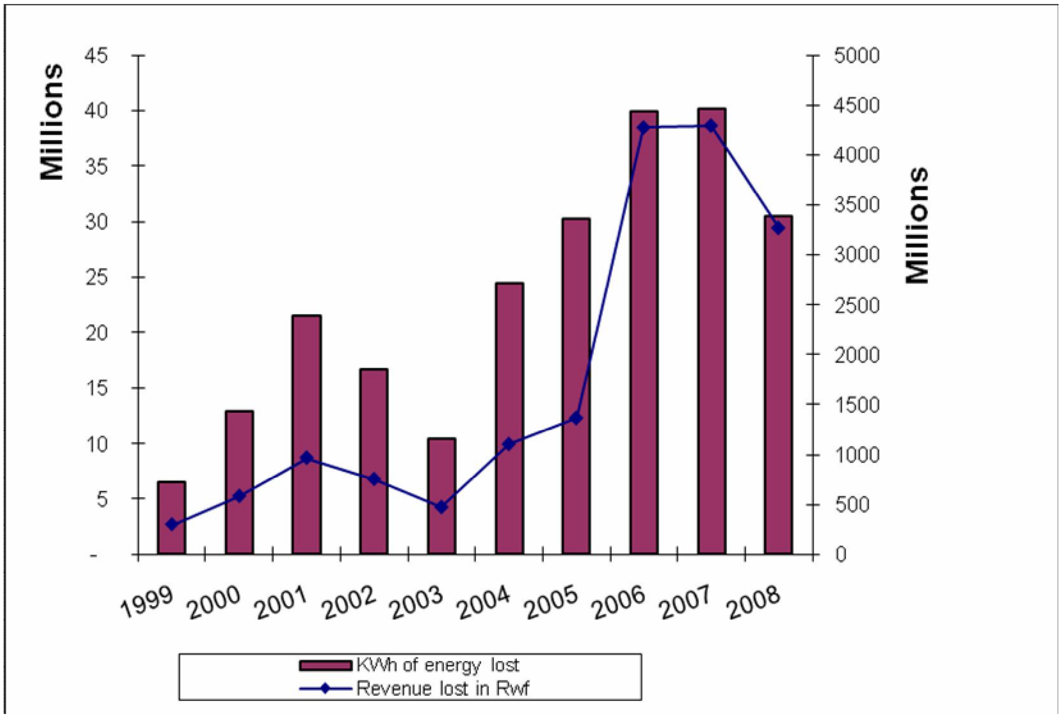
**Table 3: Technical approach in determining electricity tariff**

| | **2005** | **2006** | **2007** |
|---|---|---|---|
| Operational expenses | 14,271 | 22,146 | 22,712 |
| Investment | 205 | 491 | 25 |
| Debt Repayment | 272 | 0 | 1 |
| Return to Investor | 0 | 0 | 0 |
| Taxes | 398 | 407 | 205 |
| **Total** | **15,147** | **23,045** | **22,942** |
| Projected GWh sold | 174.3 | 253.7 | 239.5 |
| Net cost recovery price | 86.88 | 90.82 | 95.78 |
| Allowable collections (Commercial losses) | 87% | 90% | 95% |
| Final tariff (without VAT) | 99.86 | 100.91 | 100.82 |
| Final tariff With VAT | 117.8 | 119.1 | 119.0 |

***Source: USAID [2005]***

58. Taking 1998 as the baseline (peak) year for the electricity generation, the revenue lost from Ntaruka between 1999 and 2008 inclusive is cumulatively Rwf 17,365,512,500 The shortfall in power generation from the baseline was multiplied by the weighted price of the three categories of consumers namely industry, households and public service.

**Figure 6: Revenue loss by ELECTROGAS, taking 1998 as best benchmark**




- **Integrating climate change impacts in power generation**

59. Recognizing that climate change could lead to similar drops in water levels and restrictions in electricity production, the Government of Rwanda initiated a pilot project designed to increase the resilience of Rwanda's energy sector. This pilot project formed part of the regional project "Integrating Vulnerability and Adaptation to Climate Change into Sustainable Development Policy Planning and Implementation in Eastern and Southern Africa" (ACCESA).

