Community Pico Hydro in Sub-Saharan Africa: Case Study 2

Site: **Thima**, Kirinyaga District, Kenya

Background

This was the second of two schemes installed as part of a program implemented by The Micro Hydro Centre at Nottingham Trent University to demonstrate Pico Hydro technology in Sub Saharan Africa. The cost of the penstock, turbine and generator equipment was met by the project funders (European Commission) and all other costs were contributed by the 110 households which the scheme supplies with electricity.

Technical Summary

This case study describes a pico hydro plant using a 'pump-as-turbine' directly-coupled to an induction motor as generator which has an electrical output of 2.2kW. The penstock consists of 90 metres of 160mm diameter PVC pipe. The net head is 18m and the flow into the turbine is 28l/s. The electrical output of 2.2kW corresponds to a turbine-generator efficiency of 45%. The water source is the Rutui River which has a flow rate of more than 100l/s during 90% of the year. The minimum flow, measured after an unusually long period of dry weather, was 84 l/s. The generator output is regulated by means of an Induction Generator Controller to ensure that the voltage and frequency are held at the correct values during conditions of changing consumer load. Excess power is fed to a ballast load. Two 1.8kW cooking rings connected in parallel have been used for this. There are around 160 households within a 900m radius of the turbine house and 110 of these are being connected to the generator using a single-phase distribution system with insulated copper conductors. Each house has a 230V supply which is sufficient for one or two energy-saving lamps and a radio. It was not possible to connect all the houses due the proximity of some to the grid lines which supply a tea factory and a local church. Areas in the vicinity of the grid lines were avoided to prevent risk of conflict with the national utility. The locations of the generator and consumer houses were recorded using a GPS system so that a distribution plan could be developed. The average cost per house for all equipment and materials was $58 and more than 50% of this cost was contributed by the consumers. In addition the consumers contributed their labour free of charge and trees from their 'shambas' (farms) to make distribution poles.

Site Description

Kerugoya town lies 130km north of Nairobi on the southern foothills of Mount Kenya. Thima is approximately 4km north-west of Kerugoya. Travelling time from the town to the site is around 15 minutes with a vehicle. The powerhouse can be reached after a further 10 minute walk down into the steep valley along which the Rutui River flows. This river, which provides the hydro power potential, is formed at the conference of the Kangaita River and a smaller tributary 500m upstream from the turbine. There are approximately 160 houses within the vicinity, the furthest of which is 900m from the turbine house.

Community Organisation

The local community at Thima were organised and motivated from the outset. They had previously formed an association and collected money so that a transformer could be purchased because grid lines run nearby to a tea factory. This is the only way of receiving a connection to the grid in many rural parts of Kenya. In many African countries it is quite normal that grid lines pass over or very close to houses but they often have little hope of ever being connected. The relatively small power demand is simply not sufficient for them to provide a good return on investment for the utility. Unfortunately the group did not manage to raise sufficient funds for the transformer so they were unable to get grid connected. However, this group provided a good basis to form an association for the implementation and management of this project once the local hydro potential had been recognised.

Community members outside the turbine house at Thima

Intake

The design flow for this scheme was 28 litres per second. The lowest recorded flow, using the salt-gulp method of flow measurement, was 84 l/s. This was taken after a particularly prolonged dry period caused by the failure of two consecutive rainy seasons so there is a good degree of certainty that the design flow to the turbine will always be available. For pico hydro schemes, the use of natural features and semi-permanent structures is favored to avoid the high costs of civil works often associated with larger hydro projects.

Galvanised wire mesh prevents debris from entering the penstock at the intake

Bolders have been used to form a deep pool around the intake. Soil bags seal the gaps.

At this site, use was made of a natural division in the river to provide a more easily controlled flow of water to the intake. Maize sacks filled with clay soil were used to re-enforce the channel leading to the intake and bolders were positioned to form a pool with sufficient depth to ensure that the penstock is kept full. The edges around the bolders were sealed with more stones and soil sacks. A flushing pipe was also added to enable the pool to be drained quickly. The intake was formed from low-pressure PVC pipe fittings and 5mm galvanised wire mesh rolled into a sealed tube. This acts as a filter to prevent any debris from entering the penstock and fouling the turbine. Two filters are used to ensure that a sufficient flow rate was always maintained. A wooden fence at the entrance to the channel reduces the risk of large sticks and leaves entering the channel to the intake. These are swept away by the main river flow instead.

