EVALUATION OF POTENTIAL FOR SMALL (<10 MW) HYDROPOWER IN SOUTH AFRICA

By Bo BARTA and Helene RASK GRØN*

Abstract

The World Summit on Sustainable Development (WSSD) highlighted inter alia the close interrelation between water resources development and the status of energy generation in South Africa. Water use in the energy sector accounts presently for only 1 percent of total national demand for water. However, primary energy generation depends to about 85 percent on the burning of fossil fuels (i.e. coal and oils) which are producing undesirable quantities of carbon emissions and greenhouse gases into the atmosphere from the Southern Africa sub region.

In order to reduce dependency of the primary energy sector on fossil fuels, renewable energy sources and technologies (e.g. solar, wind, hydropower and biomass) are being investigated and feasible development options reconciled with the local manufacturing and technological resources. The South African Department of Minerals and Energy (DME) together with the Danish International Development Assistance (DANIDA) initiated the study for evaluating of potential in development of small (< 10MW) hydropower in suitable areas of South Africa. Despite to general belief that there is none or negligible potential for development of small hydropower the evaluation study of a firm potential (i.e. a potential determined from the confirmed information inputs) revealed that there exists a potential in doubling of present installed capacity of 35 MW to about 70 MW. This hydropower potential can be developed by refurbishing of abandoned hydropower infrastructure and development of new suitable run-of-river hydro-electric sites. The capital required to be invested is estimated at about Rand 30 million per annum over next 15 years. Depending on the load factors adopted, about 450 GWh of electrical or mechanical energy can be generated annually, mainly in the remote areas of the Eastern Cape and KwaZulu/Natal provinces of South Africa. The beneficiaries of small hydropower development are the rural clinics, schools and commercial enterprises of numerous remote communities. The development of small hydropower as stand-alone or in a hybrid combination with another renewable energy sources will contribute in short term to much needed job creation, particularly in the rural areas.

The paper overviews methodology adopted in determining of hydropower potential, illustrates selection of best locations and explains the approach in determining of energy output from the conventional as well as unconventional hydropower applications (e.g. hydropower from irrigation canals, water supply pipelines, deep mining undertakings, etc.).

1 Introduction

South African society conformed to the doctrine of equitable access to all its available resources by all citizens since 1994. Although the country is endowed with most of needed natural resources, including large coal reserves, the conventional water resources (i.e. surface and groundwater) are rather limited and unevenly distributed around the countryside.

* Water Systems Research Group, WITS, Johannesburg, RSA, (bartab@iafrica.com)

*COWI A/S, Danish Consultancy, Pretoria, RSA, (hlg@COWI.dk)

Historically, extensive development of hydropower for electricity generation has never been considered seriously in South Africa. The exception is being made to the development of hydro-electric pumped storage schemes for peak generation in combination with the water supply dam storages. Although the hydropower electricity generation in South Africa is only marginally represented within the total installed generation capacity of 45 500 MW (which is almost entirely coal-based), the small scale hydropower has been well represented through the history of electricity generation in South Africa.

Table 1: Historical milestones in hydropower development in South Africa

History milestone	Description of hydropower development (**hydropower output at the time**)	Location in South Africa (province)
1895	1st hydropower station (**300 kW**)	Cape Town (W. Cape)
1917	1st micro hydro turbine (**Francis, 48 kW**) installed by Gilbert Gilkes & Gordon (GGG)	Not known
1924	Smallest hydro turbine (**Pelton, 0,84 kW**) Installed by GGG	Not known
1927	ESKOM's first hydropower station at Sabie	(Mpumalanga)
1950	Longest lasting municipal hydropower plant (**1 MW**) commissioned at Piet Retief	Piet Retiet Town (Mpumalanga)
1971	1st large storage regulated head hydro-electric scheme (**360 MW**) opened at Gariep Dam	Orange River (Free State)
1979	1st hydro-pumped storage scheme (**180 MW**) erected at Steenbras Dam (also 1st in Africa)	Cape Town (Western Cape)
1982	1st hydro-pumped storage scheme (**1000MW**) developed mutually by DWAF & ESKOM	Bergville (KwaZulu/Natal)
1995	1st RDP pico hydropower installation (**5 kW**) developed by ESKOM and local community	Upper Tugela (KwaZulu/Natal)
1999	1st Independent Power Provider licensed to provide (**2 MW**) base load supply to a town	Lydenburg (Mpumalanga)
2000	1st long distance tunnel diversion hydro-electric scheme (**72 MW**) commissioned at Muela Dam	LHWP (Lesotho)