60. The pilot project was designed to build the resilience of Rwanda's hydroelectric sector by achieving the following objectives:

    a) restore and protect the watershed supporting the Ntaruka and Mukungwa hydroelectric facilities while helping to improve the livelihoods of local communities living within these watersheds, thereby reducing their vulnerability to the impacts of climate change;
    b) integrate climate change considerations into the management and operation of Rwanda's hydroelectric power plants; and
    c) promote the integration of vulnerability and adaptation to climate change into energy and sustainable development plans and processes in Rwanda.

61. There is no doubt that the above project has opened up EWSA ( former RECO/RWASCO) to appreciate the conservation of Rugezi ecosystem, and to prepare it to understand the rationale for Payment for Ecosystem services.

- **Rehabilitation of Rugezi ecosystem**

62. As the energy crisis intensified, it stimulated both debate and awareness about wider sustainability and environmental aspects of energy generation. Importantly, the legislation made around that time reflected in a way that Rwanda had picked lessons from the crisis. For example, Rwanda's National Environment Policy of 2003, included statements for the restoration of the natural environment through landuse management, natural resource management, and other measures (MLRE, 2003). The policy contains an entire section on wetlands in which a number of commitments are made, including establishing measures to protect wetlands and prevent their further degradation; and establishment of wetlands as state-owned property (MLRE, 2003).

63. Many of these principles were later promulgated in Rwanda's *Organic Law N° 04/2005: "Determining the Modalities of Protection, Conservation, and Promotion of the Environment in Rwanda"* (GoR, 2005). The law entails a number of specific measures aimed at reversing the degradation of wetlands. In particular, articles 85 and 86 of the Environment Law limit agricultural and pastoral activities around bodies of water, requiring these activities be undertaken at a distance of 10 meters from the banks of streams and rivers and 50 meters from the banks of lakes (GoR, 2005). Article 87 of this law also stipulates that it is "forbidden to construct houses in wetlands (rivers, lakes, big or small swamps) in urban or rural areas" (GoR, 2005).

64. The above conservation attitude cascaded to other policies and laws like the Rwanda Land Policy in 2004,.recognised wetlands as a special category of public land. It went on to state that "all marshlands must be governed by a special legislation which must be vigorously enforced".

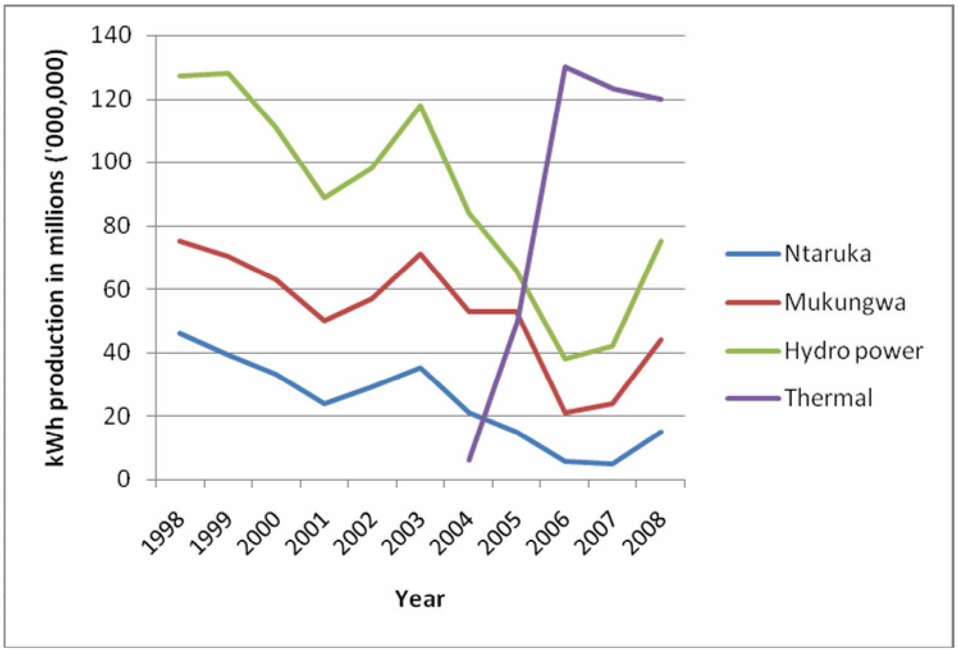
65. The subsequent passage of the Environment Law on 1 May 2005 further strengthened the legal authority of the government to control activities within the Rugezi Wetlands and along the shores of Lakes Bulera and Ruhondo. Specifically, this law enabled the government to restrict agricultural and pastoral activities to 10 meters away from the banks of streams and rivers and 50 meters away from the banks of lakes. In 2008 the Government also declared the Rugezi Wetlands a protected area.