Penstock

A community effort transformed the landscape of the riverbank within a few of hours to provide a platform at the correct level to support the first section of the penstock. Soil bags were used to secure the pipe in position and cover it to prevent sunlight damage. Locally fabricated metal posts, set into concrete, secure a suspended section of the pipe as it descends over a steep rocky slope parallel to the waterfall. A clamp lined with rubber was welded to the top of the posts and bolted around the pipe sockets where risk of a rupture was greatest.

The penstock level is marked out with string up to the proposed intake position.

A few hours later, a stone platform has been constructed to support the pipe.

The length of penstock required at this site was 90m to gain 20m of head. Class B (6bar) PVC pipe with a nominal diameter of 160mm was selected. This gives a head loss of about 2 meters with a flow rate of 28 l/s, so the net head at the turbine is 18m. This pipe was manufactured in 6metre lengths with each length joined to the next by means of a socket at one end. No PVC cement was required at the sockets, as a rubber 'O' ring was fitted which gives a pressure tight seal. One disadvantage of PVC pipe is that it is quite rigid and therefore potentially more difficult to install at a site where the landscape is uneven and rocky as in this case. Two 45º elbows were used to obtain the correct slope for the pipe down the steepest section. Other sections were carefully molded around a former after heating over a fire to give more gentle radius bends where required. A large wheel hub, securely anchored in the centre, provided a suitable shaped former. During this process it is important to fill the centre of the pipe with hot sand (plugged with maize sacks) to ensure that it does not buckle. Softening the pipe is easier over embers because the heat supplied is more even. Nevertheless, it is still important to keep the pipe moving during heating by constant rotation to prevent the plastic from burning.

Sockets enable the 6m pipe lengths to be fitted together. An 'O' ring fits in the socket recess and provides a pressure tight seal.