Denotation: ESKOM = National parastatal electricity utility, DWAF = Department of Water Affairs and Forestry, RDP = Reconstruction and Development Programme.

2 Extent of renewable energy development

At present the provision of primary energy in South Africa is vested primarily with ESKOM the largest electricity utility on the African continent. ESKOM's energy generation processes are entirely coal-based and only a marginal proportion of some two percent of the total energy production is based on the renewable resources (e.g. large hydropower, wind and solar radiation). This is a dilemma faced by ESKOM and the whole of the South African economy as well as indirectly all the economies of Southern Africa Development Community (SADC).

South Africa is one of the signatories of the Kyoto Protocol on climate change and is in principle committed to reducing emissions of heat-trapping greenhouse gases as required by the international community agreements. The pressure will inevitably be applied for South Africa to reduce its dependency on fossil-based energy generation and to increase the application of renewable technologies and available renewable resources, particularly the solar radiation, wind, small hydropower, biomass and also ocean wave power. To date the development of renewable energy in South Africa reached very marginal proportions. Table 2 below illustrates the extent of installed capacity of various types of renewable energy technology, excluding the hydro-electric pumped storage capacity.

Table 2: Present extent of renewable energy development in South Africa

Renewable energy Technology	Installed capacity (MW)	Installed capacity (%)	Remarks on energy use and present development approach
Hydro-regulated head by dams	**653**	75	Peak supply to the national electricity grid administered by ESKOM
Small hydro (< 10 MW)	**34**	4	Municipal and private supply
Hydropower in Mining operations	**Negligible**	Negligible	Mechanical power from circulating refrigerated water
Wind / water pumping	**60**	7	Water supply in agriculture
Wind / electricity	**8**	1	Municipal and private supply
Biomass	**105**	12	Use of sugar cane mills residue
Solar (mainly PV)	**5**	1	Heating and telecommunication
Urban waste	**Negligible**	Negligible	Methane from municipal refuse
Ocean / wave power	**Nil**	Nil	Technology is investigated
Total for South Africa	**865**	100	Some 2% of total SA energy capacity

Source: Barta and Stephenson (2002).

3 Climate and hydrology of South Africa

The climate and hydrological conditions of South Africa vary from arid to semi-arid in the west to sub-humid along the eastern coastal areas, with an average rainfall for the country of just over half of that of the world average. Seasonally, the timing of regional precipitation is controlled by the Inter Tropical Convergence Zone with peaking rainfall during the period from November to February for most of the northern parts of the country. The south-eastern coastal areas receive their rainfall all year round and the most southerly areas during the winter months of June to August. The mean annual evaporation (MAE) far exceeds the mean annual precipitation (MAP) in most areas, especially the central Karoo region.

Table 3: Precipitation pattern for South Africa (1921 - 2000)

Year	**Annual average (mm)**	Year	**Annual Average (mm)**	Year	**Annual Average (mm)**	Year	**Annual Average (mm)**
1921	**560**	1941	**475**	1961	**460**	1981	**455**
1925	**740**	1945	**550**	1965	**445**	1985	**395**
1930	**505**	1950	**350**	1970	**460**	1990	**545**
1931	**455**	1951	**520**	1971	**410**	1991	**520**
1935	**520**	1955	**520**	1975	**705**	1995	**520**
1940	**505**	1960	**500**	1980	**460**	2000	**745**

Source: SA Weather Bureau (www.weathersa.co.za)

The long-term average annual precipitation in South Africa is about 500 mm, of which approximately 10 percent finds its way into the river ecosystems as surface runoff. Total surface water runoff manifests annually in about 50 150 million cubic metres of water flow around the countryside. However, due to the losses in evaporation and infiltration, only about 60 percent of the river runoff can be on average considered economically exploitable. The availability of surface water for purposes of agriculture, municipal water supply, hydropower and environmental requirements is highly diversified among twenty-two primary river drainage regions, as defined by the primary morphology watersheds in South Africa.