66. In addition, the World Agroforestry Centre, OXFAM, Care International and Hydropower International have implemented projects in the Rugezi area aimed at restoring the wetlands, including activities related to agroforestry, sustainable pastoralism, anti-erosion measures and social development (REMA, 2009). Restoration of the Rugezi Wetlands has further been promoted through the Integrated Management of Critical Ecosystems (IMCE) project[20] Implemented through the Rwanda Environmental Management Authority, the IMCE project aims to assist farmers around four critical ecosystems, including Rugezi, to implement sustainable agriculture measures and improve their livelihoods.

67. Figure 7 therefore provides a convergence of many factors. It is clear that both Ntaruka and Mukungwa depicted the same pattern, reflecting their interdependence on water sources and supply. Secondly, the government's investment in thermal power relieved pressure on

both power stations after 2004. By coincidence, it is in the same period that the above restoration measures were also undertaken. So, the recovery of L. Bulera and Ntaruka power station was as result of a combination of factors.

**Figure 7: Trends in kWh production by source**




**F: Impacts of energy crisis**

68. Energy plays a crucial role in the development process, as a necessity for households first, but mostly as a production factor whose cost affects directly the price of the other goods and services as well as the competitiveness of firms. Energy is also a social development factor as it is also a means to preserve the environment.

69. As a factor of production, energy is a tool which sustains economic growth and by so doing, sustains the development of the country. The availability, the quality and the cost of the energy supply are, among others, the determinants of economic growth for countries. If all the industrial sectors need energy, the competitiveness of some of them is directly related to its cost as well as to its availability. Moreover, the energy efficiency opens the way to important investments which engender positive economic outcomes.

70. While the production of the electric power was stagnating, the demand kept on increasing. This provoked the overexploitation of the storage basins of L. Bulera and L. Ruhondo which were supposed to undoubtedly outcome in a short term drying of these lakes up to approaching the levels forbidden for any exploitation of Ntaruka and Mukungwa stations. That negatively affected the functionality of the ecosystem.

71. In order to analyze the impact of the deficit in energy on the industrial sector of Rwanda, we have dealt with the production cost and the product price as factors of productivity and that of competitiveness of manufactures. We have focused on the energy cost, especially on electric power which has changed from 42 to 81.26 Rwf per KWh, between 2004 and 2005.

72. The fact shows that the consequences of the energy crisis in Rwanda were many. The costs of production by firms increased, and for some, they had to resort to the use of generators. It also means that their emissions to the Greenhouse Gases (GHG) went up. On account of cost of energy, Rwanda was less competitive in the region. According to a report by Ministry of Infrastructure, ordinary customers in Rwanda pay 132Rwf per kWh including VAT. Kenya and Uganda on the other hand charge low electricity tariffs, that is Kenya approximately 90 Rwf/kWh and Uganda approximately 100 Rwf per kWh[12].

## G: Looking beyond power generation by dams

73. Increasingly, one is observing a practice whereby dams are no longer solely made for power generation but also for additional benefits. Such benefits include tourism (e.g through attractive architectural design) and socio-economic projects for adjacent communities; this is where Rwanda needs to go. Figure 8 illustrates this point clearly. Rwanda has to make enabling legal framework if its dams have to deliver multiple benefits.

74. In 151 countries around the world, electricity is generated at hydropower dams, and 87 countries derive 50% or more of their power from this source[13]. Whether the dams are privately owned or operated by public agencies, rather universally, the water resources that are developed for this purpose are regarded as a public asset. As a consequence, there is an increasing global trend to require that hydropower facilities provide public benefits, beyond simply serving particular customers and generating revenues for particular investors. At a minimum, national laws and policies generally require hydropower facilities to mitigate the adverse environmental effects on the river. In other cases, there is a larger responsibility imposed to make the facility “footprint neutral” through off-site compensatory measures.