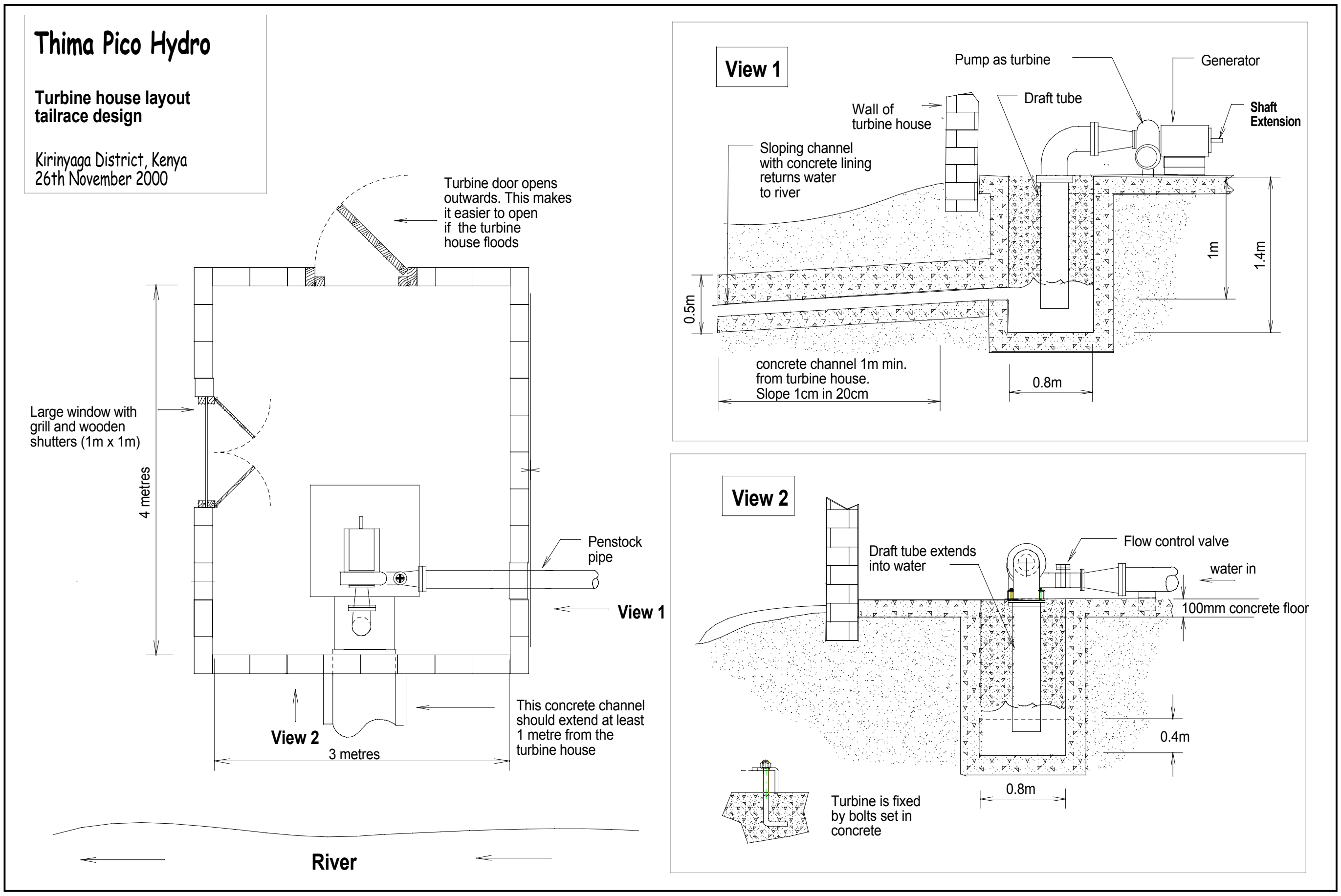
Since PVC is quite rigid, 45º elbows joints were cemented in at two points to enable the penstock to follow the shortest path to the turbine house.

Small bends were made by heating sections and then shaping around a former. Embers rather than flames (as above) should be used to avoid the risk of melting the pipe completely.

The entire penstock was supported by soil bags wherever possible and covered to prevent damage by sunlight.

Turbine House

This building houses the pump-as-turbine and generator equipment and ensures that the water is returned directly to the river. It is built above flood level but otherwise close to the riverbank. The location was chosen to maximise the available head whilst minimising the penstock length. A draft tube was added to the outlet of the pump to obtain and extra 1metre of head. Extra floor area was added to the building since the intention is to use the fan end of the generator shaft to drive a 'posho' (maize) mill. Double-ended generators such as this can sometimes be requested from the supplier or otherwise a shaft extension can be fabricated in a workshop and welded in position.



This scheme was installed in 10 days at a cost of $2,600 (excluding distribution and house wiring).

The induction motor as generator produces 2.2kW but a shaft extension provides a 3kW drive for mechanical loads.

Pump-as-Turbine

Since the head at this site was not sufficient for a Pelton turbine, another low-cost and robust solution was selected. Standard centrifugal pumps can be used as turbine generator units if carefully matched to the site. In this case a ‘mono-bloc’ type was used which is supplied with a directly-coupled induction motor. The pump impeller becomes the turbine runner and the motor is used as an induction generator. The difficulty lies in predicting precisely how a particular pump will perform as a turbine at a given site. Performance prediction equations can be used to select a particular machine if the site conditions are known. The Indian manufacturer Kirloskar Brothers supplied the pump used for this project since they have a sales outlet in Nairobi. To calculate the power output from this pump when it is used as a turbine, it is necessary to look at the pump best efficiency data which was obtained from the manufacturer. The following equations can then be used which take into account the speed increase necessary when operating the pump connected directly to an induction motor which is used as a generator.

$$Q_t = \frac{N_t}{N_p} \times \frac{Q_{bep}}{\eta_{\max}^{0.8}} \qquad H_t = \left(\frac{N_t}{N_p} \right)^2 \times \frac{H_{bep}}{\eta_{\max}^{1.2}}$$