The late and very late summer seasonal rainfall regions situated in the central and north-west areas respectively do not provide suitable hydrological conditions for any significant small-mini-micro hydropower development. However, the summer, all-year-round and winter seasonal rainfall regions provide rather suitable conditions for particularly mini/micro or pico run-of-the-river hydropower development. The share of the annual runoff from the primary drainage regions of the eastern coastal areas in so-called "high rainfall region", amounts to about 52 percent of total available runoff or some 15 000 million cubic metres of exploitable runoff. The MAP varies between 700 and 1 100 mm in this region. Theoretically, this is the most suitable region in South Africa for the development of small hydropower. This is also the most economically deprived region with regard to the domestic and industrial needs of the local population.

4 Typical morphology of river systems in South Africa

According to the regional characteristics of the physical structure of most river systems in South Africa, potential for the hydro-electric development is usually manifested in the irregular river profiles and abrupt changes in slope and gradient. The other important regional feature is that each of major tributaries to the main water course might be flowing at a higher elevation than an adjacent major tributary in the upper part of the drainage basin allowing thus for significant elevation differences suitable for hydropower development. These characteristics are typical for the major river systems in the Eastern Cape and KwaZulu/Natal provinces, both situated within the high rainfall region.

5 Categories of hydropower investigated

An overall assessment of hydropower resources potential conducted in the Baseline Study – Hydropower in South Africa (2002) subscribed to the hydropower categories break-down as illustrated in Table 4 below:

Table 4: The categories of hydropower investigated

Category	**Power output**	Range of annual utilization (%)
Pico size	**Up to 20 kW**	10 to 35
Micro size	**20 kW to 100 kW**	10 to 35
Mini size	**100 kW to 1 MW**	10 to 35
Small size	**1 MW to 10 MW**	10 to 75
Macro size (or large)	**> 10 MW**	10 to 75

It has been acknowledged that when a specific hydropower site is to be assessed, the potential of such site can be further categorized according to parameters regarding the type of layout for small/mini/micro schemes considering the following:

- High head - with no channel diversion, or

  - with channel diversion

- Low head - with channel diversion, or

  - with provision of impoundment (e.g. a weir or a barrage)

The information collected and processed in the BSHSA (2002) enabled the formation of a much needed hydropower potential database for the future reference and planning of water resources development in South Africa. The capacity of presently installed hydropower (i.e. all categories) and estimated future hydropower development potential are summarized according to the current South African provincial dispensation (see Figure 1). Available information is also summarized according to the nineteen Water Management Areas (WMAs) as per legislative requirements of the National Water Act of 1998. In this way, most of the hydropower data compiled is compatible to other existing databases on water resources. The specific attention was given to the attributes required by the Water Situation Assessment Model (WSAM) enabling for any new data to be incorporated into this model. This public domain model is administered by the Department of Water Affairs and Forestry (DWAF) in Pretoria, the national capital of South Africa.