75. In other cases, the obligation goes to sharing the revenue benefits of hydropower generation. In effect, the use of the water to generate power is “taxed”, and the tax revenue is utilized to provide an array of social services. Finally, in a few cases, hydropower facilities have been required to improve the management of the downstream floodplain by, for example, enhancing wetlands systems that also act as flood retention basins. Some notable examples are discussed below.

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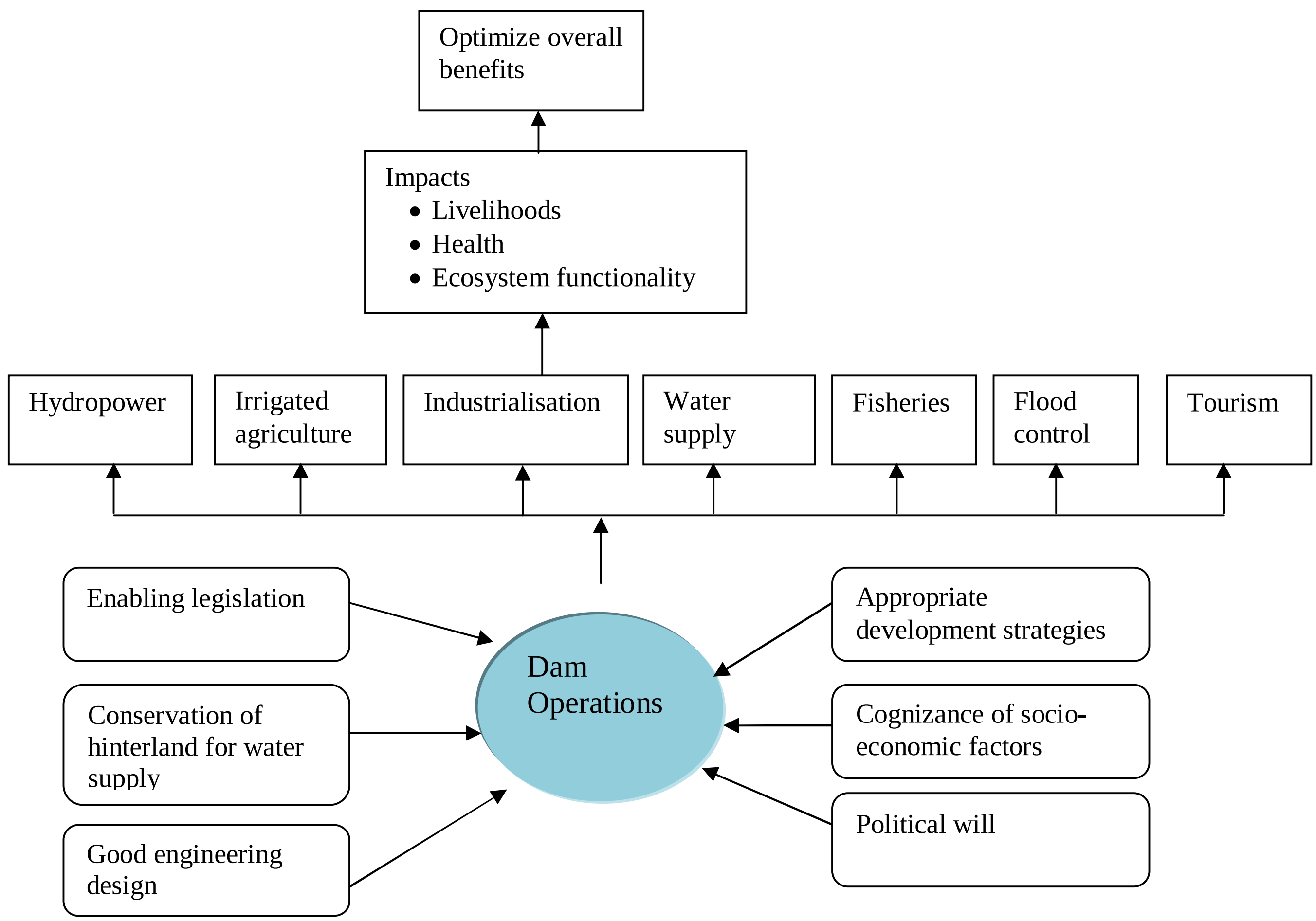
[12] http://allafrica.com/stories/201010280143.html

[13] World Commission on Dams, 2000.