Where:

Q_t = Flow rate using pump as turbine (litres per second)
N_t = Speed of turbine (rpm)
H_t = Head using pump as turbine (metres)
N_p = Speed of pump (rpm)
Q_{bep} = Flow rate at best efficiency point (litres per second)
η_{max}= maximum efficiency (%)

H_{bep} = Head at best efficiency point (metres)

Using data for a Kiloskar 515+ pump, Q_t and H_t were calculated and found to approximately match the site conditions allowing for approximately 2 metres of head loss in the penstock. Despite the prediction, the pump as turbine output was not as high as expected at the speed required for 50Hz. The diameter of the impeller was reduced on a lathe to tune it more exactly to the site conditions. A stuffing box type seal was specified rather than a mechanical seal as replacement parts for the mechanical seal are more difficult to obtain. A bronze impeller was selected instead of cast iron because of the improved resistance to corrosion.

A draft tube increases the head by 1m whilst ensuring that the turbine remains above flood level.

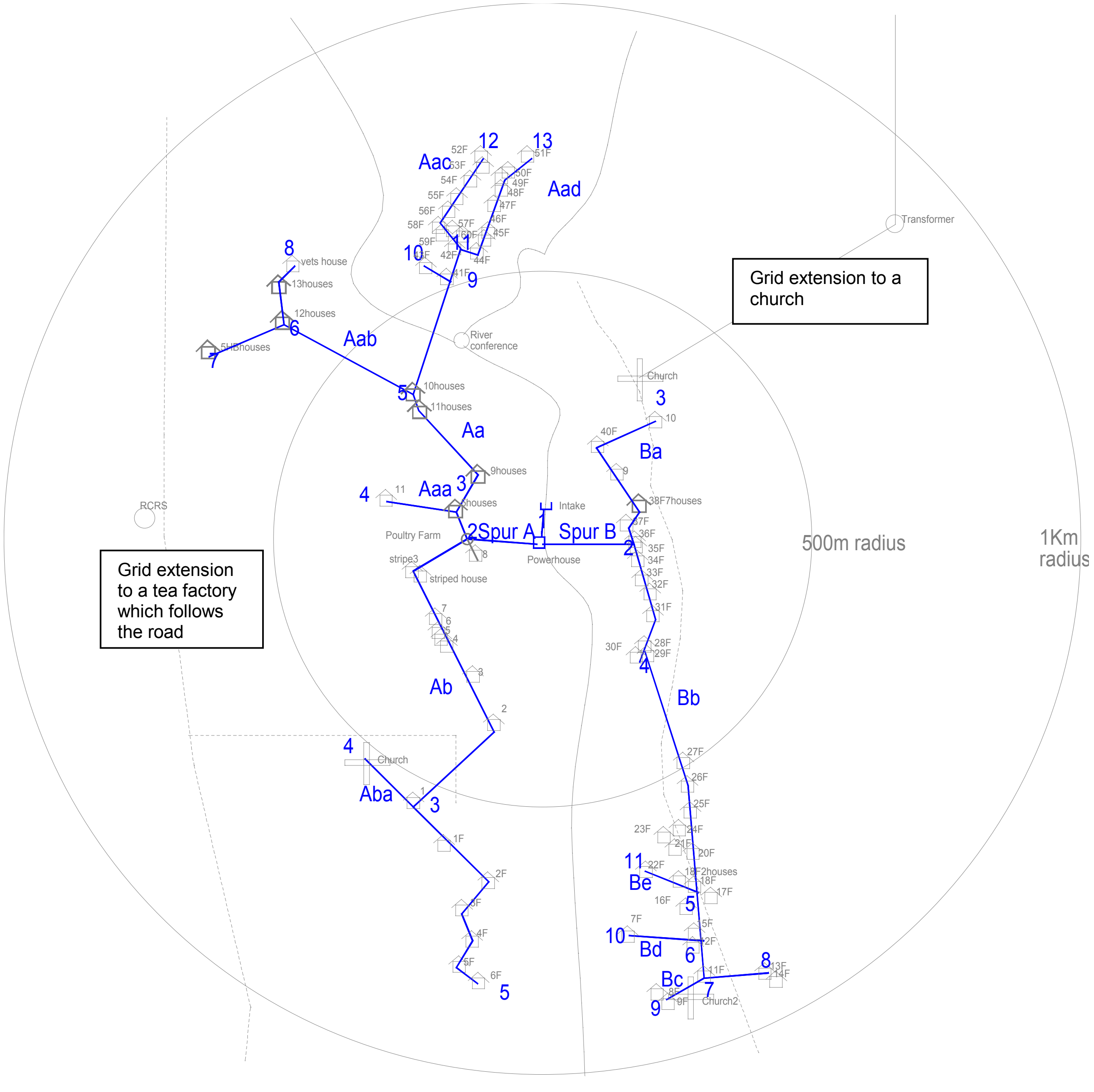
Two 1.8kW cooking rings have been used as a ballast load. An RCD (left) improves consumer safety by minimising the risk of dangerous electric shocks.

Generator

The KDS 515+ pump is fitted with a 3.7kW (5h.p.) induction motor. This produces 2.2kW of electrical power when driven by the turbine (pump impeller). The motor voltage was specified from the manufacture to be 260V rather than 240V and the winding insulation Class F rather than Class B which is standard on machines of this size. Both of these measures help to prolong the life of the windings by ensure that they operate at a much lower temperature than their rated temperature. A 3kW induction generator controller (IGC) provides voltage and frequency regulation by diverting excess power to a ballast load (two 1.8kW cooking rings). A residual current device (RCD) with 30mA tripping current maximises consumer safety by disconnecting the generator if an earth fault develops, either because of a faulty appliance or due to someone accidentally touching a live wire.

Distribution System Planning Using GPS Data

The locations of the houses shown on the plan were recorded with a relatively inexpensive GPS unit (Global Positioning System). This uses satellite technology to triangulate a precise position by 'tuning in' to 3 or more satellites (accuracy of +/-15m). The position is then referenced and stored. Downloading these points to a CAD (Computer Aided Design) program allows a map of the site to be generated. Using the CAD system, the routes for the distribution cables was worked out and drawn in to ensure that all the consumers were connected. A spreadsheet program was used tp determine the minimum cable diameters which could be used whilst still ensuring that all consumers would receive a connection with an acceptable voltage, no matter if their house lies at the end of the cable furthest from the generator. This helped to keep the connection costs for the consumers as low as possible.



Grid extension to a church

Grid extension to a tea factory which follows the road

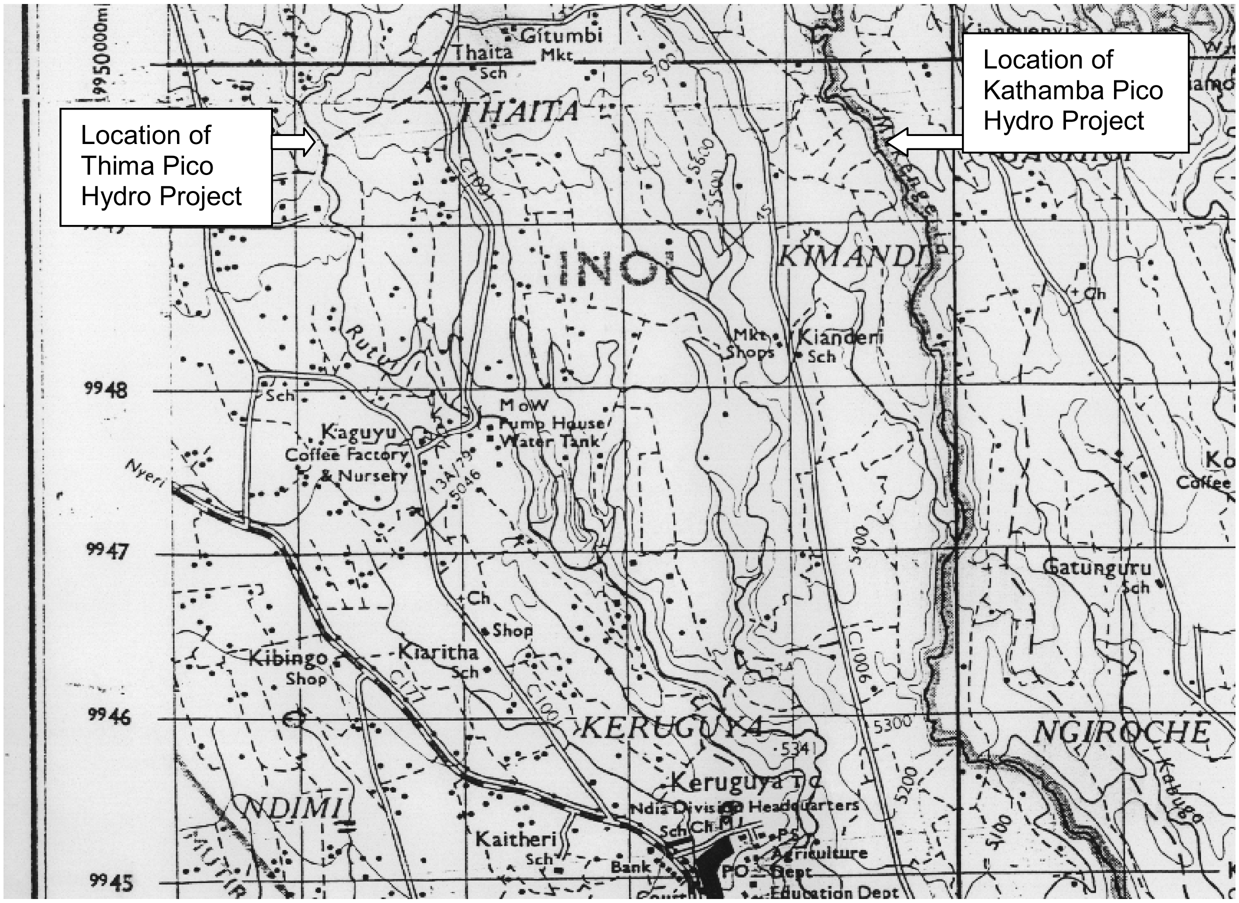
Consumer houses were surveyed using a GPS unit. Using this data a map was drawn and the network planned out. Houses which are not connected have not been shown.

Project Costs

A cost breakdown for the scheme components is given in the table below.

Scheme Components	Cost (US$)
1. Civil works (turbine house)	250
2. PVC penstock	600
3. Turbine, Generator, Controller and Protection	1,750
4. Distribution system, house wiring and energy saving bulbs (110 houses / 200 bulbs)	3,365
5. Labour costs (electrical wiring:200 shillings per house, other labour provided at no cost)	400
Total	**$6,365**

The total scheme cost averages $58 per house. This makes pico hydro very cost-effective when compared to a lead acid battery which, when bought new, not only costs more but requires regular charging, provides DC power only and has a useful life of 2 years or less. Nevertheless, batteries are still used extensively in many parts of Africa. A solar home system, providing a similar amount of power as the pico hydro, suffers the same drawbacks as battery only systems and costs at least 5 times more per house. Clearly pico hydro is limited to areas where suitable hydro potential exists, but given that the flows required are small, an extremely large number of people stand to benefit from this very affordable technology in many parts of Kenya and more broadly in Sub Saharan Africa.



Both demonstration sites are located quite close to each other and convienient for vehicle access. Travelling time is approximately 2.5hrs from Nairobi (Topographical Map: Sheet 121/4 Embu North)

Acknowledgements

The Micro Hydro Centre at Nottingham Trent University would like to thank all the project partners who have worked hard to make this scheme a success. They are Stephen Gitonga and Patrick Balla from the Energy Program at ITDG Kenya; James Muriithi and Theuri Daniel Kahiga from the Renewable Energy Department at the Kenyan Ministry of Energy and the committee and community members of Thima Micro Hydro Group 2000. The Micro Hydro Centre also gratefully acknowledge the funding provided by the European Commission for making this program of demonstration and training possible.