The Catchment Management Agencies (CMAs) which are being established within the WMAs, can also benefit from the BSHSA (2002) database in utilizing available hydropower information in conjunction with sustainable management of regional and local water resources. The capacity of installed hydropower and the future potential for developing feasible hydropower in South Africa are summarized according to the relevant categories in Table 5 below:

Table 5: Assessment of hydropower according to feasible categories

Hydropower category (power output range)	**Installed capacity (MW)**	**Potential for development**	
		Firm (MW)	**Long-term (MW)**
Pico (up to 20 kW)	0,02	0,1	60,2
Micro (20 kW to 100 kW)	0,10	0,4	3,8
Mini (100 kW to 1 MW)	8,10	5,5	5,0
Small (1 MW to 10 MW)	25,70	63,0	25,0
Subtotal for pico/micro/mini and small hydro	33,92	69,0	94,0
Large conventional hydropower (> 10 MW)			
• Run-of-river (e.g. direct intake or weir)	-	1 200	150
• Diversion fed (e.g. pipe, canal or tunnel)	-	3 700	1 500
• Storage regulated head (e.g. barrage or dam)	653	1 271	250
Total for renewable hydropower in SA	**687**	**5 160**	**1 994**
Large pumped storages (> 10 MW)	1 580	7 000	3 200
GRAND TOTAL (for all hydropower in SA)	**2 267**	**12 160**	**5 194**
Imported macro hydroelectricity (> 10 MW)	800	1 400	35 000 (+)

Note: The values of long-term potential are based on less reliable information but account for both conventional and unconventional hydropower potential in rural and urban South Africa.

Unconventional hydropower development can take place in both rural and urban areas of South Africa, such as tapping hydropower from irrigation canals, water supply pipelines, deep mining undertakings, etc. To date, there is practically no account of significant unconventional hydropower development in South Africa. However, the development of long-term potential will depend on increased public awareness about small/mini/micro hydropower. The conversion of hydropower into mechanical power is used to some extent in deep mining operations.

The development of macro hydropower in South Africa has been historically associated with the development of the primary water supply infrastructure and inter-basin transfers (e.g. Gariep and Umtata dams, Drakensberg pumped storage, etc.). This trend should be maintained and intensified to obtain the best for both the water supply and of hydropower sectors (i.e. small and macro hydropower development).

6 Firm and additional long-term development potential

The total firm potential (i.e. a potential determined from the confirmed information inputs) for development of renewable hydropower (i.e. less hydro-electric pumped storages) is at present more than seven times larger than the present installed capacity. Twice more of presently installed small hydropower capacity can be developed in the rural areas of the Eastern Cape, Free State, KwaZulu Natal and Mpumalanga.

It should be realised that with the low awareness about the potential for development of hydropower in South Africa, there is a considerable time lag in development of hydropower potential. The lead times required for developing, particularly of macro hydro schemes (up to 10 years) have to be observed in estimating development programmes.

The BSHSA (2002) verified that a firm potential for feasible and lucrative hydropower development appears to be primarily in the Eastern Cape and KwaZulu Natal provinces. The table below illustrates the present installed capacity and potential for hydropower development with possible energy production according to provincial administration.

Table 6 : Present hydropower installed capacity and firm development potential in SA

Province in South Africa	Installed capacity			Firm development potential		
	Small (<10MW)	Large (>10MW)	Production (GWh/a)	Small (<10MW)	Large (>10MW)	Potential (GWh/a)
Northern Cape		600	525		120	525
Western Cape	1,8		2	1,7		10
Eastern Cape	14,7	53	144	25,8	1 250	3 455
Free State	0,3		Neg	13,0		85
North-West				3,2		20
KwaZulu/ Natal	0,1		Neg	5,0	3 721	9 813
Mpumulanga	16,4		49	10,5		70
Gauteng			Neg	9,8		65
Limpopo	0,6		1	Neg		Neg
Total SA	**33,9**	**653**	**721**	**69,0**	**5 091**	**14 043**

Note: Pumped storage schemes are excluded from both installed capacity and firm potential.

It is determined from analysis of the information available that there is potential for development of renewable hydropower (i.e. excluding hydro-electric pumped storage potential), of about 5 160 MW which can be installed in the short to medium-term of 15 years. In installing this hydropower capacity, about 14000 GWh per annum (depending on the load factor applied) of electric energy could be generated primarily in the remote rural areas of the Eastern Cape and KwaZulu/Natal provinces.

Next to the firm potential for hydropower, additional long term (up to 30 years) pico/micro/mini and small hydropower potential can be developed using both conventional and unconventional hydropower technology, gaining potentially 24 MW and 70 MW respectively. The long-term conventional macro hydropower development potential is estimated at 1 990 MW, primarily in the Eastern Cape, KwaZulu/Natal and Western Cape provinces, providing that the potential sites are environmentally suitable for development.

7 Benefits derived from small (< 10 MW) hydropower development

Although the development of hydropower (i.e. any given feasible hydropower category) is very site specific and requires a multitude of disciplines, there are significant benefits to be derived from the development and production of hydro-energy. Pico/micro/mini and small hydropower installations are recognised as a renewable energy source which produces minimal quantities of carbon and emission gases during construction and operating life of the generating systems.

By far the greatest potential in the use of small (< 10MW) hydropower is in converting it into mechanical energy. In principle, anything that needs rotating, water can move (e.g. lathes, milling machines, planes saws, drills, grinders, sanders, etc.) The BSHSA concluded that the use of hydropower in conversion to mechanical power is presently an almost unknown quantity in rural

South Africa. The task of introducing this type of energy use should be undertaken primarily by the concessionaires when introducing and evaluating renewable energy option.

At present, some 35 MW of small hydropower is installed in South Africa, but about 30 percent is out of operation for various reasons which are indicated in the study. The firm short-term small hydropower potential is determined at 69 MW. This potential capacity can be developed by the Independent Power Producers (IPPs) or through the Public-Private Partnership (PPP) approach by the concessionaires, primarily in the Eastern Cape and KwaZulu/Natal provinces. The short to medium-term possible hydro-electricity production is estimated at some 450 GWh/year with regard to the load factor adopted. The medium-term potential for job creation only from the development of pico/micro/mini and small hydropower schemes is estimated at about 3 000 jobs, with some 1 100 jobs on a permanent basis in the operation, manufacturing and administration of hydropower development.

8 Industrial support base for hydropower development

Due to the presence of sizable mining industry in South Africa, there is a large industrial support base in existence, capable of providing needed expertise for manufacture, servicing and refurbishment of essential hydropower products (primarily mining-type equipment) for the development of small hydropower systems.

The problem identified with regard to the industrial base of hydropower is that due to the low demand and almost non-existent market, the manufacture of hydropower equipment has ended in South Africa and is being undertaken elsewhere in Africa. The same is noticeable in the line of marketing hydropower equipment from other countries on account of the negligible demand for this type of equipment. The local manufacturers and contractors capable to provide either relevant products or/and expertise are listed in Table 7 below:

Table 7: Local manufacturers and contractors associated with hydropower development

Manufacturer/ Contractor	Manufacturer's specialization in Hydropower industry	Current contact Details
Ainsworth Engineering	No direct involvement, but can supply valves and associated equipment	27+11+433-3968
APE Pumps (Pty) Ltd	Direct connection to industry providing vertical turbine pumps, mainly to the mines	27+11+824-4810
BWG Hydro Power Development	Overall micro hydropower design and installation of a complete package	27+11+391-3741
Clackson Power Company	Refurbishment and installation of small/mini hydropower equipment	27+13+758-1242
Davy Pumps & Turbines	Selection and installation of micro/pico hydro equipment	27+11+918-1571
Enerafrica (Pty) Ltd	Selection and installation of micro hydro packages	082-556-5124
Hydro Power Equipment	Mining hydro equipment primarily for mechanical Transmission (e.g. Pelton turbines)	27+11+462-1903
KSB Pumps (Pty) Ltd	Pumping equipment, reversible pumps and associated equipment	27+11+828-8950
Merz and McLellan	Refurbishment of any size of hydro-electric Equipment	27+11+886-6573

Mono Pumps (Pty) Ltd	No direct involvement, but can provide expertise and reversible pumps	27+11+609-4150
Va Tech Hydro (Alpine Industries)	Selection, manufacturing and installation of macro to small hydropower equipment	27+11+886-0900

Source: Direct personal communication with all listed manufacturers/contractors.

Historically, macro hydropower development in South Africa has been supported to a large extent by expertise and industrial products from international companies mainly through their subsidiaries located in South Africa. However, the macro hydropower industrial market has been rather dormant for many years with the exception of the hydro-electric installations of the Lesotho Highlands Water Project (LHWP).

9 Hydropower Research & Development (R&D) activities in South Africa

The R & D aspects of pico/micro/mini and small hydropower technology applications are at present vested primarily in the private sector. A handful of individuals are investing their time and expertise into micro hydropower research. There are no particular incentives being offered to promote R & D and education in hydropower. From time to time a workshop on hydropower development in South Africa is organized by one of the local universities.

10 Capital needs for small hydropower development

The short to medium-term capital needs for development of small (< 10 MW) hydropower according to the development potential in various provinces of South Africa are illustrated below:

Table 8: Estimated development capital requirements (2001 prices)

Province in South Africa	Firm potential for development (MW)	Possible production (GWh/a)	Estimated development capital requirements (R million)
Northern Cape	-	-	Negligible
Western Cape	1,7	10	12,8
Eastern Cape	25,8	170	193,5
Free State	13,0	85	97,5
North-West	3,2	20	24,0
KwaZulu Natal	5,0	33	37,5
Mpumalanga	10,5	70	78,8
Gauteng	9,8	65	73,5
Limpopo	Negligible	Negligible	7,5
Total SA	**69,0**	**453**	**519,8**

N.B.: The estimates of capital required are based on the costing approach in DANCED (2001).

The capital investment required in the medium-term for the development of small hydropower potential in South Africa will be significantly discounted by the socio-economic benefits which will be gained from access of primarily remote communities to the electrical and mechanical energy.

11 Conclusion

Contrary to general belief that the potential for development for hydropower in South Africa is very low, it has been established from the assessment of hydropower resources conducted in the

BSHSA (2002) that there exists a significant potential for development of all categories of hydropower in the short- and medium-term in the specific areas of South Africa.

The Eastern Cape and KwaZulu/Natal provinces are endowed with the best potential for the development of particularly small (< 10 MW) hydropower plants either as stand-alone or in a hybrid combination with other renewable energy sources (e.g. solar, wind and biomass and even ocean wave power). The advantages and attractiveness of small/mini/micro or pico hydropower development can be derived from its association with other uses of water (e.g. water supply, irrigation, flood control, etc.) which are critical to the future economic and socio-economic development of South Africa. The development capital should be canvassed through both water and energy sectors involving private and public participation.

The key problem areas related to the development of primarily small hydropower in South Africa were determined as follows:

- Low price of electricity supplied by ESKOM, thus low demand for alternative energy technologies, particularly renewable energy technology,
- The absence of any significant incentives hampers the development, maintenance and refurbishment of new and existing hydropower installations,
- The inherent misunderstanding about high asset value of hydropower to the communities, society and environment (i.e. modern and faster technology pushed out of sight reliable and sustainable methods and technologies),
- The complexity inherent in multi-disciplinary expertise required for sound hydropower development and rehabilitation, and
- The low public awareness about the interrelationship between water resources and renewable energy development. The awareness can be introduced and increased by radio presentations, workshops, printed matter distributed and illustration by working models.

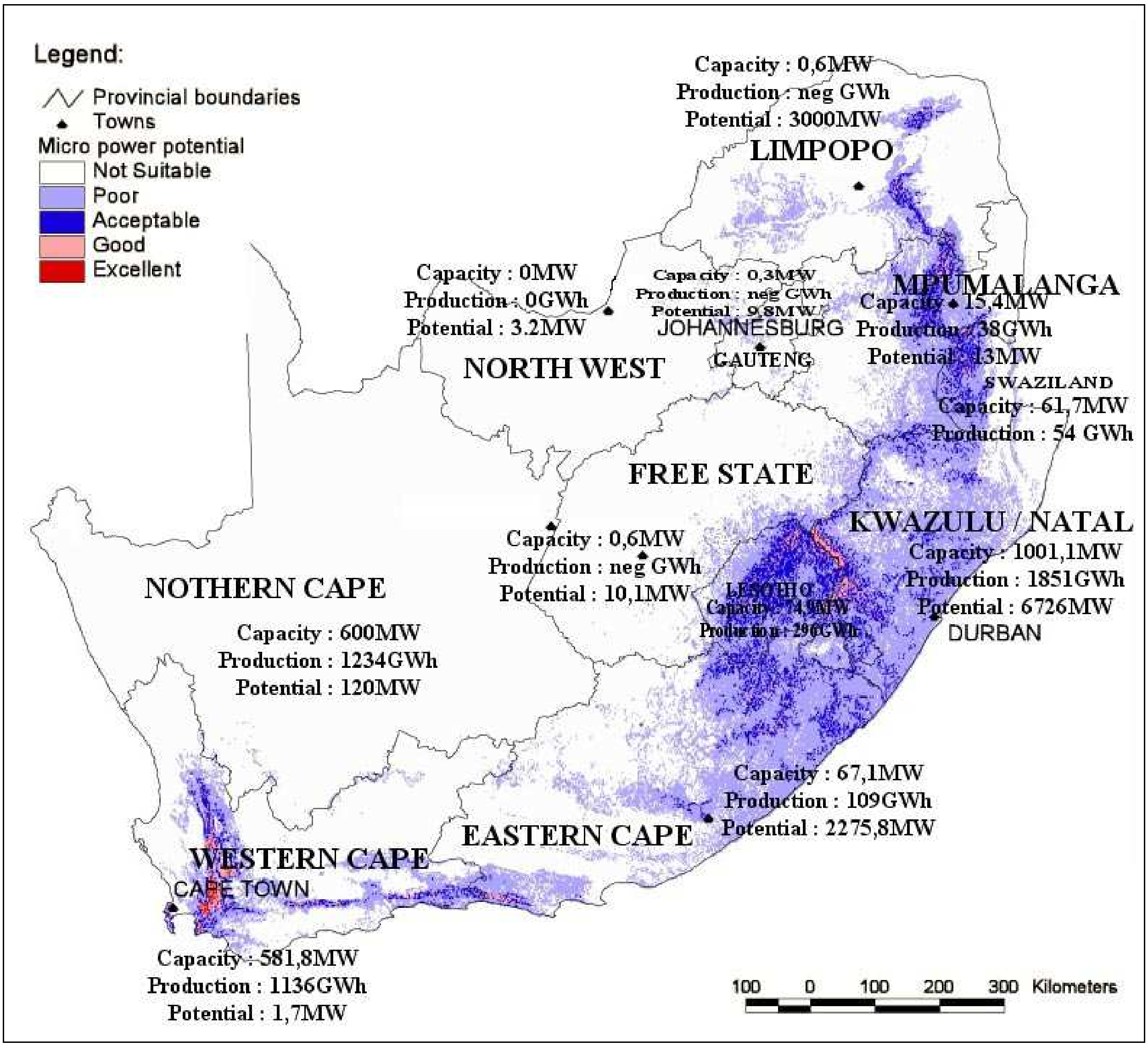

Figure 1: Provincial representation of hydropower capacity, production and firm potential in South Africa (all categories excluding imported hydropower from abroad)

References

BSHSA (2002). Baseline Study – Hydropower in South Africa. Report No. COWI P54126/EE/RE/70. Department of Minerals and Energy. Pretoria. RSA. September.

Barta, B. (2001). Utilizing water power in remote areas of the Eastern Cape. Internal Report. Water Systems Research Group. University of the Witwatersrand. Johannesburg. RSA. June.

Barta, B. and Stephenson, D. (2002). Mini-grid renewable energy potential in South Africa. Proceedings of the IET-IAHR International Conference. Water- The Lifeblood of Mankind. Arusha International Conference Centre, Tanzania. December.

DANCED (2001). Bulk renewable energy independent power producers in South Africa. Pretoria.

RSA. January.