**Figure 8: A dam as a convergence of complex web of opportunities, issues and trade-offs**




76. The overall conclusion, however, is that there is a global trend in the direction of hydropower facilities taking responsibility for their environmental performance to assure that the effect of their operations is at least neutral and sometimes confers a net benefit on its river basin or associated watersheds. Examples are given in Table 4.

77. It is event that dams have broadened the benefits they offer. These include generation of revenue. And earmarking it to finance local projects; conservation of biodiversity; conservation and rehabilitation of hinterland ecosystems to mention but a few. It is to be noted that in some cases, dams have been obliged under certain laws to offer the above benefits. Rwanda too, could take the same route by making dam operators internalize environmental impacts at source.

**Table 4: Lessons on how dams have broadened the benefits they offer**

| Country | Existing measure |
|---|---|
| 1.Colombia | % of revenues from all hydropower projects are transferred annually to the watershed agency to fund watershed management activities working with the basin communities (income raising). *(National Heritage Institute)* |
| 2.Ecuador | Quito o Electric Company pays 1% of drinking water profit to the capitalization of FONAG Trust Fund which is used for watershed management (*National Heritage Institute)* |
| 3.Ghana | Volta River Authority directly carries out forestation projects to restore vegetation on the highlands along the Volta Lake . |
| 4.Philippines | • **Executive Order No. 224**<br>Vested jurisdiction to NPC for watershed areas supporting power generating plants<br>• **EPIRA LAW (RA 9136, Sec. 34)**<br>NPC shall manage and **continue to be responsible for watershed rehabilitation and management** and shall be entitled to the environmental charge equivalent to one-fourth of one centavo per kilowatt-hour sales<br>Reforestation, Watershed Management, Health and/or Environment Enhancement Fund (RWMHEEF) at 25% of one centavo per kWh (P0.0025/kWh)<br>*http://www.doe.gov.ph/ep/ben.html* |
| 5. Lesotho | The Lesotho Highlands Water Project (LHWP) set up an innovative Lesotho Biodiversity Trust, paid for from funds generated by hydropower and water diversion scheme. |
| 6. Zambia | Zambian Electricity Supply Company working with WWF has conserved Zambia's flood in Kafue flats(6,500 km2) an area important for fishing, cattle grazing, sugarcane farming and of course hydroelectric power. The Company uses the "benefit sharing" funds to supply the project. |

## H: Conclusion and recommendations

78. This brief study has shown that the energy crisis in Rwanda in 2004 was a culmination of many factors. They are the degradation of Ntaruka's hinterland. The increased population without commensurate increase in appropriate technologies for land use, policy and institutional failures. When some of the factors started to be addressed systematically after 2004, there was recovery in the water level of L. Bulera, and subsequently in the power generation at Ntaruka. Investment in the alternative energy sources particularly the thermal power gave relief to Ntaruka. However, that came with very high capital and operational costs. To the economy, Rwanda cumulatively lost over 17 billion Rwf between 1999 and 2008 inclusive.

79. Despite its negative dimensions, the energy crisis from Ntaruka has served as a case study in Rwanda to mobilize both policy makers and the general public about the importance of environmental sustainability to socio-economic development. That should serve as an entry

point to initiate many reforms. They include introduction and operationalisation of the Payments for Ecosystem Services (PES), broadening the type of goods and services the dams should offer and defining clear rules for public-private partnerships (PPPs) in dam operations. In order for all the above to work, the GoR would need to provide enabling legislation for dam operators to take on additional responsibilities beyond power generation. Further, the GoR could, within the new legislation, oblige dam operators to set aside a fraction of their revenue for use in pre-determined type of activities. This is the lesson that has been drawn from Ecuador in Table 4.

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**Annex 1: List of people interviewed**

| Name | Title | Organisation | Contact |
|---|---|---|---|
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| 10. Robert Ndabavunnye | Rural infrastructure Engineer | MINAGRI | |
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| 17. J.N | Production Engineer | Electrogaz | |